EFORWOOD
Sustainability Impact Assessment
of the Forestry - Wood Chain

Project no. 518128

EFORWOOD

Tools for Sustainability Impact Assessment

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PP	Restricted to other programme participants (including the Commission Services)	X
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

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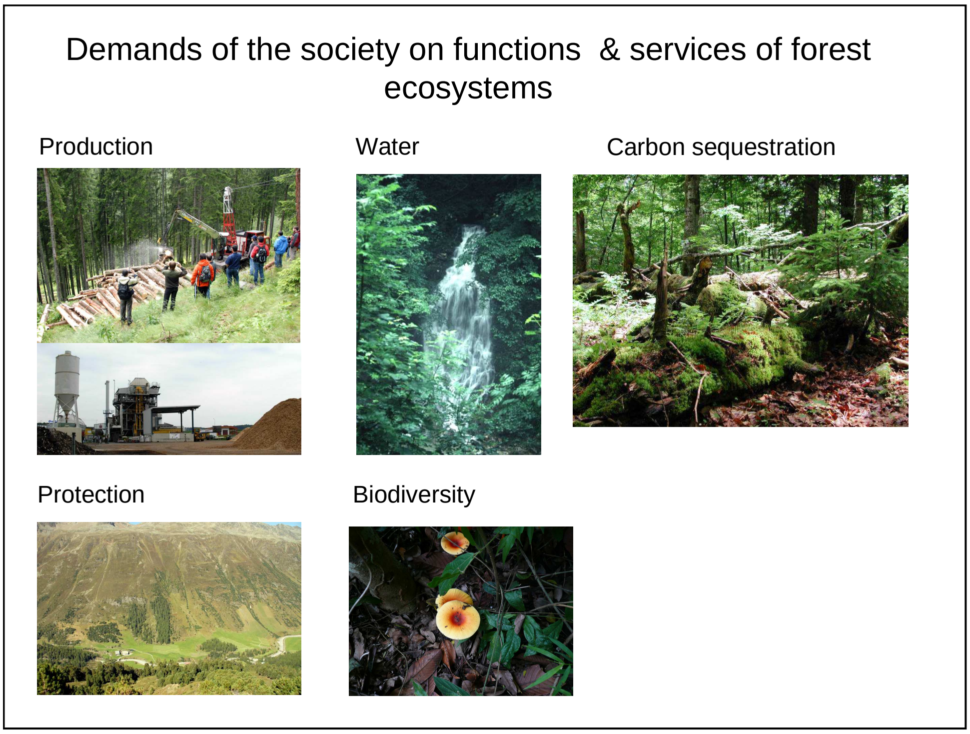
Catalogue of response functions: Forest management effect on environmental services



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ABSTRACT

This document includes a collection of examples on response functions describing the impact of forest management operations or alternatives on environmental service indicators from forests. Environmental services include biodiversity, soil quality, carbon stock and sequestration, water quality and water quantity. The catalogue is meant to illustrate possible use of simple ecological models in more complex integrated models. Final use of the response functions will often need expert assistance.

KEY WORDS

Response functions; forest management operations; forest management alternatives; biodiversity; carbon sequestration; soil quality; water quality; water quantity.

INTRODUCTION

Development of RESPONSE FUNCTIONS based on results of the literature review

→ Conceptual models: indicator = f (intensity of operation or alternative)

→ Implementation of existing models (conceptual, regression based and mechanistic)

Outcome: **Catalogue of response functions for 5 services**

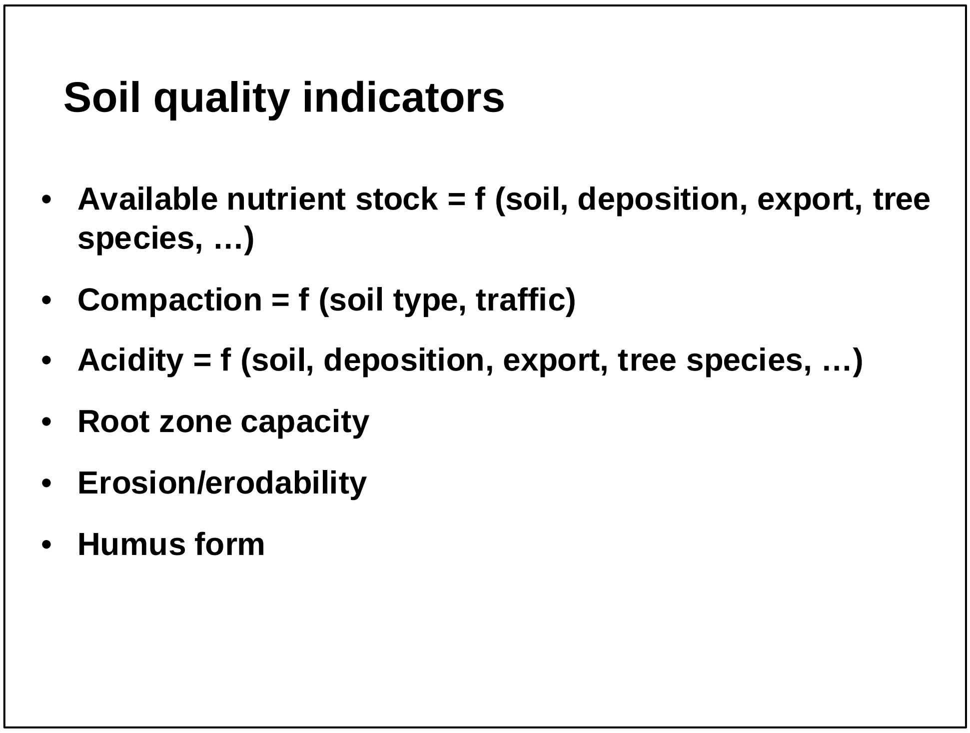
A possibility to evaluate the response of environmental services to forest management at several levels – from forest stand to region – is the conversion of experimental results into “response functions”.

In our case the response variables will be indicators for environmental services, while indicators for the intensity of forest operations will serve as independent variables. In deriving response functions for our exercise we rely on models of different complexity – from simple conceptual models and regression based models to mechanistic models.

In the following, the concept of response functions will be visualized for soil quality, biodiversity, carbon, water quality and water quantity indicators.

The purpose of this collection of response functions is to stimulate inclusion of forest management effects on environmental goods and services in the more complex modelling taking place in the Eforwood Project, especially in Module 2.

SOIL QUALITY



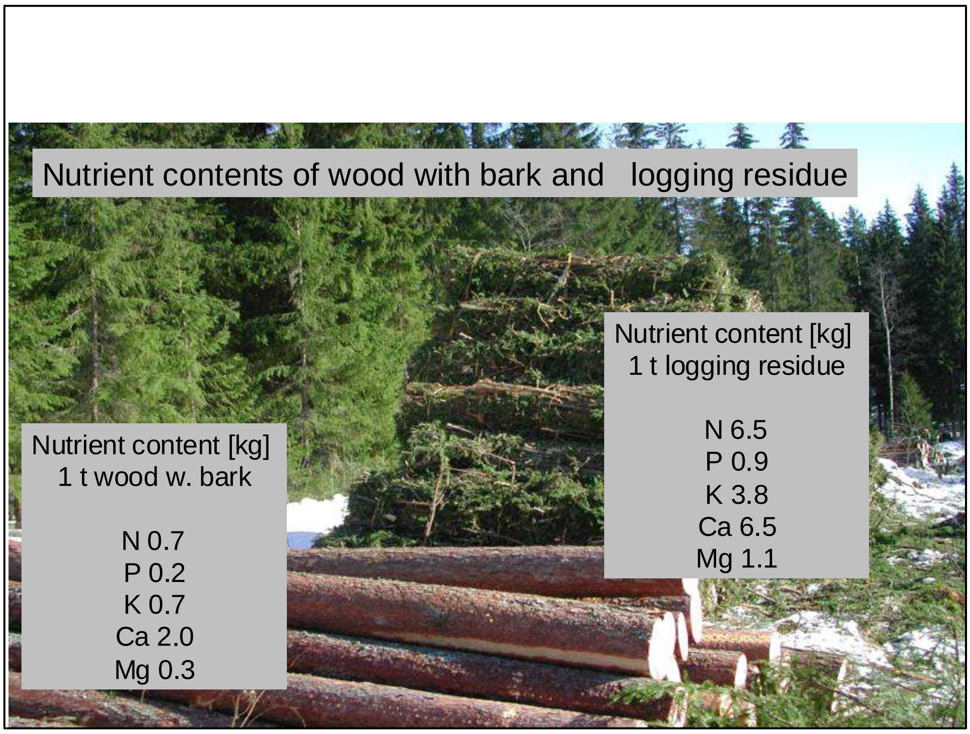
Soil quality indicators

- **Available nutrient stock = f (soil, deposition, export, tree species, …)**
- **Compaction = f (soil type, traffic)**
- **Acidity = f (soil, deposition, export, tree species, …)**
- **Root zone capacity**
- **Erosion/erodability**
- **Humus form**

Several soil quality indicators are used in the literature.
To express nutritional sustainability of forest operations for example, the available nutrient stock in the ecosystem is an appropriate indicator, depending on depth, mineral composition and particle size distribution of the soil, deposition patterns and nutrient imports (fertilization) and exports via biomass harvesting and erosion.
nutrient balance:
Delta nutrient stock = input from the atmosphere + input from mineral weathering + fertilization - losses with seepage - losses with harvest
nutrient stocks in the biomass: above ground biomass is easy to predict with models ; the variability of nutrient concentration within biomass compartments per tree species is low; nutrient extractions are therefore easy to predict
Nutrient contents soil: *high variability, analyses necessary (available from country-wise surveys etc.)*
weathering rates: reliable models exist (Example PROFILE (Sverdrup and Warfvinge 1988): *input parameters: climate (good data basie); mineralogical data (from soil analyses)Akselsson et al (2007 a,b) used such models to predict sustainability of forest production for Sweden.*

Akselsson, C, Westling, O, Sverdrup, H, Gundersen, P 2007 a.: Nutrient and carbon budgets in forest soils as decision support in sustainable forest management , *Forest Ecology and Management*, 238, 167-174.
Akselsson, C, Westling, O, Sverdrup, H, Holmqvist, J, Thelin, G, Uggla, E, Malm, G 2007 b. Impact of harvest intensity on long term base cation budgets in Swedish forest soils. , *Water, Air and Soil Pollution: Focus* , 7, 201-210.

