The Plantation Effect

An Ecoforestry Review of the Environmental Effects of Exotic Monoculture Tree Plantations in Aotearoa/New Zealand

Greenpeace New Zealand
with support from Canterbury Branch Maruia Society
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Drawing on a range of up-to-date scientific and academic research on the environmental effects of exotic monoculture tree plantations this review evaluates the ecological sustainability of current New Zealand plantation industry practices.

The review acknowledges that trees and forests are essential to nature and human society, and takes a holistic view of the plantation industry to assess claims that exotic monoculture tree plantations in New Zealand are sustainable.

Greenpeace rejects the industry's claim that current practices are sustainable. They are not. A range of significant impacts on soil and water quality, yield, natural biodiversity and ecosystem health cannot be ignored.

The review goes on to set out Greenpeace's long-term vision of an ecologically sustainable forestry industry based on a landscape approach, diversity of tree systems, zero use and discharge of toxic chemicals, longer crop lengths and restoration of biodiversity.

The review identifies ways of achieving long-term ecological and economic sustainability. Outlining a series of positive solutions the review looks at the restoration of natural site conditions and productivity, and ways to mimic nature with mixed species plantation systems that work within the limits of natural soil and site conditions. It goes on to point out that future markets lie in the demand for ecologically sustainable wood products.

The review sets out Greenpeace's arguments for the plantation industry to make its practices ecologically sustainable in order to maintain soil and water quality, and natural landscape biodiversity. The full ecological costs of industrial tree plantations have not yet been accounted for in New Zealand. This review is a first step.

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The review goes on to set out Greenpeace's long-term vision of an ecologically sustainable forestry industry based on a landscape approach, diversity of tree systems, zero use and discharge of toxic chemicals, longer crop lengths and restoration of biodiversity.

The review identifies ways of achieving long-term ecological and economic sustainability. Outlining a strategy for jobs and the environment the review looks at the restoration of natural site conditions and productivity, and ways to mimic nature with mixed species plantation systems that work within the limits of natural soil and site conditions. It goes on to point out that future markets lie in the demand for ecologically sustainable wood products.

Greenpeace also urges the plantation industry to make its practices ecologically sustainable in order to maintain soil and water quality, and natural landscape biodiversity. The full ecological costs of industrial tree plantations have not yet been accounted for in New Zealand. This review is a first step towards such an account. However, it does not attempt to be a complete comparison of tree plantations with other land uses.

2. Plantation Influences on the Environment

The influences and impacts of exotic tree plantations on some environmental parameters such as soil biogeochemistry are still largely unknown. For example, there are still no proven guidelines identifying which soil types are most susceptible to degradation, and many plantation practices degrade soil organic matter and adversely affect soil flora and fauna.

Research has recorded plantation soil nutrient decline, and whole tree harvesting will cause accelerated soil nutrient loss. And while trees are efficient at storing carbon dioxide in biomass, tree plantations are at best only a short-term store, and the plantation industry may in the long-term be a net emitter of carbon.

Many plantation practices are detrimental to critical environmental factors such as soil physical properties.

This principally involves the use of heavy machinery and tree harvesting equipment. While trees can reduce soil erosion, many harvesting and roading practices can cause sedimentation in adjacent watercourses. Plantations can help reduce storm and peak flood water levels. However, they also reduce overall water yield and flow which has significant impacts for downstream users and aquatic life.

The industry also uses and discharges a wide range of toxic chemicals such as chlorinated pesticides, herbicides, fungicides, and timber preservation treatments as well as chlorine in pulp and paper factories. Each of these uses is responsible for toxic pollution of the New Zealand environment.

3. Plantation Influences on Biodiversity

Trees generally increase diversity compared to pasture and croplands. However, exotic monoculture tree plantations do not help maintain landscape and biological diversity. Regimented, uniform rows of monocultural plantations are the opposite of diversity. Compared to natural forests the biological diversity of monocultural tree plantations is low.

Diversity has been suggested to be a primary indicator of ecosystem sustainability. Young pine plantations have been found to be poor habitat for native birds. Species that feed on fruit and nectar such as tui and kereru, and those that nest in holes or are insectiverous are particularly absent from plantations.

The frequent disturbance caused by short rotation clearfelling and herbicide spraying are among the most destructive and limiting factors on biodiversity. However, old growth plantations can provide good habitat for native species, especially orchids. Exotic monocultures also increase fire risk and can act as a source of pests and pathogens that spread into adjacent indigenous forest.

Pine plantations act to cut off islands of remnant indigenous forest from each other, reducing the chances of native species populations exchanging genes. Riparian areas are currently the major component of areas offering biodiversity protection. New Zealand's plantation monocultures are no substitute for natural forests, yet they are being promoted overseas as model forestry practices.

4. The Risks of Tree Plantations

Around the world monocultures have been found to be susceptible to pests and diseases. Major international agencies such as the World Bank and the ITTO recommend mixed species forests, preferably of indigenous species. Putting all our eggs in the monoculture basket does not make sense. Alternative species and ecologically sustainable forestry systems must be pursued as a safeguard.

Environmental stress from nutrient decline and climate change will likely cause a decline in the health of monocultural tree plantations. Evidence of climate change and increases in UV-B light indicate that plantations and other resources are under threat. A precautionary approach to forestry involving a range of species and systems is required in Aotearoa.

5. Draft Ecoforestry Criteria

Exotic monocultures are not the only option open to the New Zealand plantation industry. The government and industry have failed to set environmental leadership in ecologically sustainable forestry. Greenpeace urges the plantation industry to consider and adopt the Draft Criteria for Responsible Management of Tree Plantations set out in section 5.0 as a transition to ecologically sustainable forestry. Mixed species tree planting, particularly native species, and a transition to indigenous forest systems would greatly sustain and enhance New Zealand's biodiversity.

Precautionary action is required to put New Zealand plantation practices on a sustainable footing, and to enhance and restore biodiversity. The Draft Criteria call for:

- full landscape assessment which takes account of ecological, social and economic aspects of land use as part of a full management plan,
- community and participation rights which recognise and respect the customary rights of indigenous people,
- clear definitions of land ownership,
- a consultation process which ensures that local communities have priority for jobs, training and education,
- a sustainable yield of timber harvest that prevents loss of soil and nutrients,
- maintenance of natural biological diversity, mixed planting of native and exotic species, and transition crops back to indigenous forest systems,
- maintenance of soil, water and air quality,
- zero discharge of toxic and/or bio-accumulative persistent substances in the life cycle of forests and forest products, and
- independent monitoring of the environmental and social impacts of plantations.

Many of these actions are fully consistent with New Zealand's international legal obligations under the Biodiversity Treaty signed at the Rio Earth Summit in 1992 and would demonstrate the industry's commitment to corporate responsibility.

6. Alternative Tree Systems

The review describes several ecoforestry and alternative tree systems to exotic monoculture plantations suitable for New Zealand:

- Indigenous species plantations: successful trial plantations of indigenous trees such as kauri and totara have shown they can maintain soil and water values, and actively protect biodiversity.
- Agroforestry systems: the planting of pastoral land with mixed tree species to improve productivity and reduce erosion.
- Reafforestation with mixed special purpose species: this practice forms better habitats, has longer rotations, higher economic values and lower extraction impacts.
- Mixed tree cropping woodlands: this option incorporates timber production with other products such as nuts, fruits, honey, herbs and fungi.
- West Canadian Ecoforestry mimics natural forest processes and has many aspects which could be incorporated into New Zealand management practices.
- Traditional Pacific Island and Asian forest systems – diversity of species and systems are used to provide a diverse income source, stability of production and utilisation of a range of beneficial species combinations to increase insect and disease resistance.

7. Environmental Indicators

Ecological values have been compromised in New Zealand by the planting of exotic tree monocultures to meet human needs. However, because there has been little or no data collected on impacts in New Zealand it is difficult to assess environmental baselines and measure environmental damage.

The review sets out a draft set of guidelines for environmental indicators including water quality, water allocation, land processes, toxic pollution, conservation, endangered species, ecologically sensitive areas, fire risk, and plantation health.

Such indicators are an essential component of ecologically sustainable management and would allow for a long-term evaluation of the ecological impacts of exotic tree plantations and any future shift to ecoforestry. Forest resource accounting should also become the norm in assessing the state of the environment.

8. Greenpeace's Positive Solutions

Acknowledging that forests are a protective and regenerative cloak over the land which usually provide more protection for the soil than pasture or crops, Greenpeace rejects the industry's claim that current tree plantation practices are sustainable. They are not.

The long-term aim of the industry should be ecological and economic sustainability. This includes the restoration of natural site conditions and productivity, and aiming to mimic nature with mixed species plantation systems which work within the limits of natural soil and site conditions. Greenpeace urges the plantation industry to make its practices ecologically sustainable in order to maintain soil, water and air quality, and natural landscape biodiversity. Ecological forestry also makes economic sense because future markets lie in the demand for ecologically sustainable wood products.

As a first step the industry needs to adopt the draft criteria set out in section 5.0 by the end of 1995. Ecological sustainability can then be achieved if the industry agrees to change selected practices by 2000 and adopts:

- a landscape approach to maintaining and restoring biodiversity in land use planning which ensures long-term planting and harvesting planning at least 100 years ahead,
- a precautionary approach to forestry management,
- zero nutrient loss and erosion from plantation operations,
- the maintenance of soil, water and air quality and yield,
- the planting of native riparian strips to protect waterways from soil erosion and provide wildlife corridors,
- the zero use and discharge of toxic chemicals/pollution,
- energy efficiency and clean energy strategies which reduce plantation industry carbon dioxide emissions to at least 1990 levels by 2000,
- the restoration of biodiversity back to the landscape,
- clean production techniques such as solar kiln drying,
- totally chlorine-free pulp and paper production,
- at least a 20 per cent native species component in new plantings per year,
- at least a 20 per cent mixed exotic species component in new plantings per year,
- increased rotation cycles for exotic monoculture plantations,
- a commensurate reallocation of private and public sector research funding to support increased mixed exotic and native species system research, and

• independent certification of responsible management of the plantation industry.

Greenpeace recommends that the plantation industry and land holders commit to ecological sustainability and adopt these changes as a transitional phase towards the goal of full ecological forestry by 2025.

A Maori Perspective on Tree Plantations

Hutia te rito o te harakeke
Kei hea te koromako
E ki mai, A koe ki au
He aha te mea nui
Maku e ki atu
He Tangata, He tangata, He tangata

A question is asked –
Where is the bellbird that feeds on the shoots of the flax?
There is no answer. Another question is asked –
What is important then?
The people, the people, the people

For Greenpeace this whakatauki suggests: don’t reduce our focus to the details, stay with a holistic consideration of important things.

The spiritual and cultural threads that bond Maori to their land and resources such as water, air, land, mountains and forests are so intricately woven they are like a korowai.

With utmost caution and care each thread has been knotted so the korowai serves as a blanket that envelopes us all into its warmth.

Within the korowai of the land monocultures such as pine cropping do not fit.

In most iwi claims before the Waitangi Tribunal the three primary statements for the return of the land and resources are:

Protection, preservation, and for the future of our mokopuna [grandchildren]

Protection – is safeguarding the biodiversity (species, habitats and ecosystems) threads that interconnect us spiritually and culturally.

Preservation – the remaining natural resources that are native to the whenua [all the resources of the land] through which we are physically connected to the korowai.

For the future of our mokopuna – that within their lifetime they may also experience the intricate threads of the korowai.

Very little research has been carried out into the long-term advantages of diverse plantings of native and exotic trees that are both financially beneficial to Maori and are more in harmony with the whenua. There is more to planting trees than financial gain.

Iwi need to sit down and plan the framework for a 150 – 200 year whenua management programme that lays out step by step the best options for protection, preservation and for the future of our mokopuna. Vast tracts of Maori land in multiple ownership (for example in Northland) are being targeted by forestry interests for planting with pines. The whenua management planning would not only take account of the short-term financial gain from pines, but plan for the future by maybe planting and restoring the native forest or a mix of different types of trees. Then and only then will we retain the values and the threads of the korowai.

Pakihana Grant Hawke, Mana Tangata, Greenpeace Aotearoa.

Introduction

The essential value of trees and forests is beyond dispute. Forests contain up to 90% of terrestrial biodiversity and more than 90% of above ground biomass. They are essential to the regulation of the Earth's climate and maintenance of our water supply. They provide food, fuel, fodder, medicines and natural pesticides, recreation, wildlife habitat and are a major source of industrial fibre and building materials.

Virtually all New Zealand soils were formed by forest systems and if nature were to have her way again, Aotearoa would eventually be a forested landscape. However, a major ecological disturbance, human society, has changed all that. Following the clearance of much of our native forest, largely into pasture, tree plantations are now emerging as a major land use.

The intention of this review is to take a holistic look at the plantation industry. A life cycle analysis has been used to review the environmental impacts of the industry. It aims to broaden the parameters in which the plantation industry is currently viewed. There is no intention in this review to make a full comparison between tree plantations and other land uses.

It is beyond doubt that other land uses such as conventional agriculture are unsustainable. Greenpeace has previously criticised conventional agricultural practices, outlining the key unsustainable aspects, and proposing alternative principles and requirements for ecological agriculture in Aotearoa. However, unlike the plantation industry the farming industry is not as conspicuous in proclaiming sustainability. Plantation industry "greenwash" has appeared in international fora, general industry rhetoric, and industry promotional materials given free to schools under the guise of education resources. However, there is little scientific evidence to support the claims made. Furthermore, plantations are being promoted globally as a sustainable alternative to agriculture and as a replacement for native forest, by industry consultants from New Zealand.

This review focuses on the ecological implications of large scale exotic monoculture plantations. This principally involves one species, Pinus radiata, or Monterey Pine, from California. Undoubtedly there are benefits from planting trees on areas of introduced pasture and cropland, such as improved protection for soils and reduced erosion, better water quality, and increased vegetation complexity. However, if these trees become part of a plantation tree crop, then many of the benefits may not last.

Tree plantations are already playing the vital role of providing a substitute for wood from destructive natural forest sources. It is acknowledged that we desperately need to plant trees all around the world for a multiplicity of reasons.

We need to restore the forests. There has been a call by the plantation industry for massive global planting programmes to meet an expected demand for wood. But has the industry paused for a moment and put aside the profit margins, to question whether society is consuming too much wood, considering the current level of wasteful use? Have the impacts of the wood and timber processing industries been fully accounted for?

Tree plantations may have many benefits over other industrial land uses, but there are ecological costs, whether present, or potential. What is the wisdom of replacing one unsustainable system with another? There are of course a whole set of social and economic effects on employment, road condition and safety, noise levels, offsite pollution, local community participation and control of resources, worker health and safety, local infrastructure, and appearance. These are not examined in this review. What follows is a review of the environmental effects of exotic monoculture tree plantations in New Zealand. Plantation management criteria are identified that will assist the industry in moving to maintain and enhance ecological baselines.

1.0 Tree Plantation Influences on Soil Biogeochemical Processes

1.1 Introduction

1.1.1 Forest Soil Processes

Trees and forests interact with soils via a range of inputs, outputs, transfers and relocations through various processes. The following is a general introductory summary of forest soil processes and interactions, derived mainly from temperate managed natural forests.

Trees "filter" the atmosphere, exchanging various gases as well as air-borne particles such as dust and rain.

In industrialised regions with high atmospheric concentrations of nitrogen and sulphur compounds, near oceans with

high salt concentrations in the air, and in areas downwind from arid lands that contribute dust, this filtering effect is

more pronounced. Some trees have biological relationships that fix nitrogen from the air, as do some free growing soil bacteria and fungi. Nitrogen is also exchanged from the soil back into the air.

Trees and forests contribute variable quantities of litter (dead plant matter) to the soil organic matter. This litter varies in its chemical composition, the speed with which it breaks down in the soil, and the diverse range of soil flora and fauna that inhabit it. The byproducts of the litter breakdown are retained in the soil through chemical and biological processes. Nutrients such as phosphorus, nitrogen, potassium, calcium, magnesium and trace elements may be retained in a form that is not available for tree and plant growth (fixed pool), or may be in the plant available "pool". Moisture and temperature play critical roles in exchanges between these two pools, and uptake by plants. Nutrients may be weathered from the soil parent rock and tree root exudates may influence this.

Nutrients stored in the soil can be made available to microbes and plants through decomposition (or mineralisation), chemical exchange reactions, and by mineral dissolving. Nutrients not taken up by plants and microbes may be leached from the soil, or to deeper in the soil where they are not available. Trees take up the nutrients through their roots but may also influence the physical properties of the soil. Forest canopies tend to moderate soil temperatures, with further insulation from forest floor litter layers. Soil aeration can be altered by the tree roots, through them "breathing" or decomposing, and by changing soil porosity and density, and possibly structure.

Trees typically decrease soil water content and water yield from a catchment, although there are differences between species, and with the exception of areas where peat accumulates. Water is transferred from the soil to the air by trees and plants through evapotranspiration.

(Figure 1: A diagram of forest soil processes, interactions and nutrient cycling.)

1.1.2 The New Zealand Situation

There has been considerable debate in Aotearoa over past decades on the impacts on the soil of Pinus radiata plantations and management practices, and other species such as Eucalypts. Many claims have been left unsubstantiated. Some industry representatives claim that pines do not negatively impact on soils, but actually benefit them. This runs counter to research elsewhere in the world such as Australia, Nigeria, Chile, and Trinidad. A comprehensive review by Binkley (1994) found that different species had a range of effects on soils but there is no conclusive evidence whether these effects are positive or negative in total, or significant given the short time frames involved. It is well known that any tree will have some benefits to the soil, such as inception of dust, protection from the kinetic energy of rain, preventing some types of erosion, and moderation of temperature.

Here in New Zealand after more than 100 years of tree plantations, the effects of introduced species on the soil have received relatively little attention. There are no clear guidelines on which soil types are most susceptible to productivity declines or as to what practices are acceptable to prevent productivity loss9. However, a classification system that identifies soil susceptibility to productivity declines from nutrient removal and various management practices has been developed. According to this system, soils with high phosphorus retention capacity, little or no organic matter, and parent materials lacking in certain elements have a high potential for nutrient depletion with harvest removals. Loamy soils previously covered with native bush and receiving adequate rainfall are least likely to show a productivity decline. The risk of soil compaction during harvesting is high for clay and silt soil textures, and low for sands and gravels.

The plantation industry in New Zealand is to a large degree reliant on petro-chemical based fertilisers, fuel, herbicides and pesticides. Although the industry generally requires a considerably lower input than conventional agriculture and horticulture industries, this reliance alone may render the present system unsustainable. A plantation grower may view

a stable wood yield over two or three rotations as an indicator of soil sustainability. However, this takes no account of changes in soil quality and quantity, soil biotic activity, external costs of fertiliser production, or enhancement towards the original indigenous state.

