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# Environmental implications of whole tree harvesting in Ireland

Pierre Binggeli

## Introduction

The main consideration in any crop system is the establishment of a sustainable harvesting regime where the productivity of the system is maintained over time. Intensive cropping systems often result in a long-term decrease in yield either as a result of decreased soil fertility or due to increased pests and diseases. In agricultural systems this problem can usually be remedied by crop rotation. In forestry systems decrease in productivity are not always obvious and when present can often be addressed by altering silvicultural practices. However, trees are highly variable crops which have been grown and harvested in varying forms and have been grown in differing soil and habitat types. As a result the interactions between these various variables are difficult to understand and even harder to predict. When a new harvesting regime, such as whole tree harvesting, is envisaged its effect on the ecosystem, but especially nutrient cycle, is a major consideration to be addressed before the system is implemented.

In this report the impact of whole-tree harvesting is reviewed and special attention is given to the harvesting of Sitka spruce (*Picea sitchensis*) and Lodgepole pine (*Pinus contorta*) for biomass in Ireland. The first part of the review will summarize the relevant information dealing with the impact of tree species on soil nutrients in natural ecosystems. The impact of harvesting on natural forest productivity will be looked at using relevant examples. Relevant aspects of short rotation bioenergy plantations are also evaluated. Finally the sustainability, in terms of nutrient cycling and productivity, of plantation forestry under differing harvesting systems, including whole-tree harvesting will be looked at in detail.

## Nutrient cycling in natural forests

### Species attributes and impact on soil properties

In North America *Prunus* and *Rubus* spp. growing in logged over areas contained relatively higher concentrations of nitrogen in biomass and Prunus lower calcium concentrations in the wood and bark compared with trees in the unlogged forest (Mou et al. 1993).

There is usually much within tree variation in nutrient. For instance, in North America Yanai (1998) found that the P content of branches and twigs of trees with a DBH > 10cm was nearly twice that of stem wood and bark. This harvest removed 50 kg P/ha, five times more P than the bole-only clearcut of an adjacent watershed.

In an investigation of five temperate tree species planted on set-aside farmland Alriksson & Eriksson (1998) found that the foliage of Picea abies had twice the quantity of dry weight, Mg, K, P and N and eight times the quantity of Ca as the foliage of any of the other species. Thus the choice of tree species may strongly influence the rate of nutrient removal in whole-tree harvesting as well as stem-only harvesting. Difference in pH in the combined litter and organic layer was found, but no species-related differences in soil pools of C or acidity were recorded.

In its native range Sitka spruce grown in plantations densely colonized by *Alnus crispa* exhibited higher growth rates. The alder's nitrogen contribution in nitrogen was about 50 kg.ha-1.year-1. Alder density had no effect on spruce density but in high density alder plots the foliar N of Sitka spruce was 10-15% than in low density plots (Hudson 1993).

### Succession and facilitation

The pattern and processes of natural succession in natural forest systems is well known and the importance of early successional species in improving soil characteristics and facilitate the growth of later successional species is well reported (Callaway 1995, Walker 1993). Of particular importance is the nitrogen fixing ability of a number of species (e.g. *Alnus* spp.).

Yet is it not fully appreciated how a number of woody plant species may be inhibitory as they may halt succession or at least retard successional processes by reducing growth rates of other species. In Britain and Ireland Sitka spruce is checked by Calluna vulgaris not only in newly planted areas but also in maturing stands if C. vulgaris manages to survive in the undergrowth. Due to its shallow rooting Sitka spruce competes with *C. vulgaris* for nutrients. The use of fertilizer and usually herbicide may be avoided by the nursing effect of pine species. On oligotrophic sites Sitka spruces can be successfully planted in mixtures with Lodgepole pine on deep peats and Scot pine on heathland. These two species facilitate the establishment and promote the growth of Sitka spruce (Malcolm 1987).

**Impact of timber harvesting in natural forests**

Only through the understanding of the structure, function, and development over time of a forest ecosystem can the sustainability of timber harvesting be fully ascertained. Such a long-term investigation has been carried on in North America in the Hubbard Brook Valley in order to understand forest dynamics in relation to biotic and abiotic factors. Nutrient cycling in relation to timber harvesting has been a key component of this study (Bormann & Likens 1979).
In relation to timber harvesting they recognized three types of clearfelling systems:
1.stem-only harvesting (SOH) where all merchantable trunks between stump and crown are harvested.
2.whole-tree harvesting (WTH) where the entire portion of the tree aboveground is harvested and chipped for use in pulp or reconstituted paper products.
3.complete-tree harvesting (CTH) where the entire tree, aboveground and belowground, is harvested and chipped.

The regeneration of vegetation was not affected by SOH whilst CTH inhibited the regeneration of many species (Bormann & Likens 1979). Following WTH very high spatial variation was observed in the composition and density of the recovering vegetation, which is often the principal mechanism limiting nutrient loss following large-scale disturbance of forest ecosystems. High disturbance to the soil during the harvest operation and the poor availability of reproductive propagules lead to poor vegetation recovery (Mou et al. 1993).