Sverdrup,H.& Warfinge,P. 1988. Weathering of primary silicate minerals in the natural soil environment in relation to a chemical weathering model. *Water, Air, and Soil Pollution*, **38,** 387-408.



Nutrient contents of wood with bark and logging residue

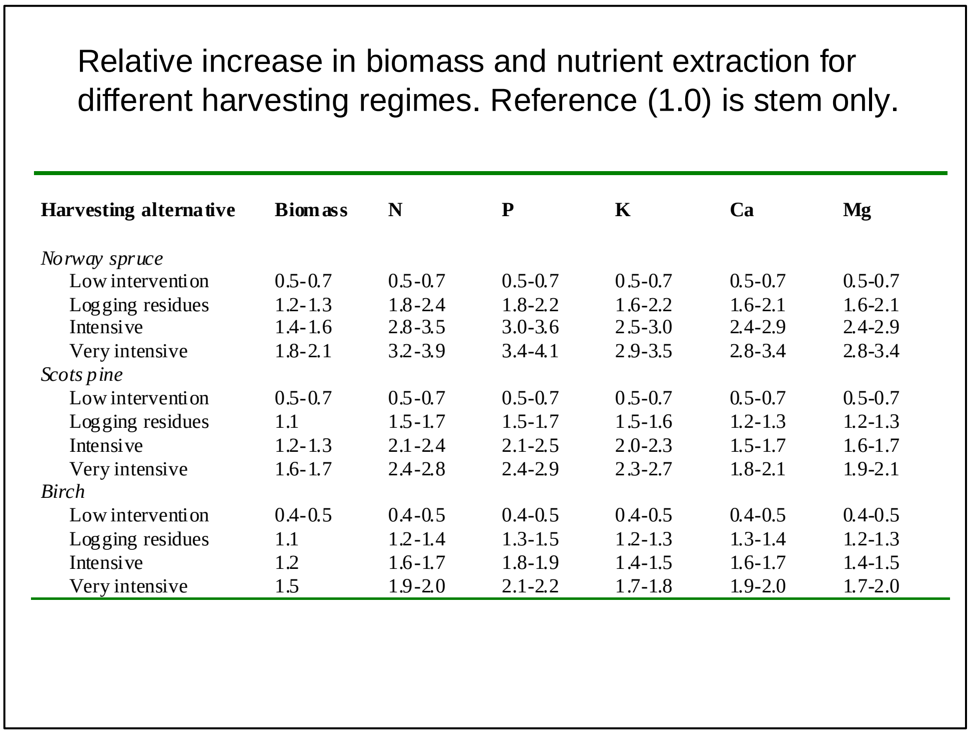
Nutrient content [kg]
1 t wood w. bark

N 0.7
P 0.2
K 0.7
Ca 2.0
Mg 0.3

Nutrient content [kg]
1 t logging residue

N 6.5
P 0.9
K 3.8
Ca 6.5
Mg 1.1

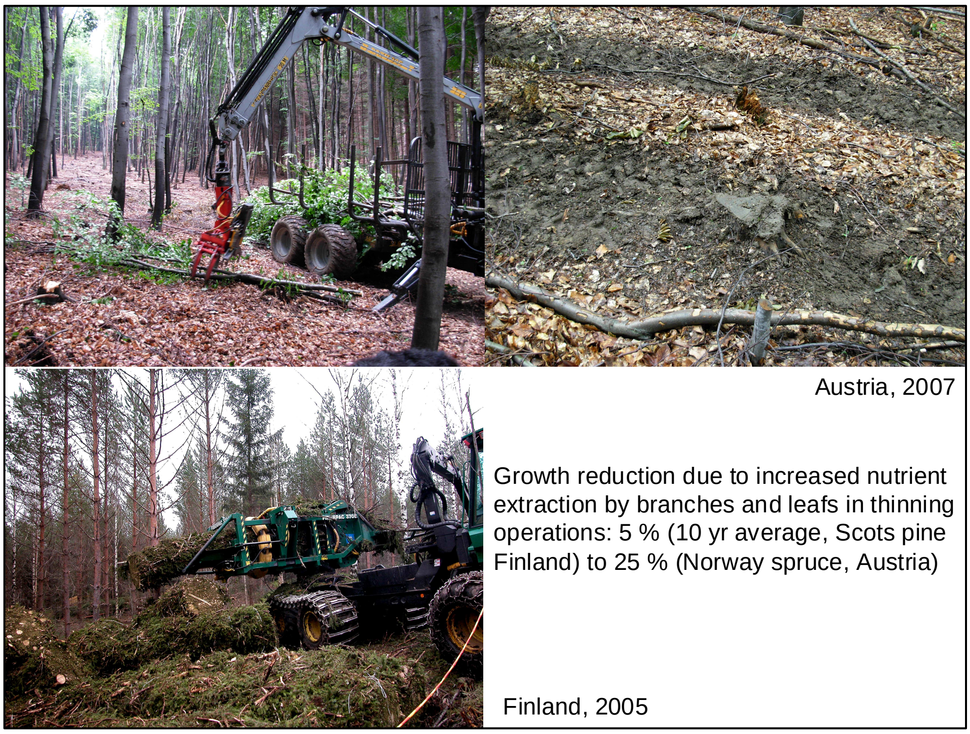
Sound databases are available for nutrient contents of different biomass fractions



Relative increase in biomass and nutrient extraction for different harvesting regimes. Reference (1.0) is stem only.

Harvesting alternative	**Biomass**	**N**	**P**	**K**	**Ca**	**Mg**
Norway spruce						
Low intervention	0.5-0.7	0.5-0.7	0.5-0.7	0.5-0.7	0.5-0.7	0.5-0.7
Logging residues	1.2-1.3	1.8-2.4	1.8-2.2	1.6-2.2	1.6-2.1	1.6-2.1
Intensive	1.4-1.6	2.8-3.5	3.0-3.6	2.5-3.0	2.4-2.9	2.4-2.9
Very intensive	1.8-2.1	3.2-3.9	3.4-4.1	2.9-3.5	2.8-3.4	2.8-3.4
Scots pine						
Low intervention	0.5-0.7	0.5-0.7	0.5-0.7	0.5-0.7	0.5-0.7	0.5-0.7
Logging residues	1.1	1.5-1.7	1.5-1.7	1.5-1.6	1.2-1.3	1.2-1.3
Intensive	1.2-1.3	2.1-2.4	2.1-2.5	2.0-2.3	1.5-1.7	1.6-1.7
Very intensive	1.6-1.7	2.4-2.8	2.4-2.9	2.3-2.7	1.8-2.1	1.9-2.1
Birch						
Low intervention	0.4-0.5	0.4-0.5	0.4-0.5	0.4-0.5	0.4-0.5	0.4-0.5
Logging residues	1.1	1.2-1.4	1.3-1.5	1.2-1.3	1.3-1.4	1.2-1.3
Intensive	1.2	1.6-1.7	1.8-1.9	1.4-1.5	1.6-1.7	1.4-1.5
Very intensive	1.5	1.9-2.0	2.1-2.2	1.7-1.8	1.9-2.0	1.7-2.0

Nutrient exports via harvesting can therefore be modelled easily. Data based on Hansen et al. 2007.

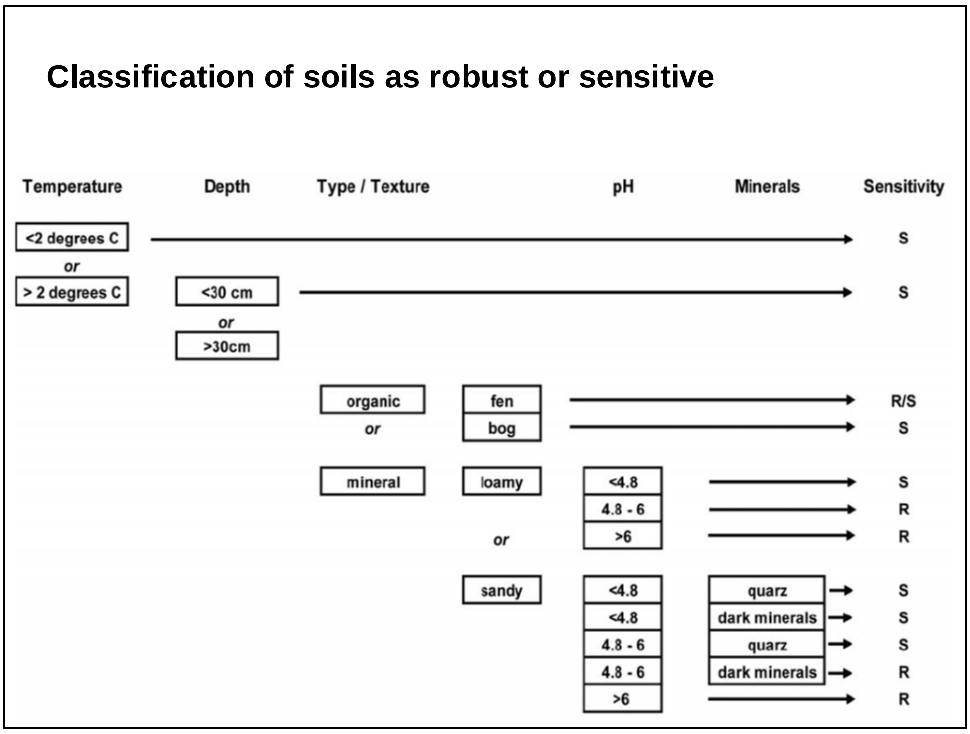


Austria, 2007

Growth reduction due to increased nutrient extraction by branches and leafs in thinning operations: 5 % (10 yr average, Scots pine Finland) to 25 % (Norway spruce, Austria)

Finland, 2005

Nutrient mining due to intensive harvesting of biomass of low dimensions like branches and needles may lead to growth reduction.