Forest researcher John Balneaves describes the situation well:

“The forester is primarily concerned with ‘cost-efficient’ tree establishment and forest management that will lead to the maximum production of merchantable timber. Little recognition is given to the possibility of that a short-term practice could create an irreparable loss of or alteration to the soil resource, resulting in long-term reduction in site productivity.”

1.2 Organic Matter

Soil organic matter (OM) is a critical soil component:

• supplying most of the nutrients held in the soil, in particular nitrogen, phosphorous

and many trace elements,

• aiding the release of nutrients from mineral sources through the action of acidic compounds,

maintenance of soil structure,

• maintaining moisture-holding capacity (holds 5 times its weight in water),

• maintaining aeration and soil porosity,

• heat absorption, and

• deactivation of chemicals and heavy metals.

Much of the forestry research on the impacts of plantations on organic matter concerns the plant OM component or biomass analysis, leaving out the soil-incorporated organic matter.

Research in Australia and New Zealand on changes in organic matter (plant) found Pinus radiata to be an efficient producer of above ground OM. With standard planting regimes peak above ground OM production occurred at ages 5 – 7 years when canopy closure is reached, followed by a peak in litter breakdown on the forest floor at ages 7 – 9. However, no account was taken of below ground biomass, the changes in soil organic matter, or the role that soil OM plays in the cycling of nutrients. Rather than a gain in productivity, it may simply be a transfer of below ground OM to above ground OM, in which case it is likely to be detrimental to site productivity and sustainability when the tree crop is removed. In comparison to natural forests, plantations tend to have higher above ground OM and lower soil and litter OM.

Whole tree harvesting will likely exacerbate the loss of OM from a soil, as the more nutrient rich tree leaves and branches will be moved off site. This already happens to a large degree on steep hill sites that are cable/skyline hauler logged, with the whole tree being moved to the landing. The branches and trimmings are concentrated in slash piles (commonly known as bird's nest or crow's nests) adjacent to the landings. Furthermore, it has been suggested that stump removal is a possible solution for the control of Armillaria root disease. This would be a major disturbance to soil and in particular the organic matter component.

In Nigeria, in comparison to native forest, Pinus spp. plantation forests have a much lower humus level, as pine needles were found to take considerably longer (3 to 6 years) to decompose than leaves of native trees (2-7 months). In New Zealand, litter of Eucaplytus regnans was found to decompose faster than P. radiata, and similarly in Australia E.obliqua decomposed faster than P. radiata. Thus it seems litter quality is important. A review of studies northern hemisphere forests found that;

"a variety of studies have shown that the ratio of lignin:nitrogen in the litter predicts both decomposition rates and N mineralisation rates better that simply N concentration."

The significance of this slower breakdown is still unclear, although it is likely to mean a slower turnover of OM, less nutrients available and lower productivity. It may also depend on a range of soil conditions. The acid nature of conifer litter may be a more significant factor (see 1.2.1 and 1.3.6)

Research in New Zealand relating to organic matter is dominated by trials on the influence of management practices on OM and litter levels. Several trials have shown that harvesting and planting operations which facilitate machine operation ignore the impact these operations can have on the displacement of the nutrients and organic material found in the slash litter and topsoil. Exposing the topsoil through slash removal increased the maximum soil temperature. Consistent reduced growth rates in P. radiata have been recorded on sites where the OM is disturbed through root-raking, windrowing, slash removal or burning, as compared to slash retention.

This emphasises the key role that soil OM plays in soil health and consequent tree crop production. A review of research experience indicates that losses in soil productivity are linked with losses in site OM and soil porosity.

Any soil disturbance will have a disproportionately large effect on soil OM as it is concentrated near the soil surface. Although in New Zealand there does appear to be move away from major OM degrading practices.

1.2.1 Soil Fauna and Flora

There are important links between soil fauna and forest productivity (Shaw et al 1991), and many forestry practices such as clearfelling, burning and fertilising can adversely affect soil and litter fauna and flora. A major review of global tree plantations found considerable evidence of degradation of the soil biological component. For instance the lack of the addition of large woody debris, as in natural forests, excludes whole ecosystems. Yet the positive effect of some soil biodiversity is well recognised, such as the role of soil mycorrhizal fungi, where many species are beneficial to

P. radiata, particularly on low fertility soils. Of the 15 basic zonal types of soil found in New Zealand, and the huge range of variations to these, only a few have been studied for baseline population and composition of soil flora and fauna.

The living part of the soil is particularly sensitive to changes in pH. There is evidence of acidification under conifer forest plantations. At the Tikitere agroforestry trial near Rotorua, planting pine into pasture lowered the soil pH significantly and decreased earthworm populations. This was particularly so in the higher density planting. Earthworms play important roles in the cycling of plant nutrients (in particular P), the turn-over of OM and maintenance of soil structure. Other studies have shown that acidification resulting from planting conifers decreased micro-organisms, and proportionately increased the levels of fungi in relation to bacteria. As would be expected different types of trees produce different types of litter. Consequently there will be differences in the composition of soil communities (particularly fungi and bacteria) and OM decomposition rates.

Fertiliser application generally appears to reduce the abundance and variety of soil organisms. This is especially so with nitrogen fertilisers, with a variable effect from liming. Mycorrhizal fungi have been reported to increase four-fold as a result of boron application. However, in other parts of the world reduced fungal growth resulting from chemical fertilisers has been reported.

1.3 Nutrient Cycles

1.3.1 Introduction

Trees play a vital role in nutrient cycling. They cycle newly weathered nutrients from deep in the soil and some species facilitate the absorption of nitrogen from the air. A first rotation of Radiata pine has been found to increase the level of some nutrients in the topsoil compared to adjacent grasslands, through either increased mineralisation of the soil organic matter or through the transfer from deeper horizons.

Most concerns regarding the environmental sustainability of tree plantations have focussed on nutrients and their subsequent effect on productivity. This is to be expected as the nutrient removal associated with fast growing plantations will cause nutrient depletion of the soil and lower productivity. Decisions on overcutting and rotation age in relation to sustainability are largely made on financial terms such as. the optimal time to cut, rather than what the soil can sustain.

Whole tree harvesting would accelerate considerably the nutrient depletion of soils, as proportionately more nutrients are stored in the leaf, bark and branch material than in the tree bole. Research into whole tree harvesting indicates that considerable quantities of nutrients are removed, in particular potassium (K), calcium (C), phosphorus (P) and nitrogen (N), and this nutrient drain is greatest under short (2-5 year) rotations. It has been estimated that whole tree harvesting (above ground only) will remove 1.5 to 4 times more nutrients than bole only harvesting. If tree roots were extracted as well then the losses would be even higher. However, under biomass harvesting for energy if may be possible to balance the nutrients through returning the ash and using nitrogen fixing species.

The response to nutrient depletion has largely been the fertiliser crutch. Globally this is an essential requirement on infertile tropical soils but also in low-fertility or degraded temperate soils from the first rotation, and on moderate to fertile sites in subsequent rotations. In New Zealand nutrient deficiencies are common.

Relying on inorganic fertilisers is unsustainable. The mining of non-renewable fertiliser base materials, the eutrophication of waterways with fertiliser run off as well as gaseous losses to the atmosphere following application, and the negative effect on soil fauna, flora and physical properties are not sustainable. The energy involved in their manufacture, transport and application, all come from fossil fuel sources.

It is suggested that yields cannot be maintained by present practices, and fertilisers are simply a short-term fix to meet certain economic criteria. As a plantation manager pointed out:

“Application of fertilisers and encouragement of N-fixing plants will provide some replenishment but ultimately it is likely there is a net loss from the ecosystem.” There may be ways of modifying present systems, or using new systems that do not require inorganic fertiliser additions, and at extraction rates that the soil can sustain. Extraction methods that process logs on site, allowing the removal of the minimal amount of wood, are another possibility.

Natural forests lose nutrients from the system over time and soils tend to become less fertile. A chronosequence of this can be seen in the natural forests of the west coast of the South Island, New Zealand. However, it has been estimated that the loss of phosphorus from three pine rotations on a infertile soil is the equivalent of 20,000 years of natural loss, and 1000 years of natural loss on a fertile recent soil. A recent report estimated that only 20% of plantation forests are presently fertilised, most commonly with boron and phosphate. If this is the case then considerable soil fertility decline in the near future would be expected, especially as much of the plantation estate is on marginal soils.

“The critical questions about the sustainability of nutrient removals with plantation harvest relate to determining the amount of organic matter and nutrients that must be retained on site; and to determining the degree to which plant-available supplies can be replaced by mineral weathering and plant litter inputs.” .

1.3.2 Carbon Cycle

Pinus radiata and other plantations have been found to be efficient producers of above-ground biomass. Considerable quantities of carbon extracted from the air by trees, however, much of this is lost through respiration (60% for beech forests in New Zealand). Also root turnover and woody debris entering the soil C pool account for a large part of the total carbon extracted. It has been estimated that globally, two thirds of C stored in living ecosystems is in the soil and that overall biomass does not change but below and above ground proportions (C allocation) alter with changes in nutrient and water availability, and temperature. Different management practices and environmental conditions can alter the carbon allocation patterns. Temperature was found to control carbon dioxide production by litter and soil. Global warming could therefore cause a rise in the quantities of carbon being released from the soil OM. Most of the recent debate relating to the carbon cycle has focussed on tree plantations and forests as carbon sinks to offset private, national or global fossil fuel carbon emission.

(Figure 2: Carbon life cycle of the tree plantation industry.)

The Carbon and Energy Balance of the Tree Plantations Industry

The greenhouse effect is one of the most widely discussed environmental issues. In the last few years many in the plantation industry have been promoting tree plantations as a carbon sink to offset the rise in atmospheric carbon levels from fossil fuel burning. Carbon credits could be pursued as additional financial benefit from plantations. Yet much of the analysis that has led to the conclusion that tree plantations provide a carbon sink does not include the complexities of the plantation life cycle. However, plantations planted onto pasture or crop land that substitute methane emissions make a positive contribution towards reducing greenhouse gas emissions.

A natural forest is generally in a state of carbon balance, where an equivalent amount of C extracted from the air is released through decomposition. Huge amounts of carbon are held as a “steady state” (up to 500 tonnes/ha of carbon in old growth temperate and tropical forests). Regenerating native forest is rapidly accumulating the C lost when the forest was cleared formerly. Tree planting carried out as forest restoration with no wood harvest intended will be storing considerable quantities of carbon.

The life cycle of tree plantations begins with site preparation for planting. If any vegetation is cleared there will be a loss of carbon through burning, decomposition or export from the site. Fossil fuels are normally used in this process by machinery or herbicides. Following planting, carbon is taken from the air by the trees through photosynthesis and incorporated into the biomass. This continues throughout the tree’s life but is largely cancelled out from canopy closure onwards by C releases from litter and OM decomposition. Fossil fuels are used in fertiliser, herbicide and pesticide applications, and during silvicultural treatments. Harvesting takes place and the wood is processed, once again using fossil fuel energy. The slash and litter remaining on the site decomposes releasing C back into the atmosphere.

It has been reported that 90% of the C stored in a pine plantation system will be returned to the atmosphere within 5 years of harvest.

By including the C lost in fossil fuel use in the harvesting and processing of wood, it was found that only solid timber and plywood remained net stores of carbon. Of all wood harvested in New Zealand only 20% ends up in medium-term carbon storage such as solid timber in housing. Paper and manufactured boards are all net emitters of carbon.

Paper and wood waste buried in dump sites often produces methane, a 6 times more potent greenhouse gas than carbon dioxide. If longer time frames are considered then solid timber can only be seen as a short-term store of C, eventually being broken down and the C released by insect attack, decay or burning.

Naturally durable special purpose timbers will therefore be longer term stores of carbon than less durable timbers such as pine. Likewise, plantations with a focus on producing solid timber for long-term uses such as furniture, will be more carbon positive that plantations focused on short-term product life. With treated timber the gains of longer C storage will likely be offset by the, energy cost of preservation treatment. However, timber is certainly more carbon positive than other building materials, such as steel, plastics and aluminium, and to a lesser extent concrete, with the exception of earth.

It is important to distinguish between real carbon "brown" sinks such as fossil fuels, and short-term cyclic "green" stores such as tree plantations. While plantation trees are growing they are storing carbon and assuming a tree cover remains on the site, then there will be net store of carbon. However, if the C emissions from forest establishment and silvicultural practices, the likely transfer of C from below ground OM to above ground biomass, and transport and industrial processing emissions are added to the above carbon cycle analysis, a different picture unfolds. Modelling the carbon sequestration by plantations (planting at the high of 100,000 ha per year), the storage or loss from wood products, and the C emission from forest management and processing, it was found that after 100 years over 50% of the net store from establishing tree plantations on non-forested areas was lost. Assuming the plantation industry does not reduce its emissions from fossil fuels, eventually C emissions in manufacturing timber products may cancel out C stored as standing biomass and in solid timber, making plantations an overall a net carbon emitter. Future energy use predictions for the plantation industry show that they are growing more than any other area of economic activity.

These scenarios have assumed that extraction is limited to the tree stem only, which may not be the case in the future with whole tree harvest being mooted. As well, global warming is predicted to have a carbon "fertilisation" effect, increasing the amounts of carbon sequestered by plants. However, it is also predicted that rising temperatures will shorten tree life and increase organic matter decomposition rates, releasing large quantities of carbon.

Afforestation with tree plantations is at best a short-term store and is seen as no substitute for a reduction in the use of fossil fuels. Any gains in carbon storage in Aotearoa could be seen as simply restoring the carbon capital of the original forest cover (53% in the mid-1800s and down to 23% currently) released in the clearing and burning over the last thousand years. We are still a long way from balancing our historical carbon budget.

1.3.3 Nitrogen (N)

Nitrogen is a key nutrient in forestry systems. It is closely linked to the soil organic matter and is made available to plants through microbial action. Many of the less productive soils with tree plantations as a land use have N as the major limiting nutrient, such as the sand country and Northland and West Coast podzols. Many plantation practices have a severe impact on the supply of N, such as burning, slash removal, and any practice that disturbs the soil organic matter. Productivity declines have been recorded as a result of lower available N and other nutrients. Small amounts of nitrogen are lost through wood removal, however, much larger amounts are lost if leaf material is removed from a site.

The practice of clearfelling itself can cause huge losses of nitrogen from the system. In Australia, on a clearfelled area of radiata on sandy soils, increased mineralisation of the soil organic matter N combined with no tree uptake meant two-thirds of the mineral N was leached below 30 centimetres soil depth. Establishment of Pinus radiata has been shown to lower soil nitrogen in comparison to native Eucalyptus forest, and lower forest floor N content in comparison to New Zealand native forest.

The common response to a N deficiency is to apply an inorganic fertiliser. However, uptake by trees of fertiliser N is usually low, and may not meet the trees N demand. Considerable quantities of inorganic N fertiliser are either lost to atmosphere or leached through soil and into water systems. Eutrophication of waterways as a result of N pollution can devastate stream fauna and flora through algal blooms and is a danger to ground water supplies. N fertilisers reduce the abundance of soil organisms, many of which may be beneficial to tree growth, and also lower soil pH. Furthermore, the production of 1 tonne of nitrogen for fertiliser releases 2.3 tonnes of carbon dioxide.

However, a more ecologically sound method of meeting N deficiencies exists. Many N fixing micro-organisms exist in the soil such as the symbiotic bacteria Rhizobium, or some species of algae. In Aotearoa legume plants commonly form associations with microbes to fix nitrogen, such as the native tutu, broom and kowhai, and introduced plants such as lupin, lotus, gorse, alder and acacia. However, in the process of fixing N they may contribute to the acidification of the soil. In north-east USA red alder has been found to have an acidifying effect on the soil. This is a problem in pastoral system with symbiotic N fixing plants (mainly clovers), and some of this fixed N and N in animal excreta is leached also.

Systems involving lupins have been highly successful on coastal sand soils, and are likely to be successful elsewhere. Many legume trees and plants such as acacias and gorse, and non-leguminous natives such as manuka (Leptospermum spp.), are excellent soil enhancers following tree crops. N fixing ground cover could be interplanted and mulched as a green manure, as some plantations are trying. Rather than applying chemical fertiliser, incorporating and utilising these natural associations would benefit the soil, and the productivity of the plantation. A recent review of northern hemisphere tree and forest systems found that soil organic matter and N content appear to be higher in stands with N fixing species (typically 10-40%), and concluded that:

"...the major effect of N fixing trees on ecosystem production and nutrient cycling probably derive more from the input of high-quality litter than from the proportional increase in the ecosystem N capital."

1.3.4 Phosphorus (P)

Like nitrogen, phosphorus is a key nutrient with a close association to the soil organic matter. More than 50% of the total P in surface soils is present in the soil organic matter fraction. Similarly, P is lost through plantation practices that disturb the soil and degrade the soil OM component, possibly to an even greater degree than N. Significant amounts of P are lost from the system through stem extraction: 15% of topsoil P being recorded in a Canterbury trial. Deficiencies of P are common throughout New Zealand, and in soils of considerable age, tree growth and nutrient cycling may be more limited by P than N.

Once again the convention has been to apply fertiliser to maintain productivity. With many of Aotearoa's soils having a high propensity to 'fix' water-soluble phosphates. Phosphates are also leached into waterways, contributing to eutrophication. However, rock phosphates appear to provide a more natural slow release P source.

There appears to be conflicting conclusions on the impact of lower pH (acidification) on the availability of P.

The conventional view in New Zealand and elsewhere (predominantly from research areas now under agriculture), is that P is less available to plants with a lower soil pH. However, in a review on nutrient recycling in natural forests, it was concluded that:

"There is abundant evidence that roots of many (tree) species exude compounds which have the ability to solubilise sources of phosphorus of otherwise low availability."

In South Island high country topsoils extractable phosphorus levels were found to be higher under conifers than adjacent grassland. The major reason forwarded was greater mineralisation of organic matter by pines and possibly the transfer of P from deeper soil horizons.

Root mycorrhizae play an important role in the P absorption, and can be especially so in low fertility soils. Other soil fauna and flora are a source of P through decomposition, emphasising the importance of a healthy soil biological component, encouraged through diversity rather than single species. It is likely that some tree species or systems will have a lower requirement for P than P. radiata.

1.3.5 Other Macronutrients (K, Ca, Mg)

Potassium (K), calcium (Ca) and magnesium (Mg) are major macronutrients for plant growth. They are largely supplied by soil parent material weathering. The level of weathering is determined by the concentration in parent material, soil relief, climate, and level of soil biological activity.

The level of nutrients available from weathering will therefore be totally dependent on individual site conditions.