Whole-tree harvesting resulted in considerably more soil disturbance, but this point may be debatable. Nutrient export was observed in all treatments after logging. For instance increases in dissolved nutrients in drainage water was recorded after SOH (Bormann & Likens 1979). Important amounts of Ca can be lost from the ecosystem in harvested timber products in WTH (Likens et al. 1998).

Dahlgren & Driscoll (1994) reported that WTH caused important disturbance leading to losses of nutrients from the soil profile by leaching, increased acidification, and high concentrations of Al-ions in soil solutions and streamwater. These effects were most noticeable the second year after cutting and disappeared after 4-5 years. The impact increased and the speed of recovery decreased with elevation where soils were shallower. Johnson (1995) carried out an investigation to determine the timing and variation in nitrogen loss. After 8 years 25-40% of the forest floor nitrogen was lost. Mechanical disturbance during logging may limit short-term nitrogen losses and steep slopes experienced the greatest losses of nitrogen and carbon. Nitrogen losses can be limited after clear-cutting by minimizing organic matter losses and promoting rapid regrowth. Significant decreases in the C/N and C/organic matter ratios in the soil was observed as a result of carbon loss from soil organic matter.

P removal in harvest was small and little loss in streamwater and sediment was recorded. Compared to the natural forest leaching of P from the forest floor to the mineral soil was higher and P mineralization was lower and Yanai (1998) concluded that whether intensive biomass removals could induce P deficiency in future rotations is unknown.

An investigation of forest floor properties following the whole-tree and stem-only harvesting of Betula papyrifera in Newfoundland revealed a decrease in available nitrogen and calcium following harvesting in both treatments. Stem-only harvesting resulted in an increase in available phosphorus. Treatments had opposite impacts on available potassium with a decrease after whole-tree harvesting and an increase following stem-only harvesting (Roberts et al. 1998).

Apart from highlighting the obvious degradation associated with harvesting the Hubbard Brook Experimental Forest does not provide definite or clear answers to the long-term impact of harvesting to the maintenance of forest productivity. Central European mixed forests, which have been harvested for centuries, would suggest that at least in the case of continuous cover forestry production has been maintained over several generations, although it is unknown whether productivity has been affected. As pointed out by Bormann & Likens estimates of long-term effects of harvesting on natural forests remain largely educated guesses, especially considering the complexity of forest ecosystems.

Further difficulties arise with the indirect impact of humans on natural forest ecosystems mainly resulting from atmospheric pollution. Likens (1991) pointed out that atmospheric deposition of sulphur in the northeastern United States, including Hubbard Brook, exceeded by three to six times limits established to protect sensitive ecological systems. Likens et al. (1998) found that soil depletion of Ca was the result of leaching due to inputs of acid rain.

## Short rotation bioenergy plantations

Short rotation bioenergy plantations are confronted with similar sustainability problems notwithstanding that different species and soil types are encountered.

Stjernquist (1994) has argued that short-rotation plantation forestry is an environmentally sound energy resource if:
1.the biomass production systems are not pressed to maximum production,
2.cultivation measures are taken to minimize nutrient

leaching,
3.the short-rotation plantations are designed for visual adaptation to the landscape, and
4.directed silvicultural measures are taken to retain and improve important habitats and protect marginal forest areas.

In essence short-rotation plantations very similar to conventional agricultural systems. Thus a steady supply of nutrients is necessary in order to maintain the system's fertility. With the exception of nitrogen all nutrients withdrawn during biomass harvesting in bioenergy plantations are contained in the ash (Stjernquist 1994) and can be returned to the plantations to maintain fertility. It is however essential not to mix industrial wood in the burning process as undesirable impurities (e.g. heavy metal) will contaminate the ashes and cause air pollution (Blackstock & Binggeli 2000).

A review by Makeschin (1994) of the effects of energy forestry on former arable soils concluded that:
1.soil physical properties are positively influenced due to the lack of frequent input of heavy machinery but the impact of harvesting on soil properties and subsequent tree growth are unclear.
2.Fast growing trees can significantly reduce soil solution nitrate and ground vegetation may also act as an important nitrogen sink.
3.In the long term the carbon and nitrogen contents of afforested soils increase.
4.The diversity of soil fauna diversity is usually enhanced.

## Plant-animal interactions

In Denmark spruce aphid infestations have caused defoliation in Sitka spruce stands and in conjunction with high nitrogen deposition increased nitrogen leaching (Pedersen & BilleHansen 1995).

In the U.K. the pine weevil Hylobius abietis kills about 33%, and sometimes the totally, of all untreated restock plants. Damage occurs during the first three years after establishment and is usually patchy. As adults emerge from stumps up to four years after felling infection can be prevented either by applying insecticide to seedlings or planting is delayed up to five years (Henry 1995).

In North America the seedling debarking weevil Hylobius congener avoids mineral soil and feeding damage was reduced by removal of brash. When planting on bare soil, and therefore brash removal, results in less damage (Henry 1995).