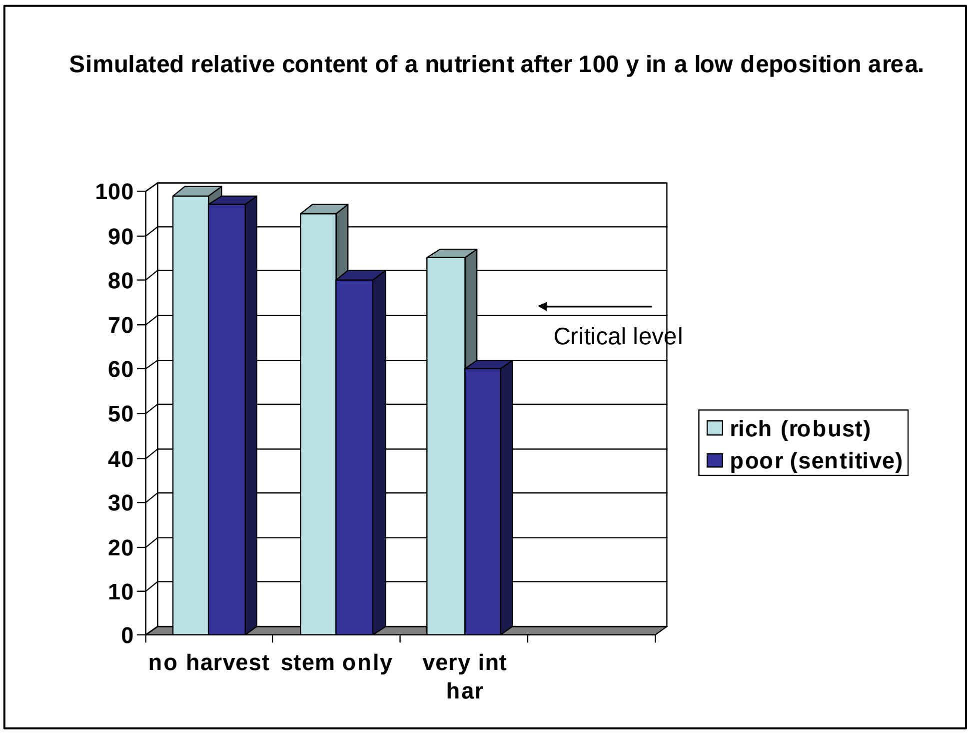
Classification of soils as robust or sensitive

For use when evaluating vulnerability of forest soils in relation to very intensive harvesting Raulund-Rasmussen et al., 2008 suggest classification of forest soils in Robust and Sensitive soils based on easily available characters.

Sensitive forest soils loose fertility, i.e. production capacity, as a consequence of element exports in biomass under the present forest production system within the relevant range of time. The decrease in fertility is caused by nutrient deficiency reducing the growth rate due to insufficient element replacement capability.

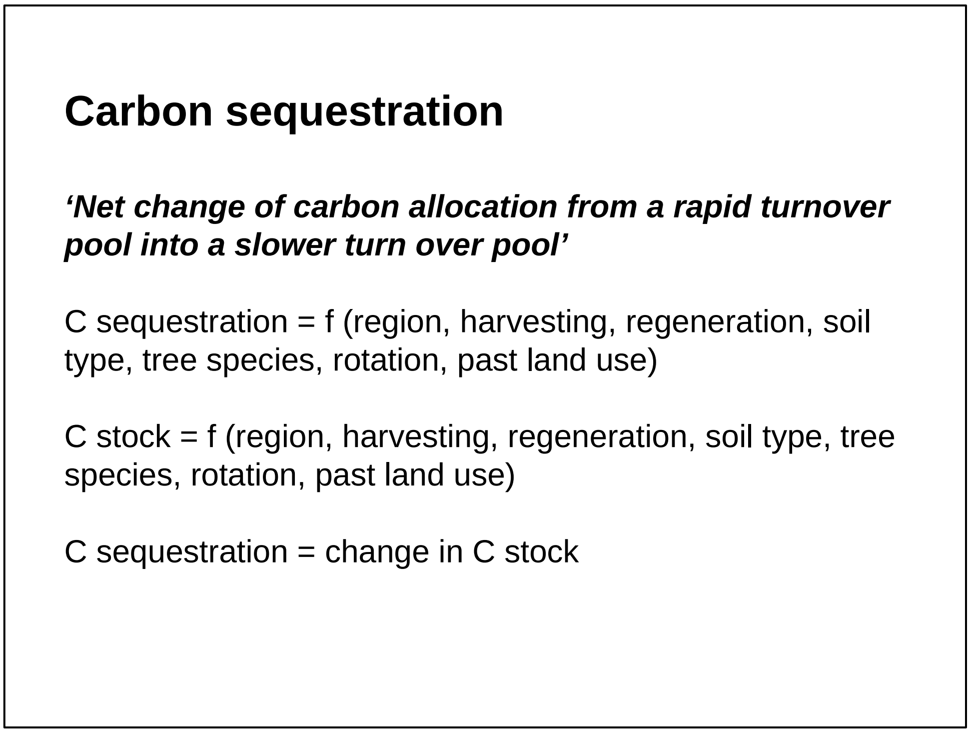
Robust soils are able to sustain productivity under the present forest production system following the export of elements in biomass either from the capital of available elements, or enter the cycle from outside sources, e.g. salt deposition, atmospheric deposition, biological fixation, or release due to chemical weathering of soil minerals.

The terms robust versus sensitive soils are of course relative and represent endpoints on a sliding scale.



Hypothetical simulation of a nutrient decrease in the soil as a consequence of harvesting on a sensitive versus a robust soil.

CARBON STOCKS AND SEQUESTRATION



Carbon sequestration

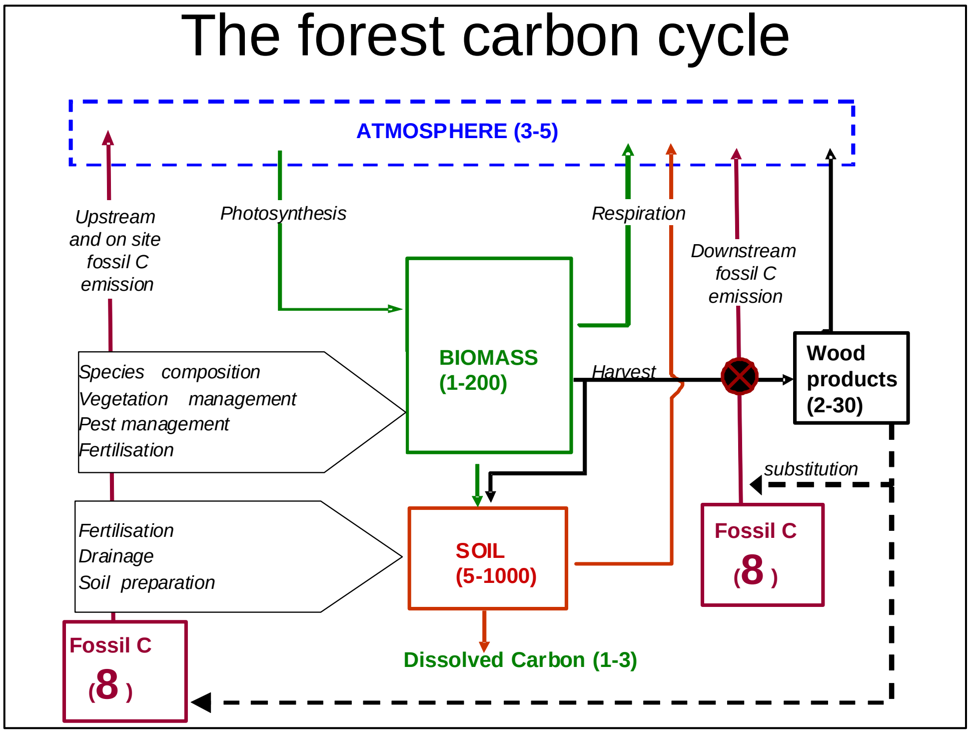
'Net change of carbon allocation from a rapid turnover pool into a slower turn over pool'

C sequestration = f (region, harvesting, regeneration, soil type, tree species, rotation, past land use)

C stock = f (region, harvesting, regeneration, soil type, tree species, rotation, past land use)

C sequestration = change in C stock

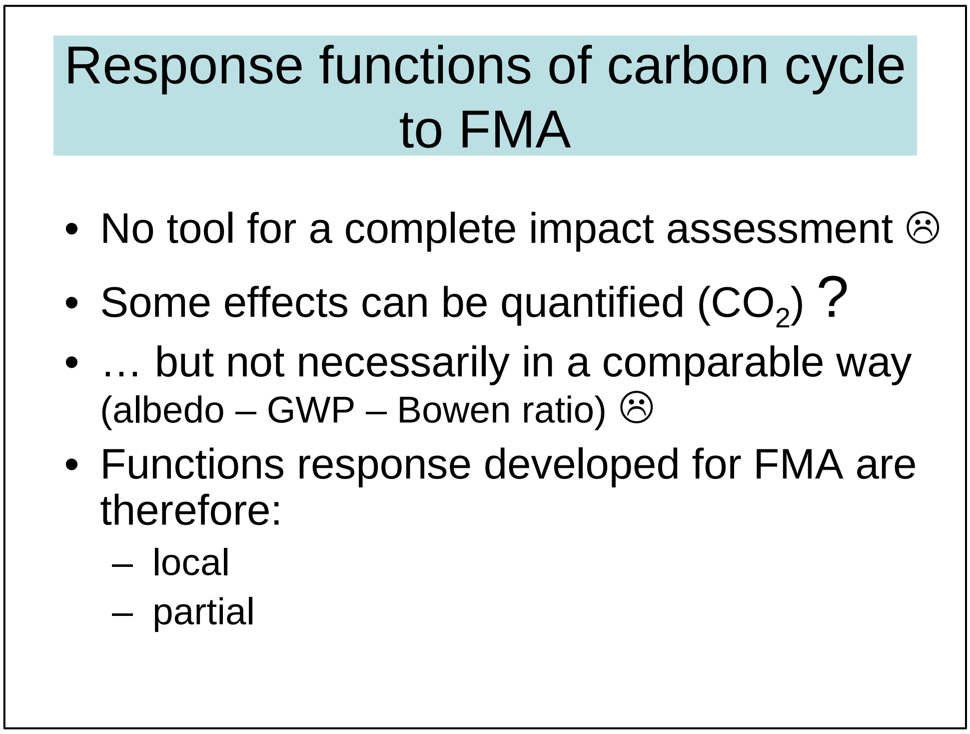
Important to distinguish between C sequestration (ongoing) and C stock (or store).



A simplified box diagram of the carbon cycle in forests. Numbers in parentheses are mean residence times (years). The first aim of this picture is to highlight the need of a complete assessment of the carbon cycle due to the number of “horizontal” interactions linking together the carbon fluxes exchanged between earth and the atmosphere. For instance, using fossil fuel for producing and applying fertilisers (rightmost upward flux) will affect photosynthesis, biomass stock, soil stock, soil respiration, harvest production, etc…

Another important point is also the impact of wood products substitution to others like steel, concrete, aluminium, fossil fuel, and the reduction induced onto the emissions of fossil fuel into the atmosphere (broken line).