For example, Zabowski (1990) found Ca inputs from weathering ranged from not detectable to 120kg/ha/yr for 34 different site and forest types, with and average of 35-45 years needed to replace Ca lost from bole removal. K and Mg weathering inputs range from not detectable to 52 kg/ha/yr. Altering the relief, temperature, pH, moisture levels and soil biologic activity over the life of a plantation rotation, or through a change of land use, will affect weathering rates. Changes in forest types/species could also alter weathering rates. Uptake of these nutrients will vary with forest species. Hardwood forests were found to have 2 or 3 times the uptake of Ca, K and Mg as conifer forests.

Ca is not normally deficient in Aotearoa soils. However, it is commonly added in lime, dolomite and superphosphate fertiliser. Ca can not be retranslocated within the plant, such as from the older leaves to the growing tissue. A continuous supply is therefore required. As Ca is stored in the tree stem and bark in relatively high concentrations. Balneaves and Dyck 1992], losses due to harvesting may be significant. Cumulative losses over 150 years in eastern USA through biomass removal and leaching have been recorded as high as 20 – 40% of total Ca. Nitrogen leaching (nitrification) and acid soils will decrease the availability of Ca. Ca is thought to encourage earthworm activity and therefore aeration of the soil.

Deficiencies of K have been reported in soils around Nelson and podzolised soils of Westland and Northland. Significant amounts of K are lost through harvesting and site disturbance100, and will contribute to productivity decline. K appears to cycle in the soil rapidly and is washed from foliage and litter. In a Nigerian study, a Pinus plantation was found to return less K to the soil than adjacent native forest.

Magnesium deficiencies occur in the North Island central plateau. However, plants generally have a low uptake.

Losses are significant through harvesting and site disturbance. Extraction rates, level of site disturbance and rates of soil weathering will likely determine whether the Mg cycle is in balance.

1.3.6 pH

All plant growth through the net uptake of negatively charged ions leaving more positive ions such as hydrogen and aluminium in the soil, could be viewed as acidifying (lowering the pH). The acidifying effect will be exacerbated by removal of the stored negatively charged ions (cations), such as through wood storage in trees and subsequent harvesting, livestock and crop production, or leaching. However, in a forest situation: a tree dies and decomposes, the cations are returned to the soil counteracting the acidifying effect.

Of course acidification can be a natural process as occurs in many natural forest soils over a long time period, from the kauri and podocarp (ancient conifer) forests of Aotearoa, to the broadleaf tropical rainforests. Rainfall is a key factor, where a higher rainfall increases the cation leaching and subsequent acidifying. The rimu forests on the west coast of New Zealand are an example of this. Litter type and leaf wash also have an influence. “Mull” forest floors (where the litter is well mixed in topsoil) commonly found under broadleaf trees is generally less acidic than “mor” forest floors (no mixing between forest floor and mineral soil) commonly found under conifers.

Part of the debate around soil ‘degradation’ of tree plantations has focussed on differences between hardwoods (broadleaf trees) and conifers. Conifer plantations have been recorded as acidifying the soil in Aotearoa, in North America, in North America and Europe, in Australia, in Chile, in Spain, and globally. It appears that the slower decomposition due to high concentrations of lignins, tannins, and fats and waxes in pine needles, leads to a more acidic organic matter and lower biological activity (see section 1.2.1). A review of species effects on soils over a range of sites in managed forests in North America and Europe, found that the pH of the plantation or forest floor may differ by up to two units on the pH scale within a few decades under the influence of different species. The reasons for this were not established in all cases, nor was it consistent between conifers and hardwoods.

It is generally considered that acidification is of critical concern to sustaining soil fertility – a lower pH reduces the availability of many key nutrients such as P, Ca, Mg, N and boron, but may increase the weathering of parent material and mineral rock within the soil. However, in the North American and European studies cited above, no association was found between acidification and N and P availability. Additional factors in relating the findings from the North American and European research to New Zealand may be the impacts of aluminium, and changes in soil flora and fauna.

A significant negative effect of acidification of soils is the release of toxic aluminium (and also hydrogen and manganese) compounds into the soil solution, subsequently inhibiting root growth, and Mg, Ca and K uptake. Acid soils were found to have decreased numbers of earthworms. These may be important concerns for the soils of Aotearoa.

In summary, it seems difficult to draw conclusions over whether or not acidification is causing degradation of soils. Significant acidification occurs under New Zealand introduced pastoral systems and is countered by applying lime fertiliser. The precautionary approach is best applied in situations of uncertainty such as this, where tree plantations could aim to maintain or restore the original indigenous forest soil conditions,. This could involve planting mixed forests of hardwoods and conifers, plantations of indigenous species, or different rotations of different species.

1.3.7 Micronutrients

Deficiencies of boron, copper and zinc have been found in Aotearoa soils. Boron in particular has been significant for Pinus radiata, and boron fertiliser is routinely applied. As there is only a small difference in soil concentrations between boron deficiency and toxicity, there is a danger of toxicity from boron fertiliser application and cases have been recorded in New Zealand. Many micronutrient levels are associated with macronutrient availability example. phosphorus and copper and zinc, with pH and levels of soil biological activity.

1.4 Soil Physical Properties

Maintenance of physical properties is crucial to sustaining a soil. A soil's physical condition can in some circumstances be the major factor limiting plant growth. Forests will generally maintain a soil's physical properties by providing a buffer from climatic extremes, contributing to soil organic matter turnover, and aerating the soil to considerable depths through their roots. Measures of a soils physical condition include bulk density (indicates porosity), resistance to penetration (compaction), water-holding capacity and temperature. Strongly linked to soil structure is the quantity and quality of the soil organic matter component (see section 1.2 for discussion of this). Soil structure is generally most developed in comparatively organic-rich mineral topsoils. Soil flora and fauna activity can greatly influence soil structure (example. earthworm soil mixing), depending on tree species and subsequent litter and soil composition.

There is considerable evidence that many plantation practices and the frequency of these practices are detrimental to a soil's physical properties. This will be dependent on soil properties and the corresponding "susceptibility of soil types to machine compaction". A hypothetical classification of soil susceptibility has been developed. Plantation practices of particular concern are those involving mechanical methods and site disturbance that effects the soil organic matter. Soil compaction on skid trails, roads and in general during thinning, clearfelling and preparation for planting, reduced soil porosity and aeration and subsequently contributed to declines in growth rates. Disturbance of the soil at clearfelling and during site preparation reduced organic matter levels, subsequently altering many properties of the soil and the level of biological activity (Powers et al 1990, Skinner et al 1989, Shaw et al 1991). Soil structure is relatively easily destroyed but very difficult to recreate.

Loss of soil organic matter and soil animals due to fire may cause a subsequent deterioration of soil structure.

There has been the suggestion that pines will cause soil physical changes such as podzolisation. There is considerable evidence that pines are acidifying and it is possible that this will eventually lead to podzolisation as happens naturally in many areas under conifers over many centuries such as west coast terrace rimu forest and kauri forest. It may be significant if the pines are grown on soils that were formed under broadleaf or mixed broadleaf/conifer forest which were under little threat from acidification and podzolisation. However, there is no direct evidence known that Pinus radiata will form podzols on soils in Aotearoa. Although the time-frame used so far is to short to assess this conclusively.

1.5 Erosion, Water Quality and Yield

Plantation forests are often in catchment areas for many river and stream systems with significant natural values, and sources of water supply for domestic, irrigation and industry. Any changes in erosion rates, and water quality and availability will have significant downstream affects. Soils do have a rate of natural erosion such as levels found under native forest, mainly determined by rainfall, topography and geology. However, changes in land use can accelerate these levels. In areas that are degraded and have high erosion rates, planting of trees will reduce soil loss through organic matter build-up and protection from sheet wash, ice needle erosion, wind erosion and rainfall impact.

Erosion is both an extensive and severe problem in New Zealand. For instance 52% of New Zealand suffers surface erosion (sheet, wind, scree), 36% mass movement (slips, debris flow, earth flow and slump), and 12% fluvial (rill, gully, stream bank). Vegetation has a significant impact on erosion rates and water quality. The highest consistent water quality in the Wellington region has been found to be from catchments that drain predominantly native forest. Loss of sediment was found to be considerably greater under pasture areas compared to adjacent mature pine forests and native forest. Tree cover will generally provide considerably better erosion protection than pasture or crops.

Forests will have a particular influence on the stability of slopes and soils. This was dramatically illustrated by the effect of Cyclone Bola on the East Coast of the North Island, where:

- regenerating indigenous scrub and forest had similar levels of protection as mature exotics,
- mature exotic plantations had less than 10% of landsliding of terrain covered with pasture, and
- slopes with trees less than 6 years old fared little better than slopes in pasture.

The critical period for slope stability under plantation forestry is in the years 2 to 8 when the roots of the old stumps lose their ability to hold the soil and the young trees have insufficient root development. Debris and sediment from slope failures can still effect stream flow and water quality more than 20 years later.

(Figure 3: Sedimentation processes and impacts.)

On erosion prone hill areas, such as the on the East Coast, systems other than short rotation clearfelling will be necessary to provide a continuous vegetation cover, such as mixed species planting, coppicing species and longer rotation species. In highly eroding areas a permanent forest cover is likely to be desirable and even areas of regenerating manuka/kanuka scrub or forest have been shown to provide adequate erosion control.

Loss of vegetative cover and soil disturbance at harvesting and during site preparation for planting are major contributors to erosion and reduced water quality. However, this is largely dependent on the method used, and a range of factors including: topography and steepness, soil type, soil moisture content, planning of location of skid tracks, and slash and understorey density.

New roads and tracks can cause major soil loss, particularly on steep terrain. Logging of a plantation by the company ITT Rayonier at Marahau, Nelson, on unstable soil, produced a deluge of silt, sand and gravel onto adjacent flat land and estuary, within 100 metres of Abel Tasman National Park. The erosion and sediment rates of these soils have been recorded in detail. In 1989 it was recommended that Marahau be added to adjacent Abel Tasman National Park, as plantations were considered as unsustainable on some areas of these sensitive erosion prone soils.

In a Marlborough Sounds hill country logging trial, it was concluded that total sediment yields from roads and contour tracks would halve, and fine sediment yields would drop by 200 – 500% if the logging method used was a skyline system rather than ground-based or simple cable systems. However, even with the skyline system sediment yields were 2 – 7 times (depending on site) the existing yield. Results such as these are critical as the most erosion occurs during forest harvesting and a few years afterwards, and about 35% of the plantations in New Zealand to be harvested over the next three decades are located on moderately steep to steep slopes of more than 20 degrees.

Similar reductions in erosion rates are to be expected with helicopter extraction compared to ground-based systems on steep terrain.

In Canada, skidders were found to produce 58% subsoil exposure compared to 11% from high-lead haulers. Similar results for subsoil exposure have been found in New Zealand, particularly on steep terrain.

Slash retention and minimal site disturbance would produce significantly less soil loss than windrowing, stumping, V-blading, burning and slash removal. Other strategies have been suggested including; partial logging of steep slopes, small logging coups, staged logging, and construction of erosion-resistant logging roads and tracks.

Another impact of soil disturbance is the loss of nutrients. One experiment found that in a stream draining from pasture, 15 times more P was "exported" on an area basis that from maturing pine plantation and indigenous forest catchments, and about three and 10 times more N than indigenous forest and pine plantation streams respectively. It would appear that mature pine plantations will likely have a water quality approximating that of undisturbed indigenous forest.

However, short rotations and clearfelling regimes preclude any comparison between the two.

The clearing of riparian strips can also have a significant impact on water quality. More soil entering the watercourse, greater fluctuations in water temperature, loss of shade, increased inputs of fertilisers and sprays, all contribute to the lowering of water quality and detrimental impacts on stream fauna and flora. In West Coast California and Washington, salmon populations have plummeted due to lack of stream shade and siltation from clearfelling. It is now generally accepted that permanent riparian buffer strips are a necessary and effective method of protecting water quality and stream flora and fauna from sedimentation, nutrient and chemical pollution, logging slash, stream bank erosion, and temperature and light fluctuations.

A paper planning exercise on riparian buffer strips found that the area (of the plantation management plan) required of them was determined by stream density. As riparian width and percentage length of waterways increase, coup size and haul distance decreased but roading requirements steadily increased. In steep unstable hill country where protection of water quality is a prime goal, rather than simply riparian buffer strips, what may be required is whole tributary headwater valley bottom protection through reversion of indigenous forest or some self-sustaining vegetation cover. This would mean production plantations or agriculture would only be carried out on the middle to upper slopes. Considerable biodiversity values would be protected through this practice also.

1.5.1 Plantation Influences on Water Yield

Water yield from catchments covered in exotic plantations is generally less than that from equivalent land under indigenous forest or in pasture. According to Dons (1987), the catchments with exotic plantations, native forest, and pasture have the following characteristics:

i) Exotic Plantations – the lowest mean flows and low flows, with similar evaporation losses to those from the native forest catchments.

ii) Forest – the lowest storm-flow yields and peak flows, and highest low flows.

iii) Pasture – the highest mean flows and peak flow rates, greatest storm-flow yields, and lowest evaporation losses

Many management practices will influence water yield. Clearfelling of forest or plantations is cited as hugely increasing run off and stream-flow, compared to both unlogged and partially logged areas. However, as a plantation re-grows, water yield declines towards pre-logging values. Tree plantations and indigenous forest will buffer flood peaks, moderating flow from catchments after rain storms. This will likely reduce downstream costs for flood control and levels of damage as a result of floods. Planting trees onto compacted soils or exposed subsoils will enhance water infiltration rates and may subsequently improve dry season low flows.

There has been considerable recent debate over water yield from pine plantations. There is concern that proposed plantations for the MacKenzie basin will reduce water yield to the hydro lakes, because research has concluded a likely 25-30% drop in run off resulting from the conversion of tussock grassland to pines. Primarily due to a change in land use through the establishment of pine (now 31 % of the catchment), flow reduction of the Tarawera River has been calculated at 27% for the period 1964-1992. Planting pine trees onto pasture and gorse covered catchments in Moutere Catchment, Nelson, reduced annual run off by 55% and ground water recharge by nearly 70%.

For all of the recorded situations the reduction in water yield from the catchments planted with plantation pines, were affecting downstream users of the water. In the MacKenzie basin Electricorp is concerned that there will be less water entering the hydro-storage lakes and therefore to feed the southern lakes power stations. In the Tarawera, lower flows are creating problems for downstream users, including ironically, the Tasman pulp and paper mill where toxic discharges have less water available for dilution. In the upper Moutere, a recent High Court decision held up a Planning Tribunal ruling requesting Tasman Forestry to remove pine trees planted on land which has restrictions (zone rural B) on the level of plantations able to be planted. The zoning restrictions enable the local councils to take account of downstream water effects. Further to this local farmers are requesting a special levy on timber companies to help with the water supply problem in the region.

These reduced stream flows may have had more serious impacts on aquatic flora and fauna than the short-term lowering of water quality as a result of timber harvesting, road construction and other logging practices. As well, in the high country, where plantations are planted around or close to bogs, flushes, seepages or tans, transpiration may result in their drying up and subsequent alteration in species composition.

The water requirements of the plantation processing industry may come into conflict with other competing users.

The manufacture of paper requires large amounts of water: approximately 75 tonnes of water for every one tonne of paper for current processing plants in New Zealand. In Dargaville, plans to establish a wood processing plant requiring large amounts of water from a local catchment have clashed with local dairy farm irrigation proposals.

There are also reported species differences in water yield. Radiata pine is regarded as a high water user (or high evapotranspiration rates) and has been planted for this purpose in some critical erosion projects. In Australia, areas under Pinus radiata had lower water yield than that of adjacent native eucalyptus forest. Observations have been made that the forest floors are dryer under conifers such as larch, than hardwoods. However, Fahey (1994) concludes that differences between species and types of mature forest are likely to be small but rainfall, climate and stand management may be just as important. Water yield is likely to become a more critical land use issue given the likely future impacts of climate change in New Zealand such as variable rainfall, higher temperatures and more wind.

The debate over water yield and rights, is currently being defined by what are seen as the most economically important values: pre-stream, instream or downstream. What is largely being left out is land use sustainability. The reliance by horticulture and agriculture on irrigation water may in itself be an unsustainable practice, being supported in the Moutere case by what are most likely unsustainable pastoral practices in the recharge zone. It may be that it is more important to reafforest the recharge zone to sustain the soil resource, and if water yield is critical then reafforest in indigenous forest.

1.6 Toxic Pollution from the Plantation Industry

An integral component of a life cycle approach to assessing exotic monoculture plantations is the use of toxic substances for fertilisers, herbicides, insecticides and fungicides, during product processing and timber treatment. These practices impact on the ecology of soils, waterways, and air.

1.6.1 Fertilisers

Fertilisers are commonly applied to tree plantations. Some fertiliser forms are highly vulnerable to leaching and atmospheric loss, such as urea.

As a consequence, pollution and eutrophication of water systems occurs. Although this is largely from agriculture at present, with the increased reliance on fertilisers and expanded planting, it will likely emerge as a major concern for tree plantation areas. Nitrate poisoning of ground water from leached nitrogenous fertilisers is a major problem in Europe and parts of Canterbury (NZ), and is connected to many human medical disorders. Boron toxicity has occurred in trees from applications of borax as a fertiliser as well as a fire retardant, wood preservative and herbicide.

1.6.2 Herbicides, Pesticides and Fungicides

More than 30 brands of herbicide, pesticide and fungicide are used on tree plantations in New Zealand, including highly toxic and persistent organochlorines. Large areas are sprayed with different chemicals. For example, around 10% of plantations are sprayed an average 3.5 times for Dothistroma control. This amounts to about 90,000 hectares sprayed every year over the past 14. Approximately 75% of new forest land and most logged plantation land is sprayed with herbicide. Synthetic chemicals and heavy metals contaminate soil, waterways and the atmosphere, as well as people, plants and wildlife. In Particular, organochlorines are toxic to stream flora and fauna, and it appears that the main input source is through direct application to the watercourse or riparian vegetation or associated with accelerated soil erosion. Stream fauna are particularly sensitive to chemical changes, such as copper.

In a Canterbury stream, applications of paraquat at 2g/m were directly toxic to amphipods and also reduced their habitat of dense beds of weeds. Both the Netherlands and Germany have banned paraquat because of its persistence in the soil. Its breakdown product 14C-carboxy-1-methyl pyridium chloride, is loosely absorbed by soil, and is potentially mobile and has leaching potential. It is extremely dangerous to humans and easily absorbed through the skin. There is no known antidote.

Diquat, a pyridine compound structurally related to paraquat, is a very dangerous poison that can drift long distances, can persist in standing water for up to 4 weeks and remains in the soil for long periods of time. Diquat is contaminated with ethylene dibromide, a carcinogen and a teratogen.