## Nutrient dynamics of brash and litter

Over the past 15 years much research has been undertaken in Great Britain on the nutrient status of Sitka spruce plantations after the clearfelling. These studies have been carried out in Wales (Plynlimon and Beddgelert) and northern England (Grizedale and Kielder) and have especially looked at the impact of whole-tree harvesting as well as the impact of brash on nutrient cycling and growth of young trees in the second rotation.

The standard felling regime of Sitka spruce plantations results in banding the brash into 8 m wide belts separated by 4 m wide strips devoid of brash. As a result the nutrient capital is restricted to a portion of the site. Two years after felling around 50% of original brash mass remain and then decrease to about 20% after 7 years (Titus & Malcolm 1999).

Soil chemical variables of Sitka spruce plantations of varying ages growing on nutrient poor soils did not show distinct trends but were found to fluctuate (Adam 1999). Three main groups of interacting chemical variables were recognized in the top soil:

1. soil bases (e.g. Ca, Mg)
2. soil acids (e.g. Al, H, pH)
3. soil organics (e.g. organic matter content, P).

Besides being toxic to the fine root system of Sitka spruce, reactive Al strongly affected the nutrient content and supply of the investigated soils.

Titus & Malcolm (1992) investigated the nutrient dynamics in the litter layer up to 7 years after clearfelling. Roughly half of the 7-year net loss of potassium was leached out of the litter layer in the first year whereas the loss of other nutrients in leachate was independent of the time from clearfelling. Nutrient losses from under brash swathes were generally greater than from cleared strips. After five years nutrient concentrations and contents of the old litter layer were higher under brash than in areas without brash (Titus & Malcom 1991). They concluded that the roots of second-rotation Sitka spruce are dependent on its decomposition for availability of nutrients as they are restricted to the old litter layer.

Titus & Malcolm (1999) found much variation in brash needle decomposition between microsites. Nutrients such as K, Na and Mg were rapidly lost from the needles whereas N was retained, and P and Ca content decreased at the same rate as needle mass loss.

Due to losses in P and Ca in harvested material Stevens et al. (1995) stated that this will probably result in long-term depletion of these elements in stem-only harvested sites. Because of greater biomass removal in WTH these effects will be significantly more severe where this system is practiced.

## Impact of differing felling regimes on tree growth

Proe et al. (1996) have investigated the effects of two harvesting systems upon growth of second rotation Sitka spruce on low fertility peaty gley sites in Kielder Forest. The addition of fertilizer to stem-only harvested plots increased mean tree volume by 13 per cent, but this increase was only observable 7 years after planting.

Twelve years after planting the mean volume of trees growing on the whole-tree harvested plots was 32% lower. Proe et al. (1996) concluded that following conventional harvesting nutrients released from decomposing residues will meet uptake requirements for 7-9 years following replanting. The removal of nutrients during whole-tree harvesting was identified as the reason for the much reduced growth rates in those plots.

Proe & Dutch (1994) reported that trees grew better during the first 3 years when planted directly through harvest residues compared with adjacent residue-free areas. They concluded that shelter and reduction in weed competition associated with residue retention were responsible for the observed differences.

## Sustainability of conifer plantations in britain and Ireland

Adam (1999) concluded that changes to forest management practices of Sitka spruce plantations in Britain are necessary in order to maintain long-term stability of the nutrient supply and site productivity. Compounding factors, such as acid deposition, and current silvicultural practices lead to lower productivity caused by a reduction in the long-term stability of the nutrient supply. His conclusions corroborate Cole's (1995) views that the long-term stability of the soil nutrient supply is of increasing concern.

Considering that these conclusions are chiefly based on the work carried on stem-only harvesting of forests and the sustainable productivity of whole-tree harvesting is even more questionable. Yet, Börjesson (2000) has recently evaluated the environmental impact of logging residue recovery and nutrient compensation in Sweden and concluded that the recirculation of woodash, produced by the burning of these residues, may greatly offset nutrient losses. He identified a number of environmental benefits including, reduced soil acidification, and in some circumstances improved nitrogen balance and reduced nutrient leaching. Toxic compounds are not a problem as long as ash from other fuels but losses in nitrogen will need to be addressed by the addition of fertiliser. In Ireland, deposition of nutrients is generally low and occasionally moderate on the mountains in the east of the island (Stapleton 1996), where, in the case of nitrogen, between about 12 to 16 kg ha-1 yr-1 is deposited. Elsewhere, nitrogen deposition is below 12 kg ha-1 yr-1 whereas in parts of England it may be greater than 28 kg ha-1 yr-1(Fowler 1997).

In Ireland it is recommended that wood ash, produced in bioenergy generation using forest residues, should be returned to the forest in order to ensure the long-term sustainability of these plantations. Still nitrogen depletion is a long term problem, especially in view of the limited aerial deposition, and addition of nitrogen fertiliser may be indeed be required to maintain productivity.

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