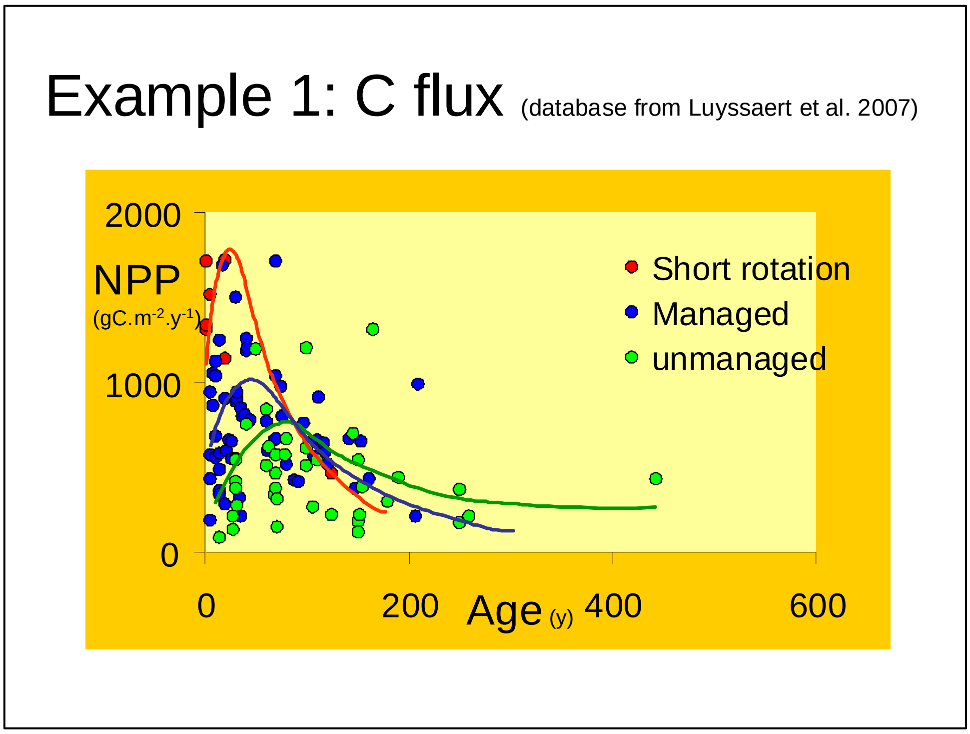
The processes are described in detail by Denis et al., 2007.



Response functions of carbon cycle to FMA

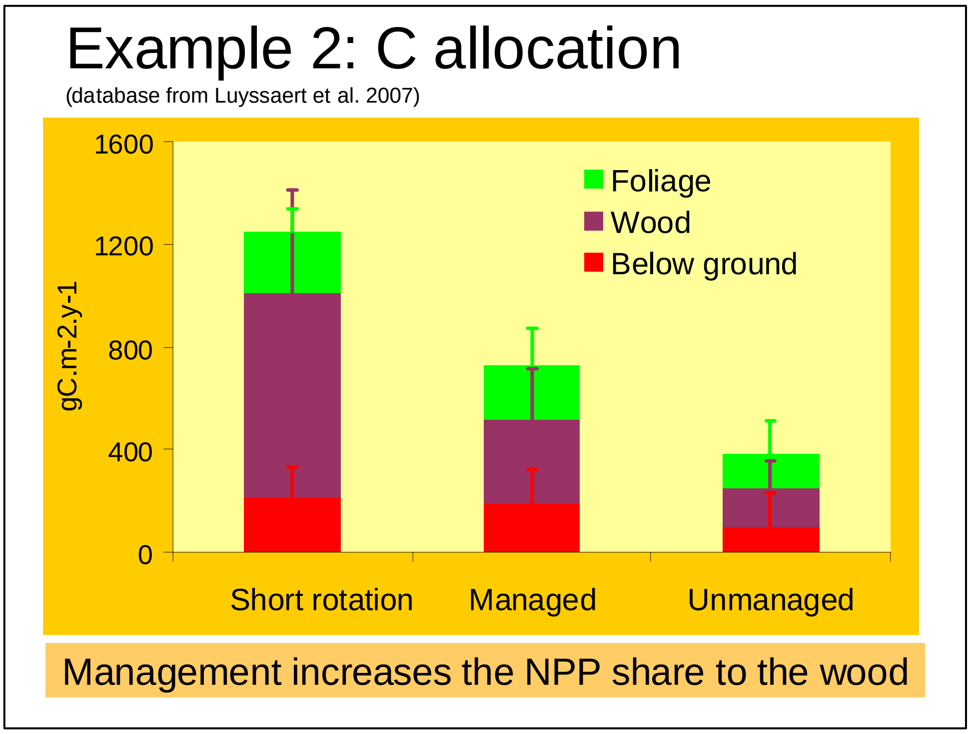
- No tool for a complete impact assessment ☹
- Some effects can be quantified (CO_2) ?
- … but not necessarily in a comparable way (albedo – GWP – Bowen ratio) ☹
- Functions response developed for FMA are therefore:
  - local
  - partial

The first dot points out that no metric allowing a consistent comparison of atmospheric effects of greenhouse gases (CO2, CH4, N2O, NOx, O3), surface energy balance (bowen ratio), albedo effect,…) does exist. The radiative forcing or global warming potential concepts are adequate for greenhouse gases and albedo effects but not necessarily applicable to energy balance at the surface.
The second dot reminds us that some of the primary effects of some of these factor can be quantified.
The third dot reminds us that our assessment is framed to only partial and local effects.



Example 1: C flux (database from Luyssaert et al. 2007)

The first example of a response function is the effect of management on the time trajectory of forest NPP, the “squeezing effect”.
Intensively managed forests, short rotation, have a higher amplitude of NPP but a shorter lifetime than unmanaged forests. See Loustau et al., 2007.

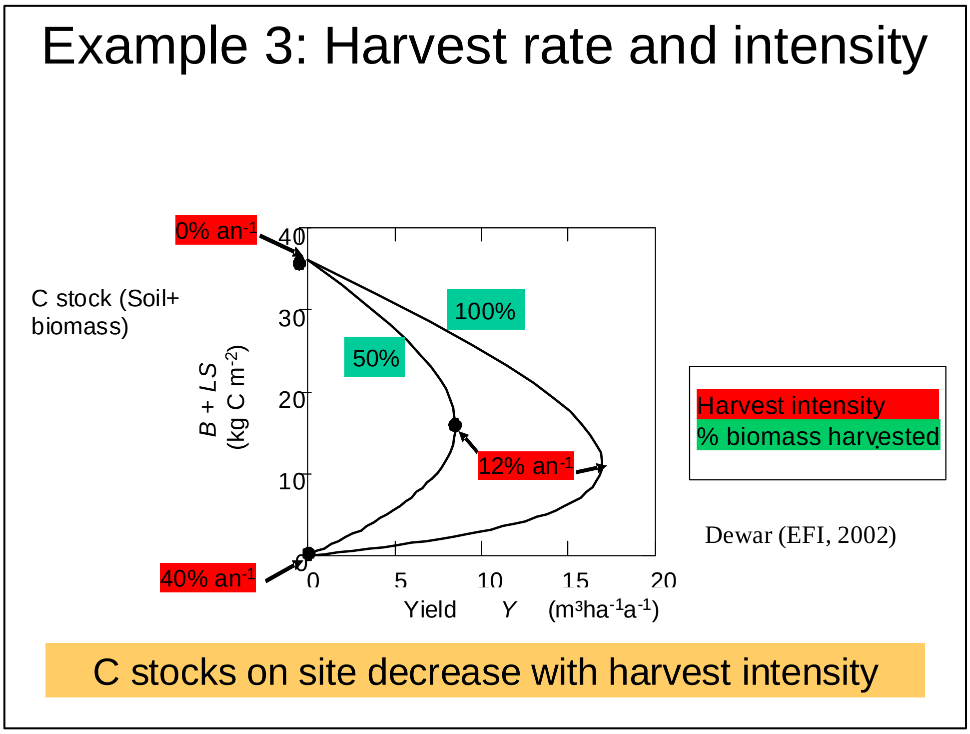


Example 2: C allocation

(database from Luyssaert et al. 2007)

Management increases the NPP share to the wood

The second example shows that carbon allocation in managed forest is shifted towards the biomass compartment harvested, the stemwood. See Loustau et al., 2007.



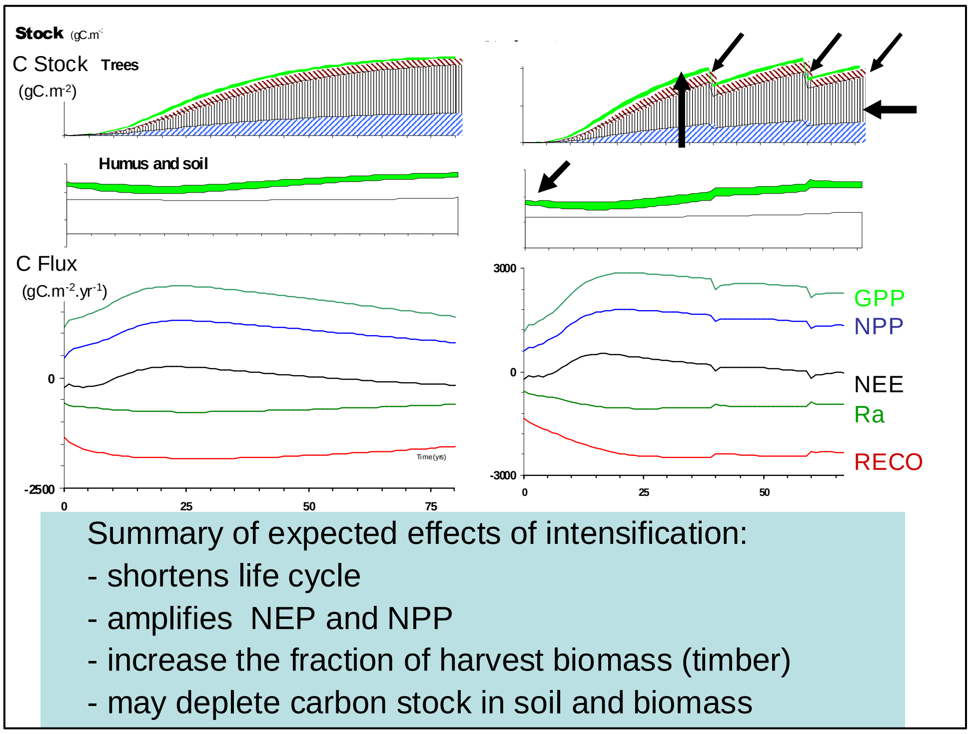
Example 3: Harvest rate and intensity

Dewar (EFI, 2002)

C stocks on site decrease with harvest intensity

A third example is the theoretical response curves of carbon stock to the production rate at different intensities of harvest and for the percentage of harvested biomass.