The three common triazines, atrazine, simazine and terbuthylazine are persistent in soils and ground water. Atrazine is classified by the US EPA as a possible human carcinogen, and strongly inhibits certain hormone receptors. The German government banned all atrazine-containing herbicides in March 1991 because of concerns over threats to ground water. Atrazine, simazine and gardoprim have all been recorded as in toxic concentrations in Canterbury ground water.

2,4-D (such as in Tordon) is both acutely and chronically toxic. In humans it is a neurotoxin, a carcinogen, and adversely affects human reproduction. In laboratory animals it causes organ damage, birth defects, and foetal damage. It effects the behaviour of fish, growth in chicks, and brood development in honey bees. 2,4-D drifts, in some cases up to 50 miles: contaminates ground and surface water, and has been linked to an increased frequency of disease in corn and pine trees. It is contaminated with several toxic compounds including dioxins and 2,4-dichlorophenol.

Glyphosate, the so-called active ingredient in Roundup breaks down into formaldehyde, a known human carcinogen and neurotoxin. There have been no studies of the toxicological and environmental fate of glyphosate in New Zealand.

The surfacants used in some herbicides can be more toxic to aquatic species and humans than the active ingredient.

Due to their toxicity and potential for spray drift, accidental dumping, run off to rainwater and long distance aquatic transport the use of toxic pesticides poses a substantial threat to freshwater ecosystems in the locality of plantations.

Picloram is extremely persistent in soils, especially in dry regions. The water solubility and mobility of picloram through soil is high, leading to contamination of the ground water. It is a known carcinogen and is contaminated with hexachlorobenzine.

2,4-D, Glyphosate, Hexazinone and triclopyr have been shown to adversely affect ectomycrrhizal fungi which increase nutrient uptake and improve resistance to stress in trees. Plantation practices that are detrimental to the soil organic matter will alter a soils ability to degrade or store chemicals and heavy metals (see section 1.2).

The long-term effects of most of these chemicals to ecosystems is unknown. Persistent and/or bio-accumulative chemicals which have the potential to negatively affect non-target species and the functioning of ecosystems, either synergistically or individually, are not compatible with an ecologically sustainable forestry industry. There are alternatives to these chemicals, such as moving away from clearfelling regimes that expose vast areas of soil, using biological controls, species and genetic selection, grazing and manual methods of competing vegetation control. Many of these require a greater research effort.

1.6.3 Chlorine Bleaching and Mechanical Processing of Pulp and Paper

The New Zealand pulp and paper industry has a significant impact on the environment.

There are two Kraft bleaching factories in New Zealand, Tasman Pulp and Paper on the Tarawera river and Kinleith on the Kopakorahi Stream which flows into the Waikato river.

Both factories have on-site chlorine production plants and use more than 75 tonnes of water for every tonne of pulp produced. They produce and discharge large quantities of effluent with a high organic matter content, lowering the oxygen content of the waste waters (such as a high Biological Oxygen Demand – BOD). The waste waters are extremely discoloured and contain a range of toxic organochlorines and resin acids.

The chemical and toxic air and water emissions from Kraft pulp and paper factories read like a “Who’s Who” of contaminants: hydrogen sulphide, methyl mercaptan, dimethyl sulphide, dimethyl disulphide, sulphur dioxide, nitrogen dioxide, several pinenes, chloroform, dichloromethane, benzene, chlorine, chlorine dioxide, lead, mercury, zinc, dioxins, and furans. The discharge of these chemicals and heavy metals have contaminated local waterways, sediments and biota.

Mechanical pulp factories, while not using chlorine bleach, do discharge waste waters with a high BOD and containing toxic resin acids. Pulp and Paper factories are also large consumers of energy and emit large volumes of the greenhouse gas, carbon dioxide.

For example, the Tasman and Kinleith factories are responsible for a significant portion of New Zealand's total carbon dioxide emissions.

Toxic substances discharged from Medium Density Fibreboard (MDF) factories, plywood factories and other wood manufacturing processes include formaldehyde.

1.6.4 Toxic Timber Treatment Chemicals

The toxic effects of timber treatment have recently come to light, with more than 600 sites potentially contaminated by the organochlorine, pentachlorophenol (PCP). There has been widespread toxic pollution of waterways from timber treatment chemical use in New Zealand. PCP and other timber treatment chemicals have been detected in Lake Rotorua, the Waikato river, the Tarawera river and Auckland's Tamaki estuary, Manukau harbour and Waitemata harbour. The PCP cleanup bill alone is set to run into hundreds of millions of dollars. Various other organochlorines have been used to treat timber such as chlordane, dieldrin and lindane. One organochlorine chemical still in use is chlorothalonil.

The environmental impacts of current timber treatment chemicals and practices have not been fully researched (for example chlorothalonil and copper-chrome-arsenic, CCA or Tanalising). CCA consists of copper sulphate, sodium dichromate and arsenic pentoxide. According to the London Hazards Centre chrome is associated with increased lung and stomach cancer amongst chrome platers and cement workers, and arsenic exposure has been linked to lung, liver and lymphatic cancer. As well as a range of sub-lethal health effects, arsenic compounds are known to be toxic to human foetuses and have been recognised as teratogens by the US Environmental Protection Agency (EPA).

The ecological and social costs of toxic timber treatment chemicals in the plantation production cycle need to be included in any assessment of sustainability. Alternative systems are needed that reduce and eliminate the toxic load on the environment, and the choice of species or system needs to include the ecological cost of any downstream processing and treatment. For example, solar powered kiln drying and alternative treatments instead of toxic chemicals.

1.6.5 Organic Compounds from Pine Plantations

Wood processing sites with uncontained log stockpiles, port log piles, or bark and sawdust dumps, are likely to leach harmful and/or toxic organic acids into the surrounding environment.

2.0 Tree Plantation Influences on Biodiversity

2.1 Introduction

"Diversity – being unlike in nature or qualities"   (Concise Oxford Dictionary)

Biodiversity is the pinnacle of nature's wealth. It is used directly by society for virtually all our essential items such as food, medicines, building and industrial raw materials, as well as many indirect and difficult to quantify uses such as ecosystem services and the earth's life support systems.

Yet many modern production systems such as large-scale agriculture and tree plantations are based on uniformity and thus can be seen as a primary threat to biodiversity conservation and sustainability. Many of the benefits of maintaining diversity and the costs of a loss of diversity are not included in the balance sheets of production systems. However, the future benefits of diversity, such as a source of productive resources, and a genetic bank of disease resistance varieties, will not be protected until diversity is incorporated into the logic of production. Current reductionist approaches to the plantation industry, where tree plantations are described as a "factory without a roof", ignore the creative possibilities of a holistic multiple use approach to forestry.

2.2 Internal Diversity: Low Diversity Inside Plantations

In comparison to natural forest ecosystems, biodiversity in monoculture tree plantations is low. Low internal diversity means: few species (canopy, understorey/ground cover, faunal), low genetic variation within species, few interactions between different species (connectedness), a limited range of habitats, and little landscape diversity. Diversity is frequently considered a primary indicator of ecosystem health, stability, and resilience. It is an essential component of land use sustainability through sustaining the evolutionary potential of the indigenous landscape. Aesthetic values are also important. Monoculture landscapes are monotonous and insensitive to the natural character of the landscape. Conifer plantations in Britain have been criticised as "monolithic blocks...imposed on the landscape without regard for its contours.", with many advocating mixed woodlands instead.

Monoculture plantations are simple systems of one type of tree of the same age, grown the same distance apart, and clearfelled at the same time:

"...a single crop-tree species, even-aged, and has been created artificially...". They are designed to produce a crop of wood in the shortest possible time. The few species of plants and animals in them tend to be generalists that are abundant elsewhere rather than specialists that have limited distribution and unique habitat requirements. However, a plantation may produce an increase in diversity if planted into introduced grass or crop lands, or on severely degraded areas, as trees tend to increase the vertical complexity of vegetation and the structural complexity of a landscape.

In New Zealand, pine plantations have been found to be poor habitat for native birds. This correlates with experience elsewhere in the world. In Sri Lanka, Senanayake (1987) observed 3 species of bird in a Pinus monoculture and 5 in Eucalyptus, compared with 25 in natural forest. Although specialist native birds are sometimes found in plantations such as the North Island brown kiwi in Waitangi pine forest in Northland, they generally require adjacent native habitat or an indigenous understorey. The strong relationship between bird diversity and vegetation complexity means birds are good general indicators of overall diversity of different habitats. Plantation tree species and soil type have been found to influence insect diversity.

In plantations there tends to be an absence of species with specific requirements. Shifts in bird composition may be attributed to the homogeneity of the canopy and tree boles, the lack of a (complex) understorey, and the lack of features such as dead wood, holes and snags. In New Zealand, native birds which feed on fruit and nectar, those that nest in holes and to some extent insectivorous species, are those particularly absent from plantations. These birds play a critical role in the fertilisation and dispersal of many tree seeds in the indigenous forest ecosystems of Aotearoa, particularly in lowland areas where only small fragmented remnants areas exist (if at all). Whereas introduced seed- and insect-eating birds such as the chaffinch, redpoll, goldfinch and hedgesparrow are common in plantations.

Birds will tend to reflect the situation of other animal (including insect) groups. In Chile, the diversity of small mammals was found to be higher in a native agroforestry shrubland than adjacent Pinus radiata plantations.

2.2.1 The Effects of Plantation Management on Diversity

The frequent disturbances caused by short rotation clearfelling and re-establishment is one of the most destructive and limiting elements on diversity. It prevents the evolution of a range of habitats or any continuity between felling cycles, or any organisms that rely on dead wood. It is also insufficient time for epiphytic plants to establish, and generally discourages the growth of creepers and vines. Although in some instances native plants (example. some orchids, ferns, fungi and lichens), will thrive in pine and deciduous forests, such as at Hamner Forest, South Island. Most important however, is the age of the plantation with the level of incidental diversity inside, such as with orchids where native species have been found in old pine plantations.

In New Zealand young plantations are particularly poor habitat for native birds but some insectivorous species thrive in conifer stands more than 30 years old. Longer rotations, leaving some mature standing trees, snags and fallen trees at harvest to provide habitat, using systems that do not involve clearfelling, and planting more than one species, will increase the number of species, habitat complexity and landscape diversity. Mixed tree planting determined by the diversity of site conditions and a gradual transition back to indigenous forest systems as a source of wood would greatly sustain biodiversity.

Suggestions by the Department of Conservation for improving plantations as habitat for kiwi in Northland include: maintaining understorey and wide native riparian areas and pockets of native bush, avoiding the use of fire, clearing small areas at a time and staggering ages, long rotations, avoiding logging at nesting time, and controlling pests.

Riparian strips are currently the major area offering biodiversity protection in tree plantations. These areas are often only narrow bands along major watercourses, with small tributaries or seasonally flowing streams being included in the normal plantation management areas. However, more and more plantation managers are recognising the role that streamside vegetation can play for both diversity of stream fauna and water quality, and for providing biodiversity reserves within a watershed (catchment). If biodiversity is to be protected for the future, every land use must incorporate a protected ecosystem network. Tree plantations will be required to meet this goal by carrying out a full landscape assessment to determine the areas required for a protected ecosystem network.

Most plantations tend to have hard defined edges. In nature, edges are sites of high diversity: meeting places for different mediums and habitats, and often involving successional phases. Hard edges will serve to lower the quality of the habitat and increase the edge ‘effects’ on the core of a forested area. Plantation systems that retain edge buffers of longer lived or permanent plantings, will increase the diversity.

Herbicide applications lower the habitat area and the number of species in the shrub/understorey of monocultures, as do insecticides, fungicides and some fertilisers (soil flora and fauna, see section 1.2.1). Herbicide application and riparian area disturbance lead to an increase in watercourse sediment and chemical levels, and an increase in light and temperature, resulting in a reduction stream fauna populations (see 1.6.2).

2.3 External Diversity:

Effects of Tree Plantations on Neighbouring Ecosystems

As a component of ecosystem disruption, biological invasion is an important agent of habitat disruption world-wide and represents a major threat to the long-term viability of natural ecosystems. Pinus and other exotic plantation species can be aggressive pioneer species through invading adjacent ecosystems. Invasive species are characterised by having abundant and easily dispersed seed, experiencing little competition when invading new areas having an absence of natural predators and successful establishment of mutualistic relationships.

As a result of invasion from shelter and timber plantations, significant areas of wilding conifers, particularly lodgepole pine P. contorta, Douglas fir Pseudotsuga menziesii, and European larch Larix decidua, are found in native montane grasslands in the central plateau of the North Island and parts of the South Island high country. Acacia melanoxylon has been reported as the most important invasive plant of the dry southern cape of South Africa. Invasion of an area of native vegetation can lead to fragmentation and displacement of native communities, through changes in abundance and distribution, nutrient and energy cycling, and trophic chain and life cycle interactions.

This has significant implications for the planting of exotic plantations adjacent to indigenous vegetation. A preference should be given to species that are less prone to invasion and to the inclusion of a buffer zone between the plantation and indigenous vegetation.

Exotic monocultures can act as sources of pests and pathogens that spread into adjacent indigenous areas. There are several overseas examples. Cercospora needle blight, caused by the fungus Cercospora pinidensifolia, is a major pest of exotic pine trees in India. First recorded in exotic Pinus radiata plantations in 1973, it now threatens the survival of the native P.roxburghii and P.wallichiana. Similarly in Kenya and Malawi, where the indigenous Juniperus procera and Widdringtonia nodifolia (Malawi’s national tree) are being damaged by the alien cypress aphid. This insect first built up its populations on introduced Mexican cypress plantations.

In New Zealand, native forest generally presents a low fire risk compared to exotic plantations. The risk of fire is much increased by a landscape dominated by exotic plantations. However, this will depend on site climatic conditions and the species and system used. Interplanting or edge buffer planting with lowly combustible species would reduce the risk, for example, silver birch.

Species that require a large range of habitats may be affected by the transformation of the landscape from indigenous to exotic monocultures. If the spatial distribution of the natural landscape becomes fragmentary, such as lacking in connecting corridors, it will effectively lead to isolation, and increased edge and ‘island’ effects. Such effects are highly detrimental to the long-term viability of animal and plant communities. Land use systems that lack a protected ecosystem network will be inhibiting the maintenance of a landscape’s biodiversity, undermining New Zealand’s moral and legal commitments to biodiversity conservation.

2.4 Indigenous Vegetation vs Tree Plantations

Aotearoa drifted apart from the ancient Gondwanaland super-continent about 70 – 80 million years ago. Surrounded by water since then, many of the plants and animals found in Aotearoa reflect these ancient connections, with relatives in Australia, Kanaky, Papua New Guinea and South America. Although the number of species in most major biotic groups is not high by international standards, the New Zealand biota is truly unique and of great scientific significance.

We have an obligation to future generations and the international community to protect and maintain global biodiversity. This has been recognised by the global community and the New Zealand government through the signing of the Biodiversity Convention.

In the past 50 years, significant areas of native forest have been cleared for tree plantations, although this practice is uncommon now. Especially vulnerable are areas of shrubland and forest regeneration, and native tussock grasslands.

In 1991 the New Zealand Forest Accord was signed by industry and conservation groups clearly defining that areas of regenerating native forest were not to be cleared for plantations. Plans for the expansion of monoculture plantations into high country native grasslands such as the MacKenzie Basin have serious implications for natural diversity and landscape values.

As outlined in 2.2 and 2.3, plantation monocultures are no substitute for natural forests, in terms of diversity of species, wildlife habitat, range of products they provide and environmental services. Not only in Aotearoa, but also in tropical regions where natural diversity is immensely higher, and local people are more reliant on their forests.

Yet the New Zealand monoculture plantation model is being marketed to the world, for example the NZ Forestry Industries' promotional video to the Earth Summit, and in international fora such as the the ITTO.

New Zealand Overseas Development Assistance (Aid) has in the past included several projects that have involved the clearance of native forest to plant exotic monocultures. These include; the clearing of some of Western Samoa's last remaining coastal lowland rainforest to plant hardwood plantations, clearing native forest for exotic mahogany plantations in Fiji and the poisoning of native regeneration with arsenic pentoxide, and involvement in the clearing of native forest to plant pine and other exotic tree plantations in Vanuatu. Although NZ ODA is unlikely in the future to fund projects such as these, unaccountable New Zealand forestry consultants continue to advise governments and industry in the Asia/Pacific region to replace native forests with tree plantations.

A vital role that planted forest systems have is to provide an alternative source of raw materials to those derived from natural forests. Over 90% of the worlds' present wood needs are obtained from natural forests. New Zealand is in a unique position in that it already has a large plantation resource to substitute any use of New Zealand native forest for timber, as well as imported unsustainable rainforest timber. However, a double standard exists with the continued advocacy by the plantation industry for the establishment of large-scale monoculture tree plantations in other countries without any attached conditions regarding indigenous forest. This advocacy should have the same conditions on native forest clearance as the NZ Forest Accord and be in full partnership with indigenous landowners or resource rights holders.

With considerable areas of pasture and croplands that were once native forest being planted in tree plantations in Aotearoa, we have the opportunity to restore former native forest land to diverse forest. It is more appropriate to be restoring and enhancing towards the original indigenous values, utilising the multitude of site specific conditions (soils and climate especially), enriching the landscape by afforesting with a diverse range of species and systems, with a special emphasis on native species that are adapted to these conditions. Exotic species could now be used as an economic transition through to plantations of native species such as totara, kauri, puriri, kohekohe, rimu and others.

Although native “scrub”, or even gorse or broom may not be valued as regeneration, it is these areas that hold the key to protection of ecological processes on a landscape scale and to ensuring the continuation of evolutionary processes. Pasture and plantation areas are also going to be required to be restored in many areas. We need to plan for the 22nd Century and beyond in terms of landscape. This will involve land use planning on time and space scales that have never been attempted before.

3.0 The Risks of Tree Plantations

3.1 The Vulnerability of Monoculture Plantations

Debate on the vulnerability of monocultures in New Zealand has raged for many years. There as those who argue that pine monocultures carry no greater risks than natural forests. Some suggest the Pinus radiata plantations may be at risk in the future, and their health is declining. Then there is a whole raft of international evidence and examples of plantation, agriculture and horticulture monocultures, that concludes they are inherently vulnerable.

The International Tropical Timber Organisation (ITTO) use the high level of risk as a justification for recommending a transfer from monocultures to mixed forests in their guidelines for planted tropical forests. It also recommends the use of indigenous species as does the World Bank Forest Policy and the Earth Summit Forestry Principles). However, the plantation industry in New Zealand refuses to acknowledge New Zealand’s commitment to preference being given to indigenous species.