These curves provides an example of a simple framework which may be used for managing the carbon balance of managed forests. See Loustau et al., 2007.

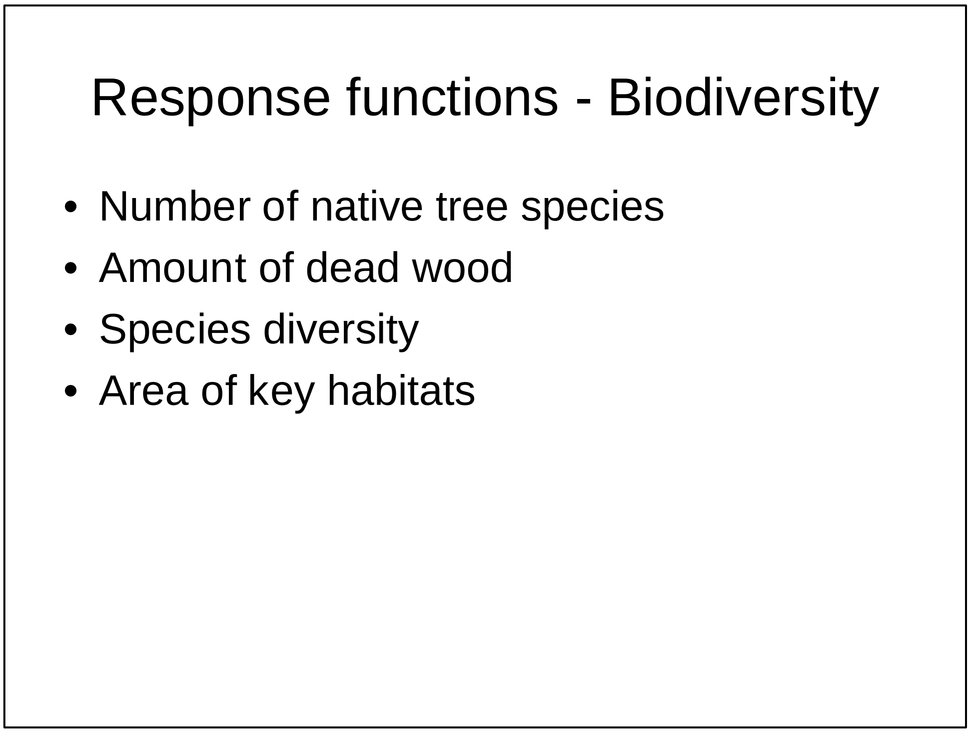


Summary of expected effects of intensification:

- shortens life cycle
- amplifies NEP and NPP
- increase the fraction of harvest biomass (timber)
- may deplete carbon stock in soil and biomass

Course of carbon stock (upper diagrams) and flux (Lower diagram) in a forest ecosystem according to two management class, unmanaged (left) and managed (right). See Loustau et al., 2007.

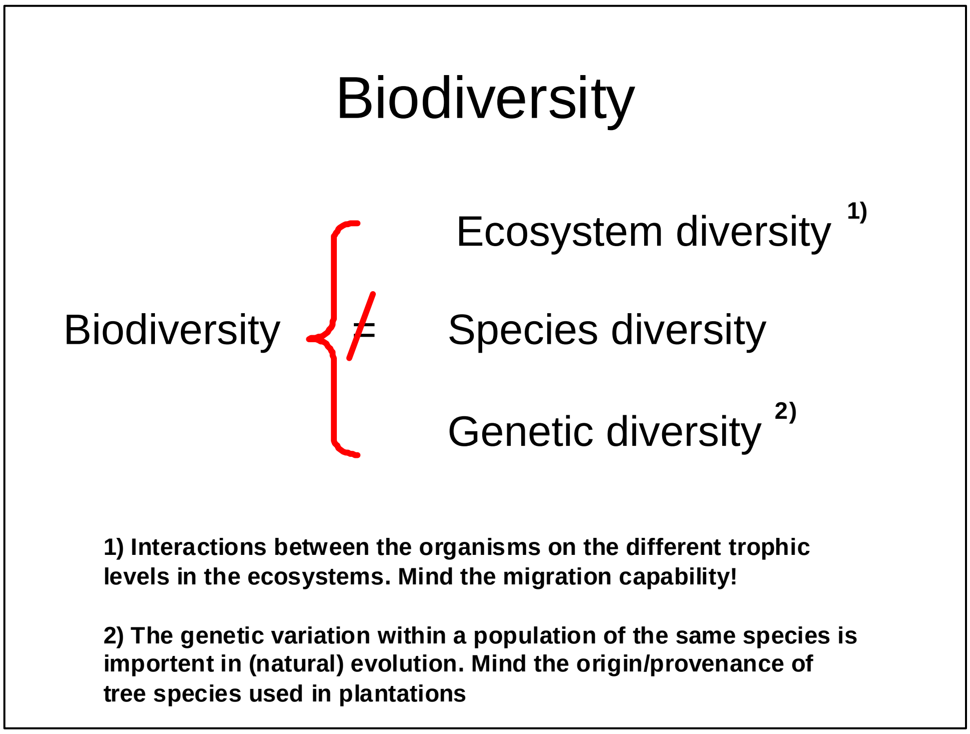
BIODIVERSITY



Response functions - Biodiversity

- Number of native tree species
- Amount of dead wood
- Species diversity
- Area of key habitats

To be able to evaluate the response of different management regimes on biodiversity a number of indicators must be combined. The optimal solution might be to combine factors which indicate occurrence of key-processes (e.g. ecological interactions, natural disturbances), variation in structures (e.g. abundance of dead wood, area of key-habitats) and/or a specific species composition (e.g. occurrence of red-listed species, species diversity). A large number of indicators have been suggested in the literature. However, the selection of indicators must also be cost efficient and practical. We suggest four different indicators. Number of native tree-species, amount of dead wood and area of key habitat will be negatively correlated with forest management intensity. Species diversity is positively correlated with number of tree species, amount of dead wood and area of key habitat.



Biodiversity

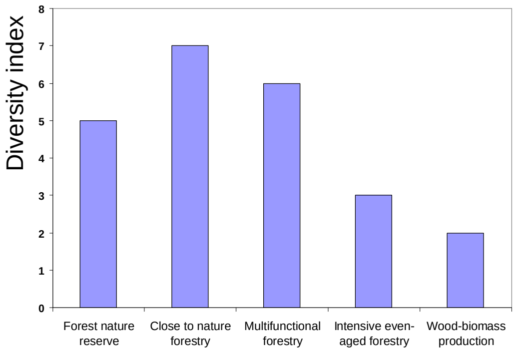
Biodiversity ≠

- Ecosystem diversity [1)]
- Species diversity
- Genetic diversity [2)]

1) Interactions between the organisms on the different trophic levels in the ecosystems. Mind the migration capability!

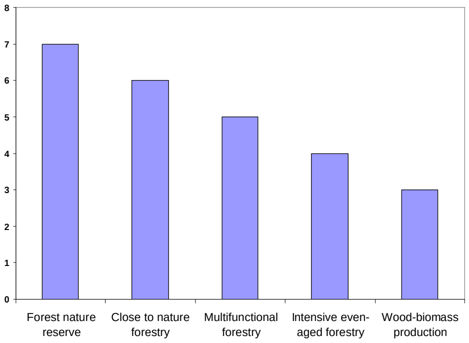
2) The genetic variation within a population of the same species is importent in (natural) evolution. Mind the origin/provenance of tree species used in plantations

Biodiversity is more or less related to several important ecosystem services and conservation of biodiversity is an important target. However, in practical conservation programmes it is not possible to work with biodiversity. Instead occurrence of specific species such as red-listed species or other key species is used as tools for conservation evaluation. Biodiversity is a broad concept not only including species number or occurrence of red-listed species, but also ecosystem diversity and genetic diversity.



Several measures of species diversity have been suggested – and are used in practise (Fischers a, Shannon-Wiener etc.,)

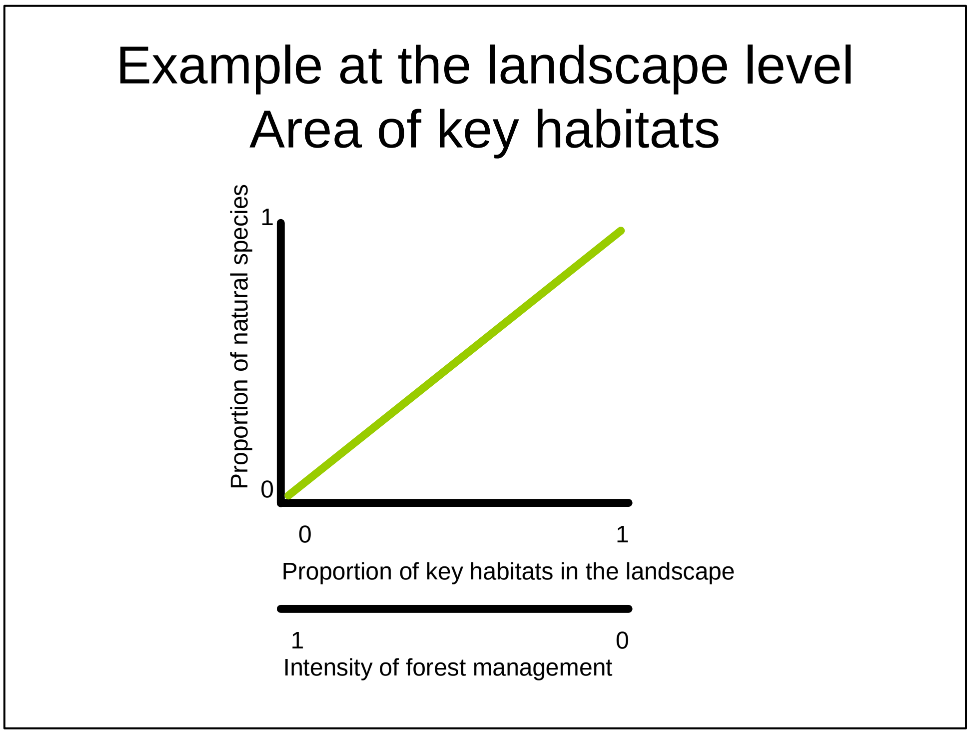
If you weight the occurence of a species by a ”quality” factor the picture may change:



The commonly used indices of diversity (e.g. Shannon-Wiener) treats all species equal. They do not distinguish between oportunistic and rare species. If you multiply the index-figure by the score from an ”rarity list” (e.g. very rare = 4, rare = 3, common = 2, very common = 1) the picture may change and better reflect the ”natural value” of the specific area or management type investigated.

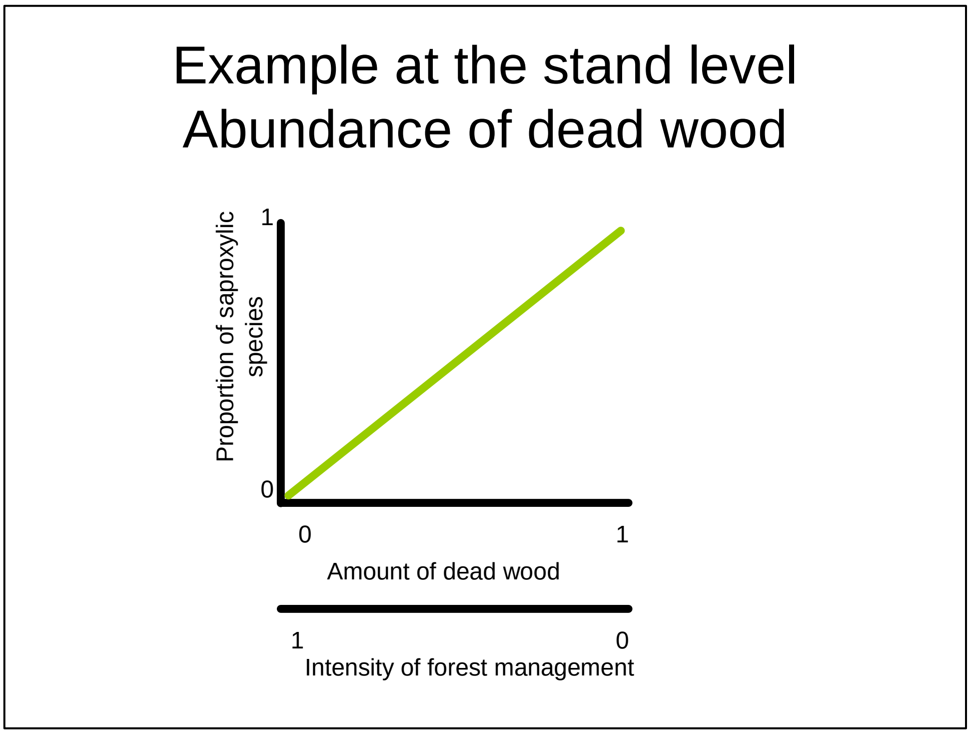
An example: In a disturbed area opportunistic species from adjacent areas may occur on the disturbed area because an empty space is created. This will increase the diversity index but lower the quality of the area if the intruding species is trivial and the vulnerable species is decimated.

However, be careful to use an objective quality factor – such as status on red list - in your manipulation.



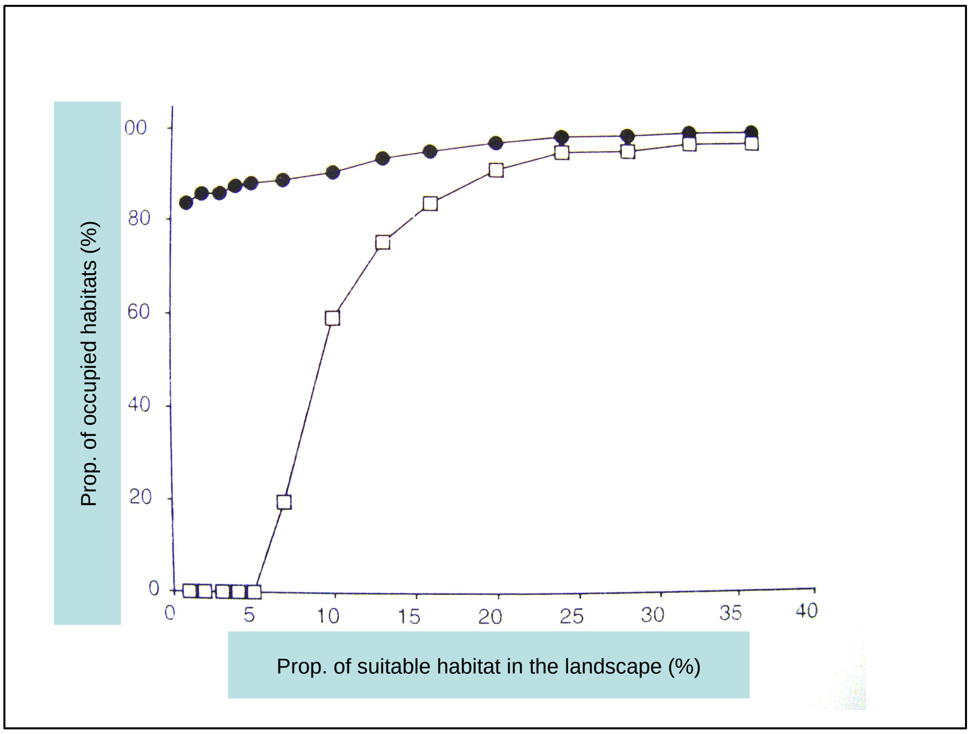
Example at the landscape level
Area of key habitats

Woodland key habitats are forest areas with no, or less intensive forest management where natural structures such as dead wood, big trees and unusual tree species occur. Instead of forestry the areas might be affected by natural disturbances. Species adapted to natural disturbances or dependent on specific structures have higher abundance in woodland key habitats, and the larger area of woodland key habitats the larger is the probability that these species will survive. Total area of woodland key habitat is therefore a good indicator of biodiversity. However, not only the total area but also the distribution of woodland key habitats and habitat types are important.



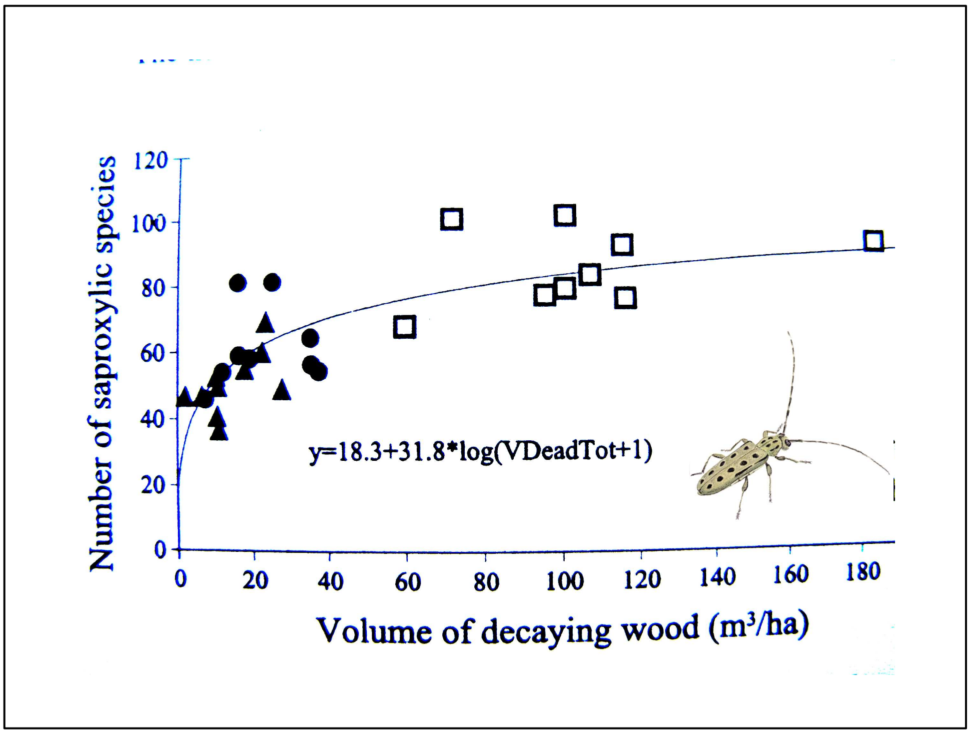
Example at the stand level
Abundance of dead wood

There are many studies showing a correlation between number of saproxylic species and abundance of dead wood, and in general there is also a negative correlation between forest management intensity and abundance of dead wood. Another factor which is important is the quality of dead wood.



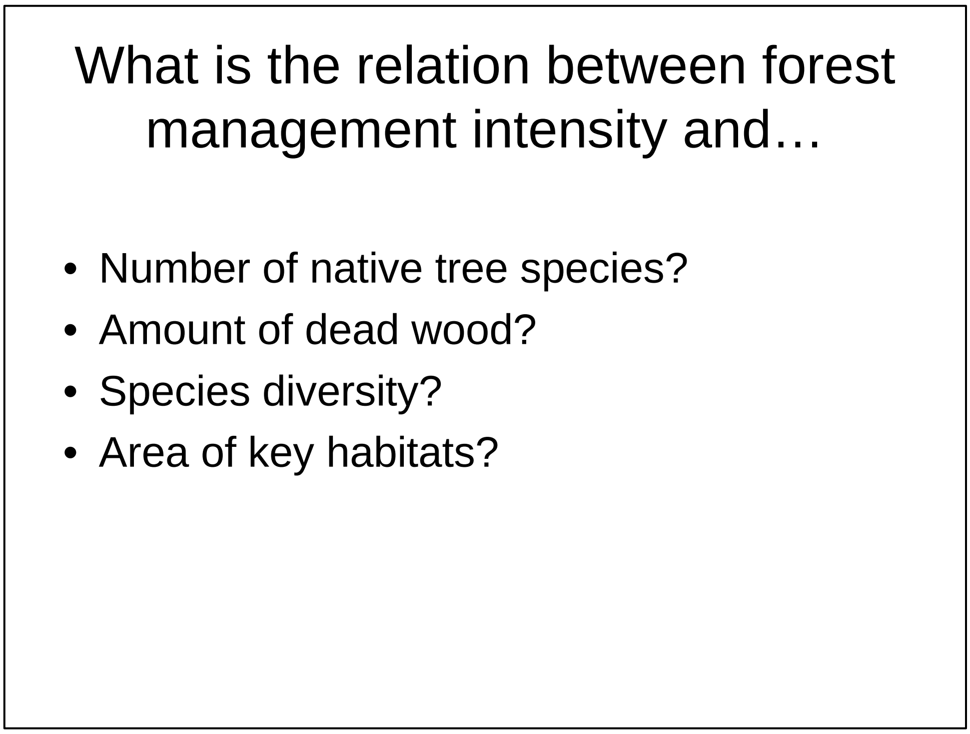
Area and distribution of suitable habitats are among the most important factor for biodiversity conservation. When the area of suitable habitats decreases landscape fragmentation increases, and some patches of suitable habitats become isolated from each other. This is a big problem for organisms with limited dispersal ability (illustrated with open squares in the figure above) and the probability that suitable patches are occupied decreases. However, organisms with good dispersal abilities (illustrated with filled circles) can persist as long as there are any suitable habitat. A landscape covered with forest is fragmented if high quality patches, such as woodland key habitats, are small and isolated from each other. The figure is based on Andrén (1996).