3.1.1 Diversity as Protection

Diversity in natural forests, agroforestry, species and habitat are critical factors in controlling pest numbers and outbreaks. This is based on experience in tropical and subtropical regions and examples such as the devastating outbreaks of leaf-blight in rubber tree (Hevea brasiliensis) plantations in South America, the loss of Gmelia arborea plantations in Jari, Brazil due to a canker fungus, or the devastation in Kenya and Malawi of Mexican cypress (Cypress lusitanica) by the cypress aphid. In the Philippines an outbreak of an insect borer in plantation of a Papua New Guinea variety of eucalyptus, precipitated the elimination of over 10,000 ha of the plantation to prevent its catastrophic spread. But the experience of agriculture both in temperate and tropical climes, has been similar, especially when it involves plants that have been clonally selected or those from limited genetic material.

Undoubtedly there are differences between tropical and temperate regions, and it appears that plantations in temperate regions are much less susceptible. Davidson (1987) considers this to be due to a combination of lower natural opportunity for infection or infestation and to better opportunities for protection and management in temperate zones. This has been claimed for New Zealand so far, where after 140 years of growing Radiata pine there has not been a devastating pest or disease such as. this excludes dothistroma needle blight, Cyclaneusma needle cast, Armillaria root disease, and sirex wood wasp outbreaks. A sirex wasp outbreak in South Australia destroyed $A20 million worth of trees in two years.

Growing mixed stands is suggested as way of reducing pest and pathogen outbreaks. Although the likelihood of a devastating outbreak is reduced, there are also more opportunities provided by a range of species, as has been the experience with other exotic species in New Zealand. However, more important determining factors will be: whether the plantation species are native or exotic, density of stocking, site conditions, provenance, and management practices [ibid].

Both exotic monocultures and mixed planting have a low diversity compared to natural forests of the same latitude and altitude, and must therefore carry an inherently greater degree of risk.

To justify large-scale planting of Radiata pine, it has been suggested by many in the plantation industry that Aotearoa has natural monocultural forests, and that Radiata grows naturally in a monoculture in west coast North America. However, there are no natural monocultures. To suggest that there are ignores the levels of intra-specific (within a species) genetic diversity, and the diversity of the understorey and forest floor.

In Aotearoa some beech (Nothofagus spp., predominantly mountain) forests that have the canopy dominated by one species grow in even-aged stands. But they are virtually all at higher altitudes and on steeper slopes than where tree plantations are established. Kauri (Agathis australis) often occurred in stands where it was the dominant canopy species. However, this tended to be confined to the ridges, with a range of species on the mid-slope, valley bottom, and at wetter sites. Planting pine ignores these differing site conditions (part of habitat and landscape diversity), with blanket planting of whole catchments. Tree plantations in New Zealand are virtually all planted on areas that were once rich diverse native forest or successional stages towards this.

Therefore the biggest uncertainty with pest and disease invasion is not if but when will it happen? For instance, significant threats to radiata pine plantations not yet present in New Zealand include some 212 insect and 92 fungal pathogens. On average 2.2 insect and 2.4 fungal pathogens are introduced each year. The immediate risk was highlighted recently with the Asian Gypsy moth scare. To claim that none of these invaders represent a major risk would be both ecological and economic folly. The industry may decide to manage this risk by simply improving port entry protection, the country’s ability to respond to outbreak, or genetic selection or modification for resistance. However, as a safeguard, alternative species, in particular indigenous trees, need to be planted.

3.1.2 Genetics and Vulnerability

It is claimed that New Zealand’s radiata pine genetic base provides plenty of variation. However, several factors suggest that this may not be the case. Research into the natural distribution of Pinus radiat has found that overall diversity is low (HT = 0.117) compared to other conifers. One of the implications of clonal selection for pest and disease resistance as well as for a range of other characteristics such as growth rate and form, is a reduction in genetic diversity, and subsequently increased vulnerability.

With the narrowing of tree genetic material, increased resistance to various pests and diseases, and increased pesticide use, there is the longer-term risk that nature will retaliate and produce a whole new mutated set of insects, fungi and bacteria. This has been the experience of medical science with the use of antibiotics and of global agriculture with genetically uniform crops. The risks of having just one major species with relatively little genetic variation are considerable.

Conversely, the selection and incorporation of wild genes into populations to give pest and disease resistance is of enormous value. This has been illustrated with several crops such as rubber plantations, rice, cocoa, coffee.

The incorporation of wild genes serves to broaden the genetic base of a species and provides the justification for the protection of natural areas that contain these ‘wild’ genes. With the remaining natural areas of Pinus radiata in North America under threat of clearance for development, the New Zealand plantation industry has not moved to ensure the protection of the only sources of wild genes. Alternatively, the use of biological control methods are preferable to the use of toxic chemicals for pest and disease control such as the introduction of the parasitic wasp Rhyssa persuasoria to control sirex wood wasp.

3.2 Effects of Environmental Stress

It has been suggested that the health of radiata pine forests is in decline. Nutrient deficiencies or imbalances, water stress, pollution, pests and diseases have been forwarded as possible reasons. Sweet (1989) came to this conclusion comparing radiata stands in California and conifer forests in Europe with those in New Zealand. He observed colour and needle drop differences, greater mortality, and an increasing incidence of disease, such as Dothistroma. It may be that physiological stress from nutrient and moisture imbalances and other environmental factors, is lowering the ability of the trees to resist pests and diseases. Research on Upper Mid-Crown Yellowing of Pinus radiata suggests that nutrient imbalances are the most likely cause, particularly Mg and K. This is consistent with the conventional wisdom in agriculture, horticulture and home gardening: a stressed plant is a vulnerable plant.

3.2.1 Climate Change Stress on Plantation Trees

Climate change will likely result in higher mean temperatures, greater extremes in climate, stronger storm winds, and larger fluctuations in rainfall and temperature. Records over the last few years indicate that indeed, climate change is happening. There are many global records of trees growing faster. However, there have also been reports of more prolific seeding It is suggested that the extra resources the tree is putting into reproduction is a stress response may severely effect the long-term health of a plantation.

A Greenpeace International (1994) climate report records a range of adverse climate impacts on plantations and tree species over the last four years that include: pest outbreaks, dryer conditions, fires, biodiversity impacts. There are also several records of the insurance industry making huge losses and pulling out of some areas, with windstorms playing a significant role. However, more significant for plantation crops and land use in general in Aotearoa and the Pacific, is the evidence from weather records of the last decade that show an increased frequency and intensity of cyclonic storms in the South Pacific. It is likely that northern and western New Zealand will be increasingly affected by cyclonic storms, such as cyclone Bola. Our current plantations may be extremely vulnerable to more cyclones and to reduce this risk, cyclone resistant species may need to be planted. In Vanuatu it was found that the only species able to withstand the extreme cyclone wind speeds was the indigenous kauri (Agathis macrophylla). Kauri in Aotearoa is likely to have the same wind firm characteristics, compared to current plantation species, and provides good ecological and economic justification for replanting kauri forests in northern New Zealand.

In Canterbury, wind is presently the biggest risk to plantation forestry. However, steps are being taken to reduce this risk by altering the orientation of plantings, maintaining high stocking rates to provide mutual support, and planting 10% of stands in Douglas fir. A precautionary approach will be necessary, especially through carrying out site specific provenance planting, buffer strips, and involving a range of species and systems.

Much of the research in New Zealand on the impacts of climate change has focused on possible increased tree growth from higher temperatures and higher carbon dioxide concentrations. There is, however, acknowledgement that increased susceptibility to insect attack or disease is the likely result of greenhouse induced climate change. This would have a significant impact on tree plantations in Aotearoa, through increasing the vulnerability, and the ecological and economic risks of pine monocultures (see section 3.1)

3.2.2 Ultra-Violet-B Light Stress

It is likely that increased future environmental stress will come from increased UV-B concentrations as a result of ozone depletion. Very little is known about the effects of UV-B on forest tree species. Preliminary evidence, however, suggests that:

“...forests may be particularly vulnerable to increases in UV resulting from ozone depletion. Long-lived plants such as trees can accumulate the damaging effects of UV radiation over many years.”

Of the 15 tree species tested in an experiment in North America, over half were found to be sensitive to UV-B and three types of pine proved to be the most sensitive (loblolly, red and lodgepole). UV radiation may alter plant sensitivity to disease, in some cases making plants more susceptible to attack by pathogens.

A recent plantation forestry research review fails to even mention the possibility of UV-B effects on trees, let alone give it research priority. As concluded by a researcher:

“Of particular concern is the lack of research into the effects of increased UV-B on tree growth and development.”

A range of uncertainties and unknowns relate to UV-B concentrations. Rather than gambling on the degree of likelihood of these changes, a more precautionary approach would include diversifying plantings to cover the risks.

4.0 A Summary of Key Unsustainable Aspects of Tree Plantations

1. Biodiversity Loss through:

a) clearance of native vegetation for establishment;

There is continued loss of our heritage of biodiversity, including species, habitat and landscape, through the clearance of native vegetation, for the planting of exotic tree monocultures. In August 1991 the New Zealand Forest Accord was signed by conservation and plantation industry organisations, giving clear guidance that native forest and regeneration was not to be cleared for plantations.

b) degradation of riparian areas and waterways;

Failure to set aside adequate riparian areas (a buffer strip of vegetation alongside streams, rivers and lakes) has resulted in a loss of a biologically diverse habitat. Forest management practices that disturb the soil are likely to cause siltation of adjacent watercourses and the subsequent lowering of water quality, and loss of stream fauna and flora. There are also considerable aesthetic and recreational values compromised by these practices.

c) invasion of planted species into adjacent natural areas;

Many tree plantation species are invasive, particularly into native grassland ecosystems. Species, habitat and landscape diversity is decreased if plantation areas invade adjacent areas

d) creation of a monoculture landscape;

Large areas of even-aged plantations of single species produce homogeneous landscapes. With this comes a loss of overall landscape diversity and the potential for plants and animals to evolve through forcing natural remnants to become landscape fragments. Plantations are only acceptable when a protected ecosystem network has been established.

Many people also find pine plantations monotonous and visually unappealing.

e) damage and loss of soil organic matter;

Practices such as burning, root-raking and clearfelling result in the loss of soil fungi, bacteria, and wildlife. These soil flora and fauna make a major part of biodiversity.

f) poor diversity inside plantations;

Frequent disturbance and clearfelling of sites discourages diversity of plants and animals, and habitats and communities. The lack of old trees and decaying logs significantly removes whole habitats for insect and microbes. Biodiversity is an essential component of sustainability.

2. Soil and Fertility Loss through:

a) damaging methods of clearance for planting and logging;

Exposure and disturbance of the soil through the use of machinery, chemicals or fire leads to a loss of soil and nutrients through exposure to light and higher temperatures, erosion by water and wind, and direct physical movement. This continues for several years until tree canopy closure or until cover by ground vegetation. In the generally short intensive harvesting period a site is extremely vulnerable. Some soil types and steepland areas are particularly sensitive. This may lead to a catastrophic sediment load on adjacent water systems and subsequent loss of water quality and stream life, and marine pollution.

b) slope instability following clearfelling;

Following clearance of initial vegetation or the previous rotation, hill and steepland soils are vulnerable to accelerated erosion, mainly slips, slumping and mudslides. In even-aged single-species plantations, from approximately year 3 to year 8, root shear strengths that hold the top soil horizons are low.

c) the unsustainable use of inorganic fertilisers;

Inorganic fertilisers alter the biology and chemistry of the soil. They are also generally derived from an unsustainable source (mined minerals and fossil fuels) and are a source of greenhouse emissions during their production and following application.

d) degradation of soil structure due to compaction by heavy machinery;

A considerable amount of heavy machinery such as bulldozers, skidders and trucks passes over the soil during extraction. Severe compaction is often confined to small areas where erosion is higher, and water infiltration, moisture retention, and subsequent plant growth is reduced.

e) excessive biomass removal;

Removal of the sawlog and other tree parts, as well as through practices such as windrowing or burning, results in a decline in site fertility. This is immediately apparent in less fertile and lighter soil types. Only a certain level of nutrients are weathered from the parent rock or extracted from the air each year: this should determine the sustainable level of extraction for a plantation.

3. Toxic Pollution of Soil, Ground Water, Waterways and the Sea, through:

a) the use of toxic timber treatment chemicals;

More than 600 timber treatment sites are potentially contaminated with toxic organochlorine chemicals such as pentachlorophenol (PCP) and chlordane. Many other sites are still at risk from toxic chemicals still in use such as chlorothalonil and copper-chrome-arsenic (CCA). The chemicals in the timber will eventually be released into the environment through leaching, when the timber rots or is burnt. There are many types of tree that produce wood that is naturally durable such as totara, kauri, puriri, macrocarpa and some eucalypts. Pine can also be left to grow for longer to develop more of its natural preservatives.

b) the use of toxic herbicides, pesticides and fungicides;

Organochlorine and other herbicides such as atrazine and grazon, are sprayed to kill competing vegetation. Pesticides and fungicides are sprayed to control pests and diseases that attack plantation trees. Some of these enter waterways through being directly sprayed, or being leached through the soil. Adjacent land may be affected by spray drift. Many of these are bioaccumulative and persistent in the environment.

c) the use of toxic chlorine chemical processes in pulp and paper factories;

The pulp and paper industry has commonly used chlorine-based chemicals to bleach pulp, dumping organochlorine contaminated waste into nearby waterways. For example, the Tasman Pulp and Paper factory dumps 5-10 tonnes of organochlorines into the Tarawera River per day.

d) the dumping and leaching of resin acids;

Bark dumps, log storage areas, and wood processing plants such as pulp and paper, MDF and plywood plants, leach and dump resin acids into waterways.

e) the emission of toxic gases from processing plants;

Manufactured board plants such as MDFs (medium density fibreboard) give off formaldehyde fumes in their production processes and other emissions.

4. Excessive Natural Resource Use, through:

a) lowered river flows;

Planting pine trees reduces the water yield and the flow of water from catchments. It is useful to reduce water run off and peak flows from former forest areas now in pasture but compared to native forest, plantation pines use more water. Plantations will be competing for water use with downstream users, such as for irrigation, fisheries and recreation.

b) use of large quantities of water in wood processing;

It takes around 75 tonnes of fresh water to make one tonne of paper from a kraft pulp and paper factory such as Tasman. The water is considered a free resource, and is returned to the river in a polluted state.

c) unsustainable use of fossil fuels;

Fossil fuels such as oil and gas are used in large quantities for energy intensive wood processing and to a lesser degree in forest planting, logging and transport. Even though plantations absorb and store carbon from the air, the industry’s use of ancient fossil fuel make the sector’s energy use unsustainable.

5. Increased Risk and Uncertainty:

a) from disease and pests and catastrophic loss;

Large scale exotic monocultures, especially when they are under nutrient stress and derived from limited genetic material, are inherently more vulnerable to pest and disease attack. The old adage of “Don’t put all your eggs in one basket” applies.

b) from climate change and increased UV-B concentrations;

Climate change is likely to bring more frequent and stronger winds, higher temperatures, and a more irregular rainfall. These will have profound changes on plantations, from more wind damage and moisture stress, to higher growth rates and pest invasion. UV-B radiation increases may weaken the immunity of trees to pests and diseases, or even kill some types of tree.

c) from greater fire risk;

In many situations plantations present a major fire risk because they have drier litter and exist in large continuous blocks. They have a considerably higher fire risk than native forest. This may endanger adjacent areas, including urban settlements and important conservation areas.

5.0 Draft Criteria for Responsible Management of Tree Plantations

A set of criteria flowing from Greenpeace International Principles and Guidelines for Ecologically Responsible Forest Use (see Appendix 1) specific to tree plantations.

Criteria

1. Planning Requirements

a) A full Landscape Assessment, carried out either individually for large plantation areas or collectively with other tree growers with small plantation areas, must be provided that clearly defines:

• indigenous peoples’ traditional land areas and claims,

• a protected ecosystem network that includes: representative and ecologically viable areas of all indigenous forest types and successional phases, riparian ecosystems, ecologically sensitive sites, steep or sensitive slopes, culturally significant areas, interconnecting corridors, naturally rare habitats, habitats of rare and endangered species and species of special scientific importance. If a landscape has insufficient indigenous forest to make up a protected ecosystem network, restoration of forest areas must be carried out,

• human use areas, including timber harvesting areas.

b) An Appropriate Land use Assessment must be provided that takes account of both onsite and offsite ecological, social and economic aspects, including evidence that:

• given alternative conservation and sustainable development options for the proposed plantation area, plantation development is the most ecologically and socially appropriate land use,

• an environmental accounting system has been used that allows all the ecological and social costs and benefits to be put alongside the financial balance sheet,

• the precautionary principle has been applied to any area of uncertainty or inadequate information,

• proposed processing of the plantation wood product uses only totally ‘closed loop’ systems, with no toxic or bioaccumulative chemical inputs, pollution or impacts on human health,

• the plantation system, timber species selection and processing output provides the maximum amount of benefit and employment in local communities,

• account has been taken of plantation and processing impact on public resources such as roading and other infrastructure, clean air, clean water, level of noise, visual aesthetics, and that local communities and affected parties are aware of any possible impact on these,

• the plantation management is compatible with and complimentary to multiple-use of the area, and traditional uses of the area are not compromised,

• for large-scale plantations over 500 ha, a full independently audited Social Impact Assessment, including the benefits and impacts to the local communities, has been carried out, and

• an assessment of community needs has been carried out, the mechanisms for local community involvement outlined, and the responsibilities of the plantation development defined.

c) An Inventory of and Management Plan for plantation use areas must be provided that includes:

• a description of the resources within the area, including size, boundaries, present vegetation and environmental situation, and key plants and animals of the plantation management area,

• a Site Assessment to identify variations in topography, slope, aspect, catchments, waterways, drainage patterns, geology, soils, erosion types, microclimates, and vegetation,

• the objectives of management,

• the silvicultural system, harvesting rate, volumes, species, site requirements, length of cutting cycle, overall management system, and any restoration plans if required,

• the location, dimensions and surface of extraction roads, waterway crossings, hauler routes, and landings that are essential to the operation, provision for fire protection, provision for pests and diseases, provision for invasion into adjacent natural areas, and guidelines and rules for harvesting and extraction,

• a soil maintenance plan describing how zero erosion from plantation management operations is to be achieved,

• methods to minimise damage to residual vegetation and soil organic matter, and to ensure regeneration, restoration or replanting,

• compliance with national and state laws that support responsible use,

• location of a number of forest reference sites that correspond with and are representative of the plantation management areas, and strategies for the conversion of plantations to the indigenous forest system. They may be located within the protected ecosystem network, and

• measures to protect and maintain adjacent and interconnected areas/ecosystems from the impact of the plantation management.

2. Community Rights and Participation

a) Plantation planning and management must recognise and respect the customary rights of indigenous peoples to own, use, manage and conserve their lands, territories and resources.

b) Land ownership must be clearly defined and undisputed. Lease or rights arrangement must be clearly recorded in a written and binding agreement. Any agreement must include clauses that allow for its cancellation if plantation management standards are not met.

c) Plantation management planning must identify and include the participation and agreement of the traditional owners or other long-settled communities affected by the plantation, as initiated in the Appropriate Land use Assessment.

d) A mechanism shall be established in agreement with local communities and affected parties, that defines consultation responsibilities and process, and in particular dispute and grievance procedures, provision for just and fair compensation in the case of loss or damage affecting the legal and/or customary rights or livelihoods of local people.

e) Evidence must be given of equitable involvement by all affected parties and that all planning and plantation management documentation has been made available.

f) People living in communities within or adjacent to the forest management area and any associated processing activities shall be given priority in terms of job training, education and employment opportunities.

g) Plantation management and processing shall meet or exceed all applicable laws and/or regulations related to worker rights and the health and safety of employees and their families.

h) Management and processing planning and operations shall incorporate the results of Social Impact Assessments.

3. Plantation and Processing Management

a) Timber harvesting and management in plantation areas must:

i) sustain the yield of timber, through;

• providing nutrient cycle budgets showing that nutrient removal from wood products is equal to the natural increment entering the soil in tree root horizons.

ii) prevent the loss of soil and nutrients from the site, and in particular zero erosion rates from management operations, through;

• the use of low-impact techniques of extraction, such as cable, highlead, or skyline log extraction systems, horse, bullock or elephant skidding, use of portable sawmilling systems, and ceasing extraction while the soil is wet,

• a planned, permanent, and surfaced minimal roading system that back-hauls fill, has minimal cut banks, and side-casts that are stable and revegetated,

• clearing in small coupes,

• leaving all slash, bark, and waste wood on site,

• minimising landing size and number and locating them on stable sites,

• using coppicing species, permanent tree cover, and maintaining a diverse understorey throughout the plantation cycle,

• excluding grazing animals and controlling introduced pests in plantation areas,

• preventing the felling of trees or the movement of slash into adjacent protected riparian areas and ecological sites,

• and by preventing wild fires.

iii) Maintain local endemic diversity and act as a transition crop back to indigenous forest systems, through;

• the enactment of steps along a restoration plan, and

• replication of the structure and function of indigenous forest by the plantation.

b) Plantation offsite effects and product processing management must:

i) Maintain water quality or yield, air quality, and visual aesthetics, through;

• zero toxic emissions or discharges from processing plants,

• the use of alternative timber treatment substances or solar kiln drying,

• the use of renewable and efficient energy practices,

• using low-noise level equipment or practices, and by

• using plantation and processing plant designs that maintain or enhance visual aesthetics.

ii) Maintain and enhance local infrastructure, roading and other public services, through;

• minimising transport of materials and contributing to the maintenance of public services, and

• recognising road safety standards and needs of local communities,

Some Prohibited Management Practices include:

• use of bio-accumulative, toxic and/or persistent substances,

• use of genetically modified organisms,

• clearfelling, or clearcutting areas that exceed the sustainable annual cut of the plantation management area within any single watershed,

• direct manipulation of soils such as v-blading, root-raking, ploughing, harrowing, and/or drainage of forest lands and peatlands for plantation establishment,

• replacement of natural primary or secondary forests (as defined by the New Zealand Forest Accord), or areas of significant natural vegetation by plantations,

• burning of vegetation prior to establishment, or slash following harvesting,

4. Independent Monitoring

a) Environmental and Social Impact Assessments and independent monitoring and certification shall be carried out at regular intervals to ensure the above criteria are being met.

b) Clear procedures must be in place for regular review and revision of the management plan.

c) Frequent inventories of the growing stock and forest structure and composition must be carried out to establish restoration progress towards imitating forest reference sites.

d) All assessments, inventories and management plans must be available to the public.

6.0 A Review of Some Alternative Tree Growing Systems

6.1 Alternative Tree systems in Aotearoa

6.1.1 Plantations of Indigenous Species

The magnificent lowland forests of former times in Aotearoa are now represented by small remnants (except for Westland), or even individual large trees. They contained large quantities of high quality timber, and if our ancestors had practiced forestry rather than forest “mining” we would still have a viable indigenous timber resource. To meet our obligations to protect the biodiversity of Aotearoa, large areas of indigenous forest will need to be restored in the landscape. It will involve planning way beyond the current 30 year time frame for centuries ahead, and the restoration of former forest areas that are now in agriculture, horticulture and plantations.

Native tree plantation trials planted throughout Aotearoa have shown that they can be successfully grown, especially through line or interplanting into existing vegetation. They have not been planted on any commercial scale as it is perceived that they are too slow growing to provide an economic return and there has been little government commitment to their establishment. As these are the species that are natural to the system and are culturally significant to the tangata whenua, their planting should be encouraged. Planted or managed as a forest rather that a plantation, they will most likely have considerably less pest and disease problems. They will maintain soil and water values, actively protect biodiversity, and of less risk than exotic monocultures. Given the expected future value of native timbers, and likely advances in growth rates through selection, indigenous species could well provide a sustainable plantation option.

6.1.2 Agroforestry systems

Agroforestry is the planting of trees into pastoral lands to improve productivity (tree products as well as animal), provide slope stability and reduce erosion. A nitrogen fixing species would be preferable for soil fertility and there may be benefits from trees transferring nutrients from deeper in the soil to the surface. However, there will likely be decreased pasture or crop production. If Pinus radiata is used, a decline in soil pH is to be expected which will affect pasture production.

There are also problems with animal damage to trees.

6.1.3 Reafforestation with mixed special purpose species.

A considerable number of combinations are possible, usually involving higher value timber trees such as walnuts, chestnuts, Cypresses, Eucalypts, Acacias and others. They generally involve a longer rotation length with the possibility of selective felling regimes. Higher value timber allows more on-site processing, such as portable sawmills for flitches or sawn timber, minimising the removal of nutrients from a site and lowering transport energy requirements. It also allows for the use of low-impact wood extraction methods and coup or individual tree felling rather than clearfelling regimes.

The mixed species will be more responsive to site conditions, allowing the maximum use of site diversity and individual species requirements. They will provide more and better quality habitat for wildlife and if planted through a landscape plan, be more visually attractive and interesting. The growing of timber species with durability properties will mean an end to toxic timber treatment. Regenerational or coppicing abilities are important considerations, especially on steep slopes or erosion prone areas where a permanent tree cover is essential. For example, the provision of shelterwood for the regeneration of shade tolerant native species, as well as legume or green manure understorey, are possibilities.

6.1.4 Mixed tree cropping woodlands

With many of the advantages of special purpose species planting, this option can incorporate timber production with other products such as nuts, fruits, honey, herbs, fungi, firewood. A wide range of species are possible producing a diverse range of habitat. Woodlands could be established as patches within a predominantly agricultural landscape to assist the transition to a protected ecosystem network involving native species. A range of maturing and harvesting times gives perpetual shelterwood for establishment and a permanent tree cover. At Long Mile Grove near Rotorua, a mixed planting of larch (Larix decidua) and redwood (Sequoia sempervirens) began with the larch providing shelter for the redwoods, promoting rapid height elongation in the redwoods through to their eventual domination of the larch.

This system tends to suit the small scale.

6.2 European/Northern Hemisphere Temperate models

6.2.1 European Shelterwood Propagation Systems (from Janssen 1991)

Crown Harvest

In this technique larger areas are rejuvenated concurrently. The canopy is opened up progressively over a period of several years. This type of harvest has been developed to encourage the natural regeneration of shade tolerant tree species. If the Crown harvest is undertaken over a long period, good quality growth occurs without the need for pruning.

Group Harvest

This technique is used for the natural rejuvenation of mixed forests. The canopy is opened up in irregular patterns of approximately 30 metres diameter. Sunlight and precipitation changes within the opening gives room for tree species with different ecological needs. Once the regrowth is established, the openings are progressively widened.

Scallop-shaped Harvest

This type of harvest also gives protection from strong solar radiation and weather effects, and allows for the rejuvenation of tree species with different ecological needs.

Combined Methods

• The Stripe Harvest – proceeds from hill-top in the form of narrow strips.

• The Group Scallop Harvest – this combination provides a diverse range rejuvenation sites, particularly related to the forest edge, and would allow a large range of different species to be used.

• The Crown-Wedge Harvest – a simplified harvesting method that considers the needs of different tree species, encouraging the growth of shade tolerant species.

6.2.2 Western Canadian Ecoforestry

Old growth rainforests in British Columbia are currently being clearfelled and planted with tree plantation type systems. Many of the harvest and management practices are similar to those of plantations in Aotearoa, such as clearfelling. However, alternative systems are being practiced that aim to protect, maintain and restore forests.

Western Canadian ecoforestry works from a principle of an initial planning process that defines a network in the landscape to be protected. A series of “Stand Level Standards” aim to maintain the composition, structure and ecological functions of the forest. This approach aims as much as possible to mimic natural forest processes with a strong emphasis on restoration and respecting biophysical limits. This ecoforestry system, involving some species that are planted here in New Zealand such as Douglas fir, has many features that could be incorporated into ecological tree plantation management.

6.3 Traditional Forestry Systems in the Pacific and Asia

Traditional systems in the Pacific and Asia are characterised by the diversity of species and systems used. This strategy has evolved to provide a diverse income source, produce stability of production, utilise a range of beneficial species combinations, and to increase insect and disease resistance. The systems often represent the integration of traditional resource management knowledge into multiple use systems. Many of the principles are of relevance for the development of sustainable land use systems in New Zealand. The following are examples from different traditional systems:

6.3.1 Agroforestry in Southern China

The history of agroforestry in China can be traced back more than 2000 years. Forests are managed as multiple use systems. Timber trees are intercropped with medicinal herbs and other farming activities. In one example Chinese fir (Cunninghamia lanceolata) is intercropped with the medicinal shrub Amomum villsoum.

6.3.2 Javanese Agroforestry

The traditional agroforestry systems often imitate the floristic diversity of natural forests, with hundreds of different species being used. Multiple use and sustainability are the basic tenets, and multiple layers are used to maximum the use of available light and space. Species constantly change in relation to vertical stratification, where intercropping is phased out to perennial shrubs and trees, as the main tree species becomes more dominant in the canopy. Leguminous species are used to fix atmospheric nitrogen and contour planting to minimise soil erosion is practiced. There are definite patterns in groups of plants that tend to be found together.

6.3.3 Pacific Agroforestry Systems

As elsewhere, where traditional societies have learned to live in their landscape, there are many examples of systems in the Pacific that have elements that are transferable. They generally involve a polyculture of over a hundred tree and

tree-like species or cultivars and are very much integrated into the village social systems. The range of different systems is virtually equivalent to the number of different sites. They are seen as key systems that meet both changing ecological and cultural needs, especially in comparison to the invading monocultural systems. As Thaman (1988) states, “Polycultural agroforestry is a basis for innovation and stability.”

7.0 Environmental Baselines and Indicators

Many of New Zealand's unique ecosystems have gone through a rapid transformation in the last 1000 years. Ecological values have been compromised to meet human needs and many current land management practices are proving to be ecologically unsustainable. It is therefore difficult to determine the baselines that are useful for establishing sustainable land management practices.

There has been little research into the development of environmental baselines and indicators in New Zealand.

Ward and Beanland (1992) have published a draft set of national environmental indicators organised according to a 'stress response' framework, to be monitored at a regional level. The Ministry for the Environment (NZ) are using the stress response concept to draft a National Set of Environmental Indicators as part of the framework for sustainable management. Other examples relevant to plantations include: World Wide Fund for Nature's 'Guidelines for sustainable and socially responsible management practices for tree plantations', and 'Ecosystem approach to monitoring land use'.

7.1 A draft set of environmental indicators

(based on Ward and Beanland)

Effects	*Variables to be assessed*	*Indicators*
1/ Water Quality		
Organic matter	BOD	
Suspended solids and deposited solids	Silt and solids	Level above baseload
Temperature and chemical changes	pH, temperature and electrical conductivity	Change in
Biological growths	Levels of P and N Area and density of growths	Functional indices
Clarity/turbidity	Optical qualities	Black disc and others
Habitat modification and loss	Area modified/lost by type	MacroInvertebrate Index
Loss of species	Species lost	Diversity Indices
2/ Water Allocation		
Lower or higher flows, and water yield.	Level of flow	% Change
Effects of low/high flows on ecosystems	Habitat modification Indicator species distribution Species lost	MacroInvertebrate Index
3/ Land Processes		
Soil erosion	Land classification (NZLRI) Vegetative cover Type/severity/extent of erosion Climatic events	Erosion plots and silt traps
Soil organic matter degradation	Quantity and quality of soil OM	Populations of earthworms or soil fauna

Soil compaction	Changes in bulk density and porosity	Level relative to soil type
Soil fertility	Nutrient levels	Levels relative to site
River bank erosion/ accretion	Rates of sedimentation Habitat changes	Indicator species change
3/Pollution/Toxic substances		
Biocide contamination	Concentrations in water and soil or in indicator species	Levels before and after
Contamination of soils air and water, by toxic residues and heavy metals	Source/type of residue and conc. Effect on indicator species Levels of Cr, Cd, Zn, Pb etc	Presence/absence and health of indicator spp.
Air quality	emission levels of substances	Carbon budget, conc. of particulates and chemical
Solid waste disposal	Leachate levels	
4/ Conservation, Ecologically-sensitive areas and endangered species		
Biodiversity loss	Fauna and flora	Presence and population and change in diversity indices
Landscape Modification	Area of unmodified landscape Area of unmodified habitat	Degree of Protected Ecosystem Network Established
Marginal/ecologically sensitive habitats	Total area remaining` Change in area over time Current use Change in vegetation composition Changes in species diversity	Change in species distribution
Rare and endangered	Location, area, number of species	
Pests and diseases introduction	Native species effected Location, area, and type of damage	Change in species
5/ Fire Risk		
Risk of fire to adjacent areas		
6/ Tree Plantation Health		
Pest and disease infestation	Level and frequency of various pests and disease organisms	Change over time

7.2 Monitoring

Environmental monitoring is an essential component of sustainable management3 and is required under the Resource Management Act. The development of a set of environmental indicators will allow the assessment of the relationship between forestry activities and the subsequent effects on natural resources and systems, and the effectiveness of the management response. However, difficulties remain in that there are few baseline standards, and virtually none that take into account site fluctuation due to seasonal and annual variation, nor ecological processes. There are also problems in establishing monitoring points, for example with water quality, the distance downstream from the site or discharge point. Forest resource accounting is an area undergoing significant developments internationally. For example, it is an initiative of the International Tropical Timber Organisation. Such practices could become mandatory in which an annual set of environmental accounts are produced by a forestry company or manager for assessment and to assist the internalisation of environmental costs and benefits. Environmental monitoring is a suitable area for government funded research, including assistance with training and development of database facilities.

8.0 Greenpeace's Positive Solutions

Greenpeace acknowledges that forests are a protective and regenerative cloak over the land. In most regards trees provide more protection for soil than pasture or crops. Wood products from planted trees also have the valuable role of substituting those from destructively harvested natural forest sources.

However, it has been claimed that New Zealand's exotic monoculture tree plantation industry is sustainable. This is not the case. The environmental effects of current exotic plantation regimes in New Zealand make the plantation industry unsustainable. For example, a range of significant impacts on soil and water quality, and yield, as well as on natural biodiversity which result from exotic monoculture plantations cannot be ignored. Furthermore, the timber treatment and processing component of the plantation life cycle has resulted in serious toxic impacts on the environment.

Of particular concern is the current short time frame and narrow fiscal framework of plantation planning which does not incorporate medium and long-term environmental costs. Genuine sustainability is important because future markets lie in demand for ecologically sustainable wood products. In the meantime Greenpeace acknowledges that some players in the industry have made progress towards sustainability and looks forward to seeing industry-wide adoption of the actions set out in this review.

The long-term aims of forestry land use should include the restoration of natural site conditions and productivity.

For the New Zealand plantation industry this means aiming to mimic nature. Future forestry plantation systems will need to work within the natural limits of soil and site conditions, rather than effectively mining out thousands of years of soil biogeochemical capital, while being temporarily propped up by toxic fertilisers, herbicides and pesticides.

As a first step towards ecological sustainability Greenpeace calls on the plantation industry to adopt the draft criteria set out in section 5.0 by the end of 1995.

In line with the draft criteria for responsible management of tree plantations, Greenpeace calls on the New Zealand plantation industry to adopt the following policies and practices by 2000:

- a landscape approach to maintaining and restoring biodiversity in land use planning which ensures long-term planting and harvesting planning at least 100 years ahead,
- a precautionary approach to forestry management,
- zero nutrient loss and erosion from plantation operations,
- the maintenance of soil. water and air quality and yield,
- the planting of native riparian strips to protect waterways from soil erosion and provide wildlife corridors,

- the zero use and discharge of toxic chemicals/pollution,
- an energy efficiency and clean energy strategy which reduces plantation industry carbon dioxide emissions to at least 1990 levels by 2000 in line with New Zealand's legal Climate Convention obligations,
- the restoration of biodiversity back into the landscape,
- clean production techniques such as solar kiln drying,
- totally chlorine-free pulp and paper production,
- at least a 20 per cent native species component in new plantings per year,
- at least a 20 per cent mixed exotic species system component in new plantings per year,
- increased rotation length for exotic plantations,
- a commensurate reallocation of private and public sector research and development funding to support increased mixed exotic and native species system research, and
- independent certification of responsible management of the plantation industry.

Greenpeace recommends that the plantation industry and land holders commit to ecological sustainability and adopt these changes as a transitional phase towards the goal of full ecological forestry by 2025.

APPENDIX 1

Greenpeace International:
Principles and Guidelines Towards Ecologically Responsible Forest Use.

Introduction: The Purpose of This Document.

Worldwide, awareness is quickly growing that many forest practices used by logging industries are intolerably destructive. The environmental and human rights movements have succeeded in showing that the causes of forest destruction in both tropical and temperate regions can be linked in many cases to the consumption patterns of wood products in industrialised countries. This growing awareness extends to the most obvious causes; the pervasiveness of forest products in everyday life, especially in industrialised societies, and the global reach and market-driven fervour of these societies to obtain the necessary raw materials regardless of the real ecological, economic or social costs.

Many individuals, corporations and governments now recognise and acknowledge their responsibility as consumers for exacerbating this problem. Some are taking steps to end their role in forest destruction. This ethical response is having increasingly strong effects on the international marketplace for forest products. For example, major producers of paper end products and some of the largest publishing houses are now dedicating themselves to purchasing only responsibly produced materials.

As a result of this emerging market ethic, forestry companies are seeking to convince customers that their existing forestry practices are responsible and sustainable. Inevitably, forest industry led claims of responsible and sustainable forest practices are proliferating. These are based on a range of different, often conflicting, and typically inadequate standards. They provide little confidence to either consumers, or to groups challenging destructive forestry operations.