Andrén, H. 1996. Population response to habitat fragmentation: statistical power and the random sample hypothesis. Oikos 76: 235-242.



The number of saproxylic species of beetles is correlated with the volume of dead wood. Consequently dead wood is a good indicator of one part of the biodiversity. However, the relation is probably not linear. Above 20 m3 of dead wood/ha the increase in number of species seems to be lower. Based on Martikainen et al. 2000.

Martikainen, P., Siitonen, J., Punttila, P., Kaila, L. and Rauh, J. 2000. Species richness of coleoptera in mature managed and old-growth boreal forests in southern Finland. Biological Conservation 94: 199-209.



What is the relation between forest management intensity and…

- Number of native tree species?
- Amount of dead wood?
- Species diversity?
- Area of key habitats?

High variation of habitats, structures and processes in the landscape and in the stand in general means a higher number of available ecological niches, which means higher diversity of species and genotypes. In all kinds of silvi-culture it is important to create a more simple ecosystem to decrease competition between the target species and other species. In intensive forest management the goal is to focus on one, or just a few, tree species and dead wood are removed in order to create homogenous monocultures. Intensive forest management and biodiversity is only possible to combine on the landscape level. In landscapes with high abundance of dead wood, high number of native tree-species and large area of woodland key habitats the probability of species survival is higher. However, as we show in the figures on page 26 and 27 the relation between species occurrence and habitat area or substrate abundance is not always linear. Successful conservation is only possible if the abundance of an important structure or area of an important habitat is exceeding a certain threshold value. These values might vary in time and space.

Other possible response functions

- Continuity
- Structural complexity

There are a number of other possible response functions that are relevant for biodiversity. A long continuity of certain key resources in the stand or in the landscape definitely affect the probability of species survival. Some examples might be continuity of tree cover, large tree, dead wood etc. The structural complexity in general also affect the biodiversity. However, these factors are not so easy to measure or to put figures on.

WATER QUALITY

Forest management and water quality:

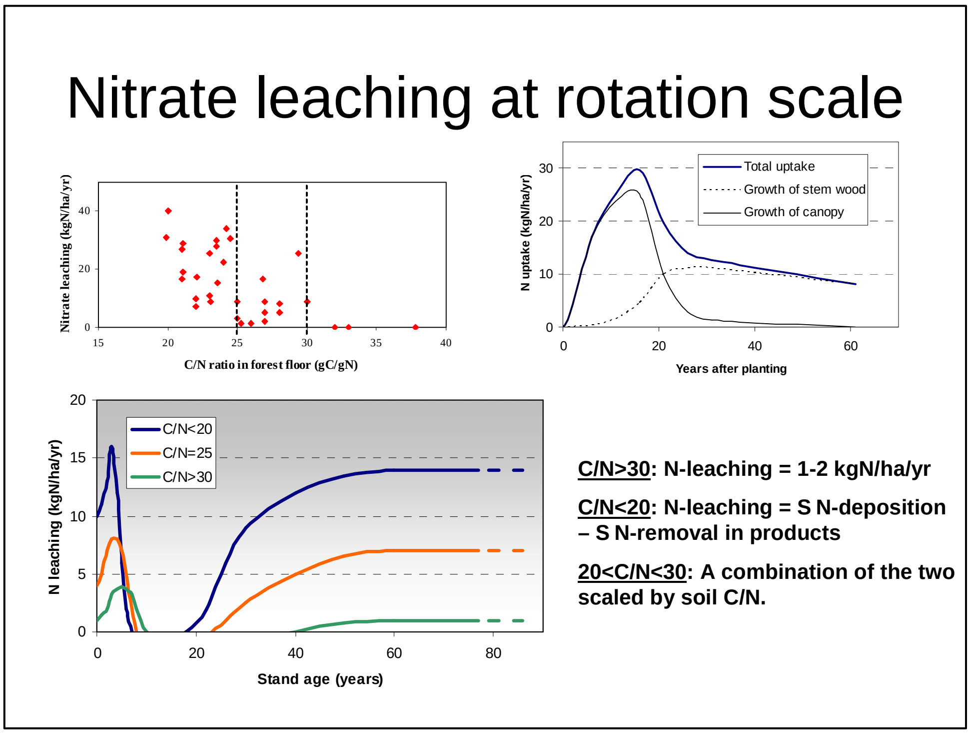
- NO_3^-, H^+, $Al_x(OH)_y^z$, DOC = f (deposition, harvesting export, soil, water surplus, soil preparation)

Water quality is an ambiguous concept. We therefore used a set of indicators of water quality that were previously identified (Raulund-Rasmussen et al., 2006) in the analysis. The identified indicators were pH, alkalinity, and the concentrations of nitrate, dissolved organic carbon (DOC) and dissolved aluminium.

Our main emphasis in the following is on nitrate leaching, (i) because most forest management operations will have an effect on N cycling, and (ii) because nitrate leaching is an acidifying process in it self and thus is important for the responses of the acidity and aluminium indicators. After the dramatic reduction in acidifying inputs from sulphur emissions, the anthropogenic contribution to acidification is dominated by ecosystem processing of N emission.

Negative effects on water quality related to acidity indicators may occur when the soil has reached the aluminium buffer range ($pH < 4.5$) and fluctuations in concentrations and loads may be strongly related to nitrate as the most dominant anion influenced by forest management activities.

The impact of forest management on DOC and suspended solids are mainly of local importance and no response functions have been identified yet.



Nitrate leaching at rotation scale

C/N>30: N-leaching = 1-2 kgN/ha/yr

C/N<20: N-leaching = S N-deposition – S N-removal in products

20<C/N<30: A combination of the two scaled by soil C/N.

The discussion of forest management impacts on N leaching often have focused on the peak in N leaching that occur after clear felling. The response is usually most pronounced at high N status but the duration is longer at low N status (first part of lower figure), both the extent of the peak and the duration is dependent on the reestablishment of the plant N sink. This peak in N leaching may have a short local impact on freshwater.

At the rotation scale as well as at the landscape scale (i.e. an groundwater reservoir) the impact of harvest is of minor importance, especially since the peak in N leaching is followed by period of high or complete N retention. In the period up to canopy closure the N cycle is dominated by a strong plant N sink, since the trees are building the N rich canopy components (twigs, foliage, bark) (upper right figure). Thus at the rotation scale (and landscape scale considering that stand ages are approximately equally distributed in a forest district) the N leaching impact is dominated by the conditions at the mature stage (lower figure). The N leaching in mature forests is in part determined by the soil C/N ratio i.e. the strength of the soil N sink (upper left figure, see also next slide).

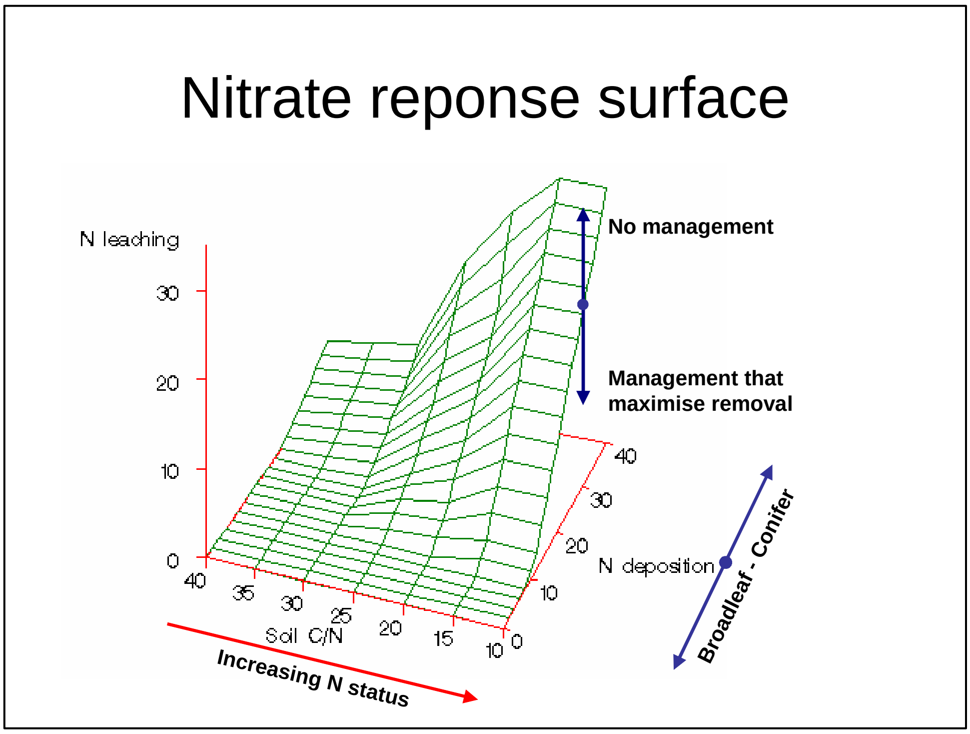
Based on these considerations N leaching over the rotation scale can be predicted as follows and illustrated in lower figure:

C/N>30: The soil N sink dominate the N cycle. N is effectively retained. However at high N deposition (>25 kgN/ha/yr) some leaching may occur as hydrologic driven leaching. N-leaching = 1-2 kgN/ha/yr

C/N<20: The N cycling is dominated by the plant N sink. The soil can no longer retain significant amounts of N. Thus over the rotation N-leaching approximates Σ N-deposition – Σ N-removal in products.