Greenpeace has been involved over the last several years in the development of effective standards for responsible forest use. Our work has included input to the Forest Stewardship Council, and dialogue with industry and small-scale forest harvesting operations.

In response to repeated recent inquiries, and to better assist both forestry companies and forest product consumers, Greenpeace is now making publicly available the following principles and guidelines which it has developed towards ecologically responsible forest use.

These standards express principles and guidelines which are universally applicable, and thus rather general.

Greenpeace is preparing other work that describes in greater detail how these principals apply to several specific regional forest ecosystems.

The purpose of this paper is to put forward a set of globally universal principles that, rather than being a final end product, are a starting point towards comprehensive standards. We foresee an evolutionary process and periodic revisions. Comment and suggestions are desired and welcomed from the concerned public; environmental, indigenous, consumer, human rights, scientific and development organisations; industries; governments; and others.

The Importance of a New Relationship with Forests.

Humanity depends on the healthy functioning of the planet's natural ecosystems for its survival. Functioning forests provide many essential services such as regulating climate and cycling nutrients. They are sources of food, fibre, fuel, medicines, building materials and cultural and spiritual values for a diverse range of human cultures. Forests are also home to the bulk of the world's rich evolutionary heritage in the form of tens of millions of unique species of life.

Forests sustain us, but we are not sustaining them. Centuries of predatory human use of forests has reduced, degraded, destroyed and even completely eliminated forest ecosystems. Hundreds of thousands, if not millions, of forest dependent species face extinction in the next few decades from destructive forest use if present trends continue.

Today the principal threats to forests come from industrialised societies, due both to the large scale and intensity of forest exploitation practices, and to the wasteful and irresponsible consumption patterns of the resultant forest products encouraged. Industrial societies must redefine their relationships with forest ecosystems and establish their responsible ecological niche. Consumption and production patterns must be adjusted to levels that do not threaten the biological diversity and sustainability of forest ecosystems.

Towards this goal, Greenpeace advocates that management of forest ecosystems be based on the study and application of the ecological properties of natural forests. Management processes must mimic natural processes. In effect, the lead role for determining how to design managed forests should be handed back to nature.

Because human knowledge about the ecological properties and species composition of natural forests at present is profoundly limited, extensive and comprehensive protected areas are necessary as a precaution against inadvertent and irreversible damage from forest use. Only in this way can the full diversity of forest components, structures and functions be protected and maintained. Finally, precedents for respectful human relationships with forests do exist among many indigenous cultures. In this regard, upholding their rights, respecting their cultures and incorporating their ecological wisdom into forest management planning will be an essential and necessary step towards the goal of establishing a respectful relationship between industrial societies and forests.

What is a Forest?

Forests are ecosystems of carbon dioxide-evolved species that form interconnected webs of ecological relationships. Together they sustain the whole, not the production of any one part or commodity. The forest web exists at all scales, from the microscopic to the global. Trees, the most obvious part of a forest, are critical structural members of a forest framework. However, growing trees are only a small portion of the structure needed for a fully functioning forest.

There are no isolated compartments in a forest, only steady transitions between various living and non-living parts.

The following principles and guidelines are universal in the sense that they are intended to be applied to forest-modifying activities worldwide. They are especially intended for use by corporations and governments in conducting planning, carrying out forest-modifying activities, or purchasing materials originating from forests. The principals can also serve as guidelines for individuals who wish to evaluate the sensibility of products made by particular corporations or the effectiveness of corporate and/or government policies, programmes and practices

I. Principles of Respectful Human Relationships with Forests.

I.1. Conservation of biological diversity.

I.1.1 The integrity of forest ecosystems must be maintained at all scales, from the microscopic to the ecosystem level.

I.1.2. The natural biological diversity of forests must be protected at all spatial scales and through all time frames.

I.1.3. The ecological composition, structure and functions of forests, including landforms, climate, water, soil, and nutrient cycles, must be protected and maintained, or restored where required due to past human activities.

I.1.4 The ecological knowledge of indigenous peoples in relation to forests must be recognised, respected, valued and applied as a critical part of defining ecologically responsible forest use.

I.1.5. Tree farms or plantations must not replace natural forests.

I.2. The precautionary principle.

I.2.1. Activities with the potential to lead to irreversible damage of forests must be prohibited.

I.3. Rights and participation.

I.3.1. The customary rights of indigenous people's to own, use and manage their lands, territories, and resources must be recognised and respected in all forest management plans.

I.3.2 The public has the right to open, transparent and accountable planning processes for forest use. Forest use decisions must provide for the meaningful involvement of those groups affected by proposed uses, including but not limited to, indigenous peoples, local communities and non-governmental organisations.

I.4. Forest planning.

I.4.1. Forest planning shall look first on what to leave, and then on what to take.

I.4.2. Negative impacts to the ecosystem from one use must not compromise the potential for other uses.

I.4.3. A full life cycle approach to relevant forest products must be considered when evaluating forest use alternatives.

II. Guidelines for Respectful Forest Use.

II.1. Forest use areas shall be defined after the establishment of a protected ecosystem network within each landscape used by human beings.

II.1.1 Protected ecosystem networks shall be respectful of indigenous peoples' customary rights.

II.1.2 Protected ecosystem networks shall be designed based on the principles of landscape ecology and the conservation of biological diversity.

II.1.3 Components of a protected ecosystem network include: large protected reserves, riparian ecosystems, ecologically sensitive sites, culturally significant areas, representative and ecologically viable areas of all forest types and successional phases, cross valley corridors, naturally rare habitats, and habitats for rare

and endangered species.

II.1.4 If a landscape has insufficient indigenous forest to make up a protected ecosystem network, restoration of forest areas must be carried out as an integral part of the determination of appropriate human use areas.

II.2. For every forest use area a representative reference site(s) must be set aside and fully protected.

II.2.1 Reference sites shall be representative of the indigenous forest in the forest use area as determined by landscape characteristics, biotic and abiotic components and the naturalness of the reference site including its history.

II.2.2 Reference sites may be selected from, but are not limited to, areas set aside within a protected ecosystem network.

II.3. Forest use areas shall be managed to mimic reference sites in structure, composition and function.

II.3.1 Reference sites serve as models for corresponding use sites. Inventories of composition, structure and functions of reference sites shall be used to establish minimum standards necessary to design ecologically responsible forest use.

II.3.2 Inventories shall occur on forest use sites to determine any differences between the site being planned and the reference sites. These differences shall be used to strengthen, but not weaken, the minimum standards established from reference sites.

II.3.3 Forest operations will seek to minimise differences in composition, structure and functioning between the reference sites and the forest use sites over time.

II.3.4 A management plan consistent with these Greenpeace principles and guidelines and appropriate to the intensity, scale and frequency of forest operations must be prepared. Management plans will be for specific forest ecosystems and must include provisions on the protection and maintenance of adjacent and interconnected ecosystems as relevant.

II.4. Provisions for frequent monitoring of the impacts of operations in the forest use area and procedures for regular review and, if needed, revision of the management plan must be established.

II.4.1 An environmental assessment shall take place following extractive activities to make sure that forest composition, structure and functioning is being protected.

II.4.2 Frequent inventories of the composition, structure and functioning of forest use areas – as appropriate to the intensity, scale and frequency of forest operations – and of their reference sites shall occur to determine progress towards minimising differences between them.

II.4.3 All assessments, inventories and management plans must be documented and available to the public.

III. Some Prohibited Management Practices

Following the principle of handing the design of forest management back to nature, all human activity shall be limited to the least possible intensity. In practical terms, this means that many presently applied forest management practices must be avoided. The following is only a very partial list of these prohibited practices, but includes the use of:

• bio-accumulative, toxic and/or persistent substances;

• genetically modified organisms (GMOs);

• clearcutting, and the creation of other significant artificial openings in the forest canopy;

• the use of heavy machinery apart from on permanent roads;

• planting of non-indigenous genetic material, whenever possible;

• direct manipulations of the mineral soil such as ploughing, harrowing, and/or drainage of forest lands and peatlands.

Annex: Definition of Terms

Biological diversity – as defined in the UN Convention on Biological Diversity, "Biological diversity means the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems."

Restoration – Restore the forest at the site and landscape scalesto mimic natural forest composition, structure, function and processes. Restoration must be carried out with the involvement of indigenous peoples and local communities, as appropriate. The restored forest must be protected from the human activity that caused the previous degradation.

Clearcut – An opening in the natural forest canopy resulting from the cutting and removal of all merchantable trees which damages the structure, composition and/or functioning of the forest.

Definition of Clearcut-free.

'The absence of any significant artificial opening in the forest canopy, in accordance with the principles of ecological forest use.'

In order to be classified as Clearcut-free, the following measures must be taken:

1. A protected ecosystems network must be established in the forest landscape prior to any timber cutting.

2. Any timber cutting must occur within timber zones established through ecosystem-based planning.

3. Timber cutting must maintain fully functioning forests at all scales through time.

References

Adams, J.A. 1978: Long-term aspects of nutrient loss from forest soils and ecosystems. NZ Journal of Forestry 23 (1): 10-20.

Altieri, Miguel A. 1983: Agroecology – The scientific basis of alternative agriculture. University of California, Berkeley, USA.. 162p.

Anstey, Clive, Thompson, Steve, and Nichols, Karen 1982: Creative Forestry – a guideline for forest managers. NZ Forest Service, Wellington. 117p.

Attiwill, Peter M. and Adams, Mark A: 1993. Tansley Review No.50 Nutrient Cycling in Forests. New Phytocology, 124: 561-582.

Bain, J. 1981: Forest Monocultures – how safe are they? An entomologist's view. NZ Journal of Forestry 26 (1): 37-42.

Baker, J.B. 1978: Nutrient drain associated with hardwood plantation culture. Proceedings of the Second Symposium on Southeastern Hardwoods, pp.48-49.

Baker, T.G. and Attiwill, P.M. 1985: Loss of organic matter and elements from decomposing litter of Eucalyptus obliqua L'Herit. and Pinus radiata D.Don. Australian Forest Research 15(3) : 309-19.

Ballard, R. and Will, G.M. 1981: Accumulation of organic matter and mineral nutrients under a Pinus radiata stand. NZ Journal of Forestry Science 11(2): 145-51

Balneaves, John M. 1990: Maintaining site productivity in second-rotation crops, Canterbury Plains, New Zealand. In: Dyck and Mees(ed) 1989, FRI Bulletin No. 159.

Balneaves, J.M. and Dyck, W.J. 1992: Slash retention a viable option to ensure sustained site productivity. NZ Forestry May. p13-16

Barnett, A. 1992: Deserts of Trees – the environmental and social impacts of large-scale tropical reforestation in response to global climate change. Friends of the Earth, London. 62p.

Beets, P.N., Payn, T.W. and Jokela, F.J. 1993: Upper mid-ground yellowing in Pinus radiata forests. NZ Forestry, Aug: 24-28.

Benecke, U. and Evans, G. 1987: Growth and water use in Nothofagus truncata (Hard Beech) in Temperate Hill Country, Nelson, New Zealand. Reprinted from: The temperate Forest Ecosystem (ITE symposium no.20) Eds. Yang Hanxi, Wang Zhan, J.N.R. Jeffers, P.A. Ward. Institute of Terrestrial Ecology, Grange-over-Sands, Cumbria, LA.

Bergin, D.O., Kimberley, M.O. and Marden, M. 1993: How soon does regenerating scrub confront erosion. NZ Forestry, Aug: 38-40.

Bishop, Nick 1992: Natural History of New Zealand. Hodder and Stoughton p74-77

Broderick, T. 1994: Hira forest harvesting – Environmental issues. NZ Institute of Forestry Conference, “NZ Plantation forestry – a sustainable resource.” Hira Forest – field trip.

Buchanan, Andrew H. 1990: Timber engineering and the greenhouse effect. Proceedings of the International Timber Engineering Conference, Tokyo, October.

Bull, P.C. 1981: Native birds in pine plantations? NZ Journal of Forestry, 26 (2) : 210-231

Burnet, A.M.R. 1972: Effects of paraquat on invertebrates in a Canterbury stream, New Zealand. N.Z. Journal of Marine and Freshwater Research, 6: 448-455.

Carey, M.L., Hunter, I.R., Andrew, I. 1982: Pinus radiata forest floors : factors affecting organic matter and nutrient dynamics. NZ Journal of Forestry Science 12 (1): 36-48.

Chou, C.K.S. 1981: Monocultures, species diversification and disease hazards in forestry. NZ Journal of Forestry 26(1) : 20 -36

Ciesla, W.M. 1991: Cypress aphid: a new threat to Africa’s forests. Unasylva 167, Vol. 42: 51-55

Clout, M.N. 1984: Improving exotic forests for native birds. NZ Journal of Forestry 29 (2); 193-231

Collins, Chris 1992: Wastepaper recycling in New Zealand. (Executive) Report No. B113, prepared by Eden Resources Ltd for PAPRO NZ.

Comerford, N.B., Kidder, G. and Mollifor, A.V. 1984: Importance of subsoil fertility to forest and non-forest plant nutrition. In: Forest soils and treatment impacts. Proceedings of the 6th N.A. Forest Soil Conference, Tennessee. Ed. Earl Stowe. 381-404.

Corker, R.J. and Fahey, B.D. 1994: Separation point granite terrain erosion and sedimentation risk. Landcare Research Contract Report: LC9394/70. Prepared for: Tasman District Council.

Cornforth, I.S. 1970: Reafforestation and soil nutrient reserves in the humid tropics. Journal of Applied Ecology 7: 609-15.

Davidson, J. 1987: Bioenergy Tree Plantations in the Tropics: Ecological Implications and Impacts. IUCN Commission on Ecology Paper No 12.

Davis, Murray R. and Lang, Murray H. 1991: Increased nutrient availability in topsoils under conifers in the South Island High Country. NZ Journal of Forestry Science 21(2/3) 165-179.

Delamore, R. 1994: High C forestry: a conservative perspective. NZ Forestry, Feb: 5-9.

Dons, A. 1987: Hydrology and sediment regime of a pasture, native forest, and pine forest catchment in the central North Island, New Zealand. NZ Journal of Forestry Science 17 (2/3): 161-78

Duncan, M.J. 1993: Does planting pines reduce recharge? New Zealand hydrological annual symposium. NIWA Freshwater, Christchurch, New Zealand.

Dyck, W.J. and Beets, P.N. 1987: Managing for long-term site productivity. NZ Journal of Forestry November : 23-26.

Dyck, W.J. and Mees, C.A. (Ed.) 1990: Long-term field trials to assess environmental impacts of harvesting. Proceedings, IEA/BE T6/A6 Workshop, Florida, USA, February. IEA/BE T6/A6 Report No. 5. Forest Research Institute, Rotorua, New Zealand. FRI Bulletin No. 161.

Dyck, W.J. and Mees, C.A. (Ed.) 1989: Impact of intensive harvesting on forest site productivity. Proceedings, IEA/BE A3 workshop, South Island, New Zealand, March. IEA/BE T6/A6 Report No.2. FRI Bulletin No. 159

Dyck, W.J. and Menzies, M.J. 1992: Submission to Forest Products Research Review, Science Review No. 6R. November.

Electrocorp 1993: Submission to Canterbury Regional Council on Mackenzie District scheme changes [?]

Engunjobi, J.K. and Onweluzo, B.S. 1979: Litter fall, mineral turnover and litter accumulation in Pinus carribaea L. stands at Idaban, Nigeria. Biotropica 11: 251-255.

Environment Bay of Plenty. July 1994. Draft Tarawera river management plan.

Estock, D., Freedman, B. and Boyle, D. 1989: Effects of the Herbicides 2,4-D, Glyphosate, Hexazinone, and Triclopyr on the growth of three species of fungi. Bulletin of Environmental Contaminants Toxicology 42: 835-839

Ewel, John J. 1986: Designing agricultural ecosystems for the humid tropics. Ann. Rev. Ecol. Syst. 17: 245-71

Eyles, G.O. 1983: The distribution and severity of present soil erosion in New Zealand. NZ Geographer 39(1): 12-18

Feller, M.C. 1981: Water balances in Eucalyptus regnans, E. obliqua and Pinus radiata forests. Australian Forestry 44 (3)

153-161

Firth, J. and Murphy, G. 1989: Skidtrails and their effect on the growth and management of young Pinus radiata. NZ Journal of Forestry Science 19(1): 22-28

FAO (Food and Agriculture Organisation of the United Nations) 1991: Shifting Cultivators – local technical knowledge and natural resource management in the humid tropics. Community Forestry Note 8 by Katherine Warner. 80p

FAO 1989: Agroforestry – initiatives by farmers in Thailand. RAPA Publication 13, Bangkok.

Forest Research Institute 1991: The greenhouse effect. What's new in forest research No. 205.

Forest Research Institute 1990: Contribution of tree roots to slope stability. What's New in forest research No. 196.

Forest Research Institute 1988: Erosion and sediment production from forest roads in south-west Nelson. What's New in forest research No. 168.

Forest Research Institute 1987: Impact of rising levels of atmospheric CO2 on New Zealand's forests. What's New in Forest Research No. 148.

Forest Research Institute 1980: Mycorrhizal fungi of radiata pine in New Zealand. What's new in forestry research No. 89.

Forest Research Institute 1980: Streamflow from forests. What's New in forest research No. 92.

Forrest, W.G. and Ovington, J.D. 1970: Organic Matter changes in an age series of Pinus radiata plantations. Journal of Applied Ecology (7): 177-86

Franz, G. 1971: The microbiological characteristic of some natural and cultivated soils in three ecological regions of Chile. Plant and Soil, 34(1): 133-158.

Fuller, R.D., Simone, D.M. and Driscoll, C.T. 1988: Forest clearcutting effects on trace metal concentrations: spatial patterns in soil solutions and streams. Water, Air and Soil Pollution, Vol.40, No.1-2: 185-195.

Gadgil, Ruth I., Sandberg, Adriana M. and Graham, J.D. 1984: Lupinus arboreus and inorganic fertiliser as sources of nitrogen for Pinus radiata on a coastal sand. NZ Journal of Forestry Science 14(3): 257-76

Gates, Phil. 1993: The monotony tree. BBC Wildlife February, p13

Gilliam, J.W., Schipper, P.N., Beets, P.N. and McConchie, M. 1992: Riparian buffers in New Zealand forestry. NZ Forestry August. p21-25.

Goh, K.M. and Heng, S. 1987: The quantity and nature of the forest floor and topsoil under some indigenous forests and nearby areas converted to Pinus radiata plantations in South Island, New Zealand. NZ Journal of Botany 25 (2) :243-254

Goulding, K.W.T. and Stevens, P.A. 1988: Potassium reserves in a forest, acid upland soil and the effect on them of clear-felling versus whole-tree harvesting. Soil Use and Management, Vol.4, No.2: 45-51.

Grace, J.C., Carson, M.J. and Carson, S.D. 1991: Climate change – implications for Pinus radiata improvement. NZ Journal of Forestry Science 21 (2/3): 123-134

Graynoth, E. 1979: Effects of logging on stream environments and faunas in Nelson. NZ Journal of Marine and Freshwater Research, 13 (1): 79-109

Graynoth, E. 1992: Long-term effects of logging practices in streams in Golden Downs State Forest, Nelson. Proceeding of the Fisheries/Forestry Conference, 27-28 February 1990, Christchurch. Eds: J.W. Hayes and S.F. Davis.

Halkett, Laurie. 1991: Response to 'A Place for Pines'. Terra Nova, June 1992.

Hammond, H. 1991: Seeing the Forest among the Trees. The case for holistic forest use. Polstar, Vancouver.

Handiside, J. 1994: Protecting the monoculture. NZ Plantation Forestry – A Sustainable Resource, 1994 Conference Papers. New Zealand Institute of Forestry Inc. pp.75-83.

Hansen, A.J., Spies, T.A., Swanson, F.J. and Ohmann, J.L. 1991: Conserving biodiversity in managed forests. Bioscience Vol. 41 No. 6 : 382-392

Hawke, M.F. and O'Connor, M.B. 1992: The effect of agroforestry on soil pH and nutrient levels at Tikitere. Agroforestry Research Collaborative Report No. 23.

Hodges, R.D. 1978: Who needs inorganic fertilisers anyway? The case for Biological Agriculture. The International Institute of Biological Husbandry, Suffolk, England.

Honey, Brian G. and Buchanan, Andrew H. 1992: Environmental impacts of the New Zealand building industry. Research Report 92-2, Dept. of Civil Engineering, University of Canterbury, Christchurch, NZ.

Hood, I.A. and Sandberg, C.J. 1993: Armillaria-a hidden disease of Pinus radiata. NZ Forestry, Aug: 29-32.

Hornbeck, James W. 1990: Cumulative effects of intensive harvest, atmospheric deposition and other land uses. pp147-54 In: Dyck and Mees (Ed.) 1989, FRI Bulletin No. 159.

Hunter, I.R., Dyck, W.J., Mees, C.A. and Carr, K. 1988: Site degradation under intensified forest harvesting: a proposed classification system for New Zealand. IEA/BE Project A3 (CPC-10) Report No.7 July 1988.

Hunter, I.R. and Skinner, M.F. 1986: Establishing radiata pine on the North Auckland podzols. NZ Forestry 17-23.

International Tropical Timber Organisation (ITTO) 1993: ITTO Guidelines for the Establishment and Sustainable Management of Planted Tropical Forests. ITTO Policy Development Series 4.

ITTO 1991. Beyond Guidelines – an action programme for sustainable management of tropical forests. ITTO Technical Series, No.7, Yokoh, Japan. p.68.

Jackman, Gordon. 1991: Greenpeace Draft Report on the NZ Pulp and Paper Industry.

Jackman, Gordon 1992: The deadly legacy – a report on the toxic contamination of New Zealand by the indiscriminate use of pentachlorophenol (PCP). Greenpeace NZ.

Jackson, D.S. 1973. Water use by forests. New Zealand Forest Service Reprint No.703. Reprinted from proceedings of soil and plant water symposium, DSIR Information Series, 96: 94-101.

Janssen, Hella 1992: A place for pines. Terra Nova, June. pp45-46

Janssen, Hella 1991: Sustainable land management practices (especially forestry and for riparian areas) to maintain and improve water and soil and habitat for plants and animals in the Nelson/Marlborough area. Unpublished report.

Jen, Mark S. and Song, Yajie 1992: Agroforestry in Southern China: the share holding integrated forestry tenure (SHIFT) system. Tropical Resources Institute News, spring, p11-14

Johns, M. 1994: Plantation pines under attack – worms put on ice to fight killer wasps. Geo Australasia, Vol.15, No.4: 11-12.

Jorgensen, Jacques R., Wells, Carol G. and Metz,, Louis J. 1975: The Nutrient Cycle: key to continuous forest production. Journal of Forestry, July, p400-403.

Journal of Pesticide Reform, 1991: Vol. II No. 3

Jurgensen, M.F., Frederick, D.J., Madgwick, H. A. I., Oliver, G.R. 1986: Soil Development under Pinus radiata and Eucalyptus regans plantations. New Zealand Journal of Forestry Science 16 (1): 69-77.

Kimmins, J.P. 1977: Evaluation of the consequences for future tree productivity of the loss of nutrients in whole tree harvesting. Forest ecology and Management.

Kinraide, T.B. 1991: Identity of the Rhizotoxic aluminium species. Plant and Soil, 134: 167-178.

Kirk, Patrick and Smith, Mark 1992: Helicopter logging – an environmental logging case study. Logging Industry Research Organisation Report Vol. 17 No. 7.

Klitscher, Ken 1990: Forestry and the greenhouse effect. NZ Forestry February. p9

Kurtz, W.A. 1989: Significance of shifts in carbon allocation patterns for long-term site productivity research. pp149-64 In: Dyck and Mees (Ed.) 1988: FRI Bulletin No. 152.

Ledgard, N.J. 1988: The spread of introduced trees in New Zealand's rangelands – South Island high country experience. Tussock Grasslands and Mountain Lands Institute – Review 44, Lincoln, Canterbury. p1-8

Leitch, C. and Fagg, P. 1985: Clopyralid herbicide residues in streamwater after aerial spraying of a Pinus radiata plantation. NZ Journal of Forestry Science 15 (2) :195-206

Lewis, N.B. and Harding, J.H. 1963: Soil factors in relation to pine growth in South Australia. Australian Forestry 27: 27-34. Cited in: Jurgensen etal 1986.

Liping Pang 1993: Tarawera River Flow Analysis. Environment Bay of Plenty, Environmental Report 93-2, October.

London Hazards Centre: Toxic Treatments (pers. comm. July 1994, Paul Johnston, Greenpeace Earth Sciences Laboratory, Exeter University, UK).

Lord, Janice M. and Norton, David A. 1990: Scale and the spatial concept of fragmentation. Conservation Biology Vol. 4 No. 2 June : 197-202

Lucas, Di 1987: Woodlots in the landscape. Landscape Publications, Wellington.

MacLaren, J.P and Wakelin, S.J. 1991: Forestry and forest products as a Carbon Sink in New Zealand. FRI Bulletin No. 162.

McLaren, R.G. and Cameron, K.C. 1990: Soil Science. Oxford University Press. 294

Madgwick, H.I.A. and Webber, B. 1987: Nutrient removal in harvesting mature Pinus radiata. NZ Forestry, November. pp15-18

Magill, Rob 1991: Chopper on the devil's elbow. Terra Nova June. p24 & 33

Marschner, H. 1991: Mechanisms of adaptation of plants to acid soils. Plant and Soil, 134: 1-20.

Mead, D.J. and Gadgil, Ruth L. 1978: Fertiliser use in established radiata pine stands in New Zealand. NZ Journal of Forestry Science 8: 105-134

Mestal, Rosie 1993: Clinton wants plan to reconcile forestry and wildlife. New Scientist 10th April. p10

Ministry of Forestry. Forestry Report, 30 Sept. 1993.

Ministry of Research, Science and Technology – Te Manatu Putaiao 1991: New Zealand Science Review No 2 – Plantation forestry research. 57p

Mollison, Bill 1991: Introduction to Permaculture. Tagari Publications, Tyalgum, Australia. 198p

Monroe, D.H., 1988: Ecological and public health implications associated with the use of glyphosate herbicides. Environmental Consultants Northwest P.O. Box 309, Stanwood WA 98292 USA.

Moran, G.F., Bell, J.C. and Eldridge, K.G. 1988: The genetic structure and the conservation of the five natural populations of Pinus radiata. Canadian Journal of Forest Research 18 (5): 506-514

Moyes, M. 1991: Windstorm – new loss dimensions of natural hazards. Publication of Munich Reinsurance Co.

Murphy, G. 1984: A survey of soil disturbance caused by harvesting machinery in New Zealand plantation forests. Forest Research Institute, Rotorua. FRI Bulletin No. 69.

Murphy, G.E., Blundell, W.M. and Fahey, B.D. 1991: Environmental constraints on forest harvesting in the Marlborough sounds. Forest Research Institute, Rotorua. FRI Bulletin No. 166.

National Coalition Against the Misuses of Pesticides, 1991: Technical Report, Vol. 6, No.6 June

Norton, David A. 1990. Disruption of natural ecosystems by biological invasion. unpublished paper.

Nunn, Patrick. In press: Greenpeace Report of recent history of extreme weather events.

O'Connor, K.F., Overmars, F.B. and Ralston, M.M. 1990: Land evaluation for nature conservation. Conservation Sciences Publication No.3, Dept of Conservation, Wellington. 328p

O'Hara, Helen 1992: Forests in Crisis – The myth of sustainable forestry. The Women's Environmental Network, Canada. 92p

O'Loughlan, C. 1994: The forest and water quality relationship. 1994 Conference Papers, NZ Plantation Forestry – a Sustainable Resource. New Zealand Institute of Forestry Inc.pp.40-46.

O'Loughlan, C. 1986: Forestry and Hydrology. pp13-15 In: NZ Forestry Handbook, NZ Institute of Foresters.

Orwin, Joanna 1991: Forestry: sustaining the land. Terra Nova June, p34-35

Ovington, and Madgwick 1957:

Panayton, T. and Ashton, P.S. 1992: Not by timber alone – economics and ecology for sustaining tropical forests. Island Press, Washington, 282pp.

Pardy, G.F., Bergin, D.O. and Kimberley, M.O. 1992: Survey of Native Tree Plantations. FRI Bulletin No. 175.

Park, Geoff 1991: The tragedy of Falealupo. Terra Nova No. 2 February pp38-41

Parker, R.W. and Parker, A.L. 1986: Boron. lead and zinc as contaminants in forest ecosystems: A literature review. FRI Bulletin No. 103.

Pimmentel, David etal (eight other authors) 1992: Conserving biodiversity in Agricultural/Forestry systems. Bioscience Vol. 42 No. 5: 354-362

Ping, Liping. 1993. Tarawera river flow analysis. Environmental Report 93-2, Environment Bay of Plenty.

Poffenberger, Mark (Ed.) 1990: Keepers of the Forest – land management alternatives in Southeast Asia. Kumarian Press, USA. 289p

Poggiani, F., Zen, S., Mendes, F.S. and Spina-Franca, F. 1984: Cycling and loss of nutrients in forest stands for energy production. IPEF Instituto de Pesou isas e Estudos Florestais, No.27: 17-30.

Poole, Barry 1992: Quoted in "Eucalyptus: Spread risk and add protection." NZ Forest Owners Assn Bulletin March.

Post, W.M., Emanual, W.R. Zinker, P.J., Strangenberger, A.G. 1982: Soil carbon pools and world life zones. Nature 298: 156-159

Powers, R.F., Alban, D.H, Ruark, G.A., Tiarks, A.E. 1990: A soils research approach to evaluating management impacts on long-term productivity. In: Dyck and Mees (Ed). FRI Bulletin No. 159.

Ried, Walter V. and Miller, Kenton R. 1989: Keeping Options Alive – the scientific basis for conserving biodiversity. World Resources Institute, Washington, USA. 128p

Rosoman, G. 1993: A Review of Plantation Forestry in Erromango Island, Vanuatu, unpublished Greenpeace report.

Ruark, Gregory A. and Blake, John I. 1991: Conceptual stand model of plant carbon allocation with a feedback linkage to soil organic matter maintenance. In: Dyck and Mees (Ed) 1990; FRI Bulletin No. 161.

Sawyer, J. 1993: Plantations in the tropics, environmental concerns. The IUCN Forest Conservation Programme.

Schmidt, H. 1981: Die Wiese als Oekosystem, 176p (in German). Cited in: Janssen 1991.

Sedjo, Roger A. 1989: Forests to Offset the Greenhouse Effect. Journal of Forestry July.

Senanayake, R. 1987: Some strategies for effective communication in tropical forest issues. Loris 17: 191-195, In: FoE 1992.

Senyk, J.P. and Smith, R.B. 1991: Estimating impacts of forest harvesting and mechanical site preparation practices on productivity in British Columbia. pp 199-211 In: Dyck and Mees (Ed) 1990. FRI Bulletin No. 161.

Shaw, C.H., Lundkvist, H., Moldenke, A. Boyle, J.R. 1991: The relationships of soil fauna to long-term forest productivity in temperate and boreal ecosystems: processes and research studies. In: Dyck and Mees (Ed) FRI Bulletin No. 161.

Shelbourne, C.J.A. 1992: Submission to Forest Products Research Review, Science Review No. 6R. MORST, Wellington.

Shiva, Vandana 1991: Biodiversity, Biotechnology and Profits. pp43-58 In: Biodiversity -Social and ecological perspectives, World Rainforest Movement, Penang, Malaysia.

Simpson, J.A. and Ades, P.K. 1990: Screening Pinus radiata families and clones for disease and insect pest resistance. Australian Forestry 53 (3) :194-199

Singh, S., Khan, S.N., Misra, B.M. and Uniyal, K. 1982: Some important diseases of pines in India. Indian Forester 108: 86-92

Skinner, M.F., Murphy, G., Robertson, E.D., Firth, J.G. 1989: Deleterious effects of soil disturbance on soil properties and the subsequent early growth of second-rotation radiata pine. In: Dyck and Mees, FRI Bulletin 152.

Skinner, Malcolm and Nordmeyer, Alan 1989: Strategies for the alleviation of nutrient deficiencies in young radiata pine plantations in New Zealand. pp298-303 in: Efficiency of stand establishment operations, FRI Bulletin No. 156

Smethurst, P.J. and Nambiar, E.K.S. 1990: Distribution of carbon and nutrients and fluxes or mineral nitrogen after clear-felling a Pinus radiata plantation. Canadian Journal of Forest Research 20(9) 1490-97

Smith, C.M. 1992: Riparian afforestation effects on water yields and water quality in pasture catchments. Journal of Environmental Quality, Vol.21, No.2.

Smith, P.J.T. 1987: Variation of water yield from catchments under grass and exotic forest, east Otago. Journal of Hydrology (New Zealand) 26: 175-184.

Soule, M. 1992: A vision for the meantime. Wild Earth, The Wildlands Project. Special issue, pp.7-8.

Squire, R.O., Flinn, D.W., Campbell, R.G. 1991: Silviculture research for sustained wood production and biosphere conservation in the pine plantations and native eucalyptus forests of south eastern Australia. In: Dyck and Mees (ed). Forest Research Institute, Rotorua, NZ, FRI Bulletin No. 161.

Stevenson, Philippa 1992: The scandal of the PCP dumps. Terra Nova, July p10-15

Studholme, Bill 1993: Quoted in Chch Press in “Wind biggest forestry risk”. 12th March.

Sutton, Wink 1991: quoted in New Zealand Herald July 9th 1991.

Sutton, W. R.J. 1991a: New Zealand radiata pine plantation – an example of sustainability. Paper presented to the SAF National Convention, San Fransisco, California 4-7 August.

Sweet, G.B. 1989: Keynote address – Maintaining health in plantation forests. NZ Journal of Forestry Science 19 (2/3) : 143-154

Szabo, Michael. 1994: New Zealand’s poisoned paradise. New Scientist, 31st July, 29-33.

Taranaki Regional Council 1992: Sustainable land use in the Taranaki hill country – a case study. Taranaki Regional Council Technical Report 92-19.

Teramura, Alan H. 1991: Global change research: ozone depletion and its impacts. Statement to the senate committee on Commerce, Science and Transportation. November .

Thaman, R.R. 1988: Fijian Agroforestry: Trees, people and sustainable polycultural development. P143-171, In : Fiji’s Rainforests – our heritage and future. Proceedings Vol. 1. The 2nd National Conservation Congress, Suva, Fiji, 9-10 June.

Turner, John and Lambert, Marcia J. 1988: Soil properties as affected by Pinus radiata plantations. New Zealand Journal of Forestry Science 18 (1): 77-91.

Valasco-de-Pedro, F. and Lozano-Calle, J.M. 1979: Synecological changes in ground microfauna following reforestation with exotic species. Anales-de-Edafelogia-y- Agrobiologia, 38: 5/6, pp.871-879.

Valentine, John 1992: quoted in NZ Forestry, February 1992. p4

Visser, R. and McConchie, M. 1993: The impact of riparian buffer strip characteristics on forest harvesting. Logging Industry Research Organisation Report, Vol.18, No.10.

Walsh, P.J., Day, K.R., Leather, S.R. and Smith, A. 1993: The influence of soil type and pine species on the carabid community of a plantation forest with a history of pine beauty moth infestations. Forestry, 66(2): 135-146.

Ward, Jonet C. and Beanland, Ruth 1992: Contributions to a national set of environmental indicators to be monitored at a regional level. Information Paper No. 36, Centre for Resource Management, Lincoln University.

Watts, M. 1991: Ecological Agriculture in New Zealand. GPNZ submission to Ministry of Agriculture on MAF Policy Paper 106: Sustainable agriculture, a policy proposal. July. 22p.

Whitehead, D. 1992: Current status of climate change research in relation to forestry in New Zealand. Prepared for the National Science Strategy Committee for Climate Change.

Whyte, A.G.D. 1973: Productivity of first and second crops of Pinus radiata on the Moutere gravel soils of Nelson. NZ Journal of Forestry 18: 87-103

Will, Graham 1985: Nutrient deficiencies and fertiliser use in New Zealand exotic forests. FRI Bulletin No. 97. Rotorua, NZ.

Will, G.M., Hodgkiss, P.D. and Madgwick, H.A.I. 1983: Nutrient losses from litterbags containing Pinus radiata litter: influences of thinning, clearfelling and urea fertiliser. NZ Journal of forestry science 13 (3):291-304

Winterbottom, Robert and Hazlewood, Peter T. 1987: Agroforestry and sustainable development: making the connection. Ambio Vol. 16 No. 2-3 100-110

World Bank 1992: Forest Policy , World Bank, Washington USA.

Yeates, G.W. 1988: Earthworm and Enchytraeid populations in a 13-year-old agroforestry system. NZ Journal of Forestry Science 18(3): 304-10

Zabowski, D. 1990: Role of mineral weathering in long-term site productivity. pp55-71 In: Dyck and Mees (Ed.) 1989, FRI Bulletin No. 159.

Zonneveld, Isaak S. and Forman, Richard T.T. 1990: Changing Landscapes: an ecological perspective. Springer-Verlag., Chapt. 14: p261-278