20<C/N<30: Here the soil N sink is less predictable (although it will still be related to and decreasing with soil C/N) and will depend on the level of N deposition as well (see next slide). A combination of the two above scaled by soil C/N can be used as a reasonable estimate. It would be better to use measurements such as simply a KCl-extraction of soil mineral N below the root zone to improve prediction.

Note: Soil C/N ratio when used in this way usually refer to the organic layer. This works well for soils with mor or moder humus types, but for mull type soils mineral soil C/N ratios (0-5 cm) need to be used.



Nitrate reponse surface

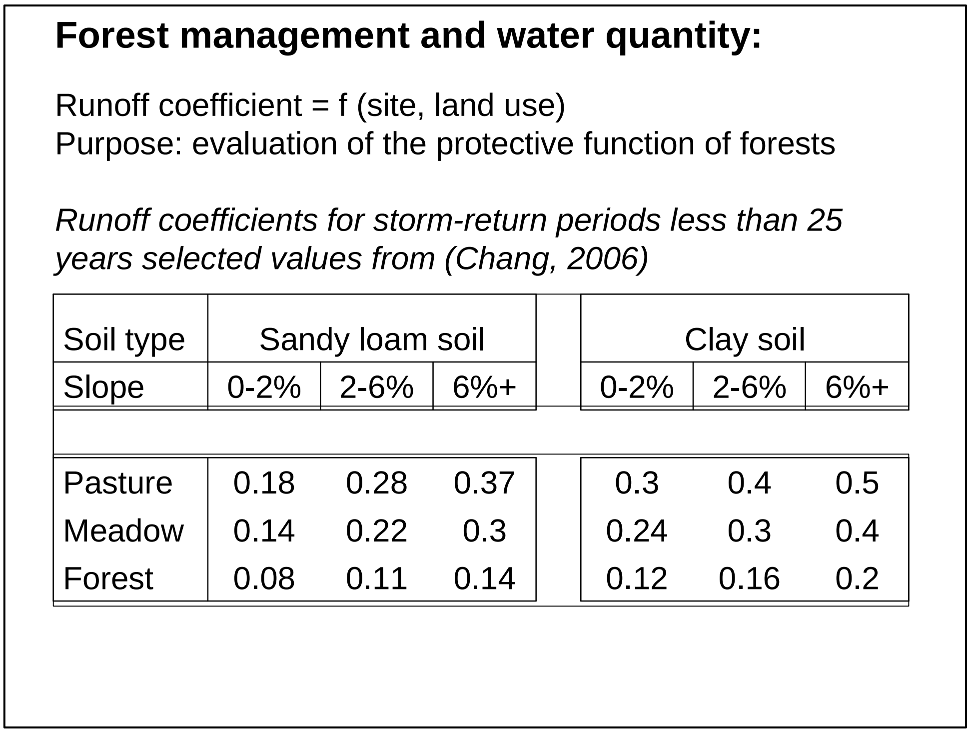
As a background for the evaluation of that impact on nitrate leaching caused by management activities, the role of air pollution and site conditions is summarised in the following (and illustrated as a response surface in the figure). There is a threshold at 10 kg N ha-1 yr-1 in throughfall input below which almost no nitrate is leached. Nitrogen deposition explains approximately half of the variability in N leaching. Part of the remaining variability could be explained as an effect of ecosystem ‘N status’, that may be described by interrelated variables like foliar N content, litterfall N flux, forest floor C:N ratio and mineralisation rate. For coniferous forests, needle N content above 1.4%, and/or forest floor C:N ratio lower than 25 were thresholds for elevated nitrate leaching (see also previous slide). There is some evidence that the threshold in C:N ratio may be more generally valid since mineralisation increase with decreasing C:N and nitrification does only occur in the forest floor at C:N ratios below 24-27 (Gundersen et al., 2006).

The main influence of management on nitrate response are exerted through:

A) **The tree species choice.** Tree species have different filtering capacity and conifers generally receive higher dry deposition than broadleaved species. This effect can probably be attributed to a leaf area (LAI, average over the year) effect and species specific effect on turbulence. These are to our knowledge not quantified currently. As a rough approximation the following can be used: Conifer dry deposition N = 2 x Broadleaf dry deposition N. Through tree species choice forest management thus can change N deposition to a forest area.

B) **The effect of N removal in products.** As discussed previously the soil N sink is negligible at low C/N ratio soils (>20) and increasing as C/N increases, thus at lower C/N ratios the size of the plant N sink gets important. For forests with no or minimal management (protected forest reserves) the response surface in the figure may be lifted (N leaching = N deposition, at low C/N), whereas increased N removal, e.g. by use of early thinnings and harvest residues for bioenergy, will reduce N leaching (lower the response surface in the figure).

WATER QUANTITY



Forest management and water quantity:

Runoff coefficient = f (site, land use)
Purpose: evaluation of the protective function of forests

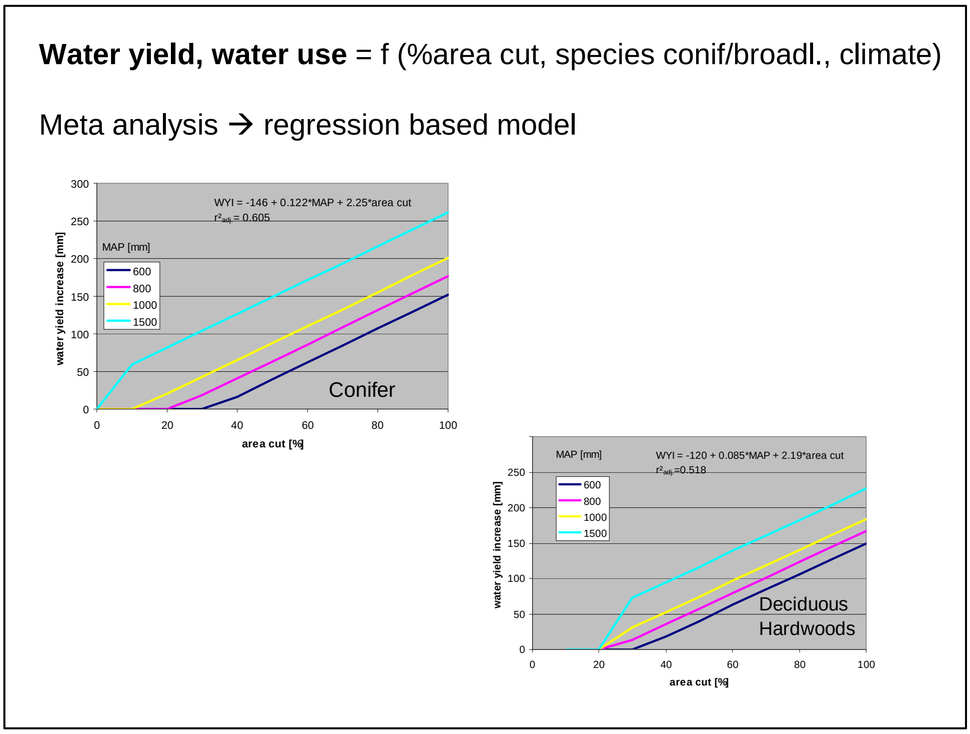
Runoff coefficients for storm-return periods less than 25 years selected values from (Chang, 2006)

Soil type	Sandy loam soil			Clay soil		
Slope	0-2%	2-6%	6%+	0-2%	2-6%	6%+
Pasture	0.18	0.28	0.37	0.3	0.4	0.5
Meadow	0.14	0.22	0.3	0.24	0.3	0.4
Forest	0.08	0.11	0.14	0.12	0.16	0.2

At the landscape scale differences in (sub-)surface runoff under different conditions may be predicted using runoff coefficients. Both simple site parameters (soil texture, slope etc.) and land use will have an impact upon this factor. The table shows, that forests will have a higher retention capacity than other land use types.

Based upon 700 rain simulation experiments, Markart et al. (2004) have derived a simple indicator system to prognose runoff coefficients under conditions of torrential rain based upon characteristics of site,soil and vegetation. It has not yet been tested whether such a system is sensitive enough to evaluate FMAs.

Markart G., B. Kohl, B. Sotier, T, Schauer, G. Bunza and R. Stern 2004:/A Simple Code of Practice for Assessment of Surface Runoff Coefficients for Alpine Soil-/Vegetation Units in Torrential Rain (Version 1.0)] (in German). BFW-Dokumentation; Schriftenreihe des Bundesamtes und Forschungszentrums für Wald, Wien Nr. 3/2004, 88 p.

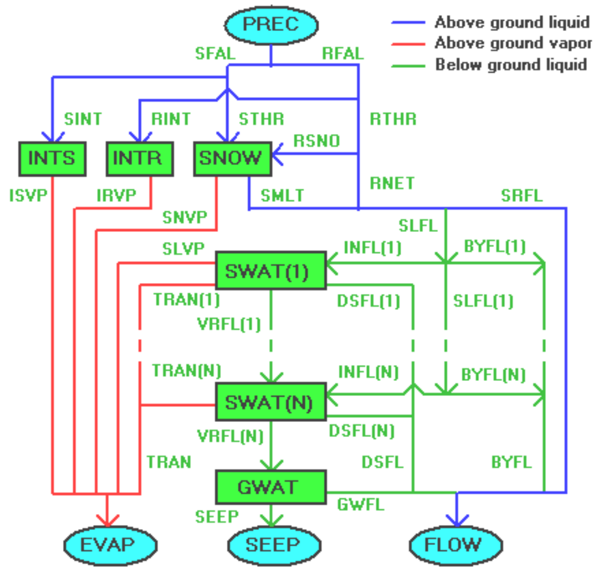


Water yield, water use = f (%area cut, species conif/broadl., climate)

Meta analysis → regression based model

The response of runoff or water yield to harvest (area cut) at a catchment scale can be expressed as a linear response function (see Katzensteiner et al., 2007, EFORWOOD D 2.2.2). The effect depends on annual precipitation and has been modeled on the basis of a meta-analysis of literature values for conifers and broadleafed trees separately. Assuming a normal forest model, the share of clearcut areas in different FMA's can be used to predict the indicators water yield or water use by the system.

Flowchart of BROOK90 (Federer, 1995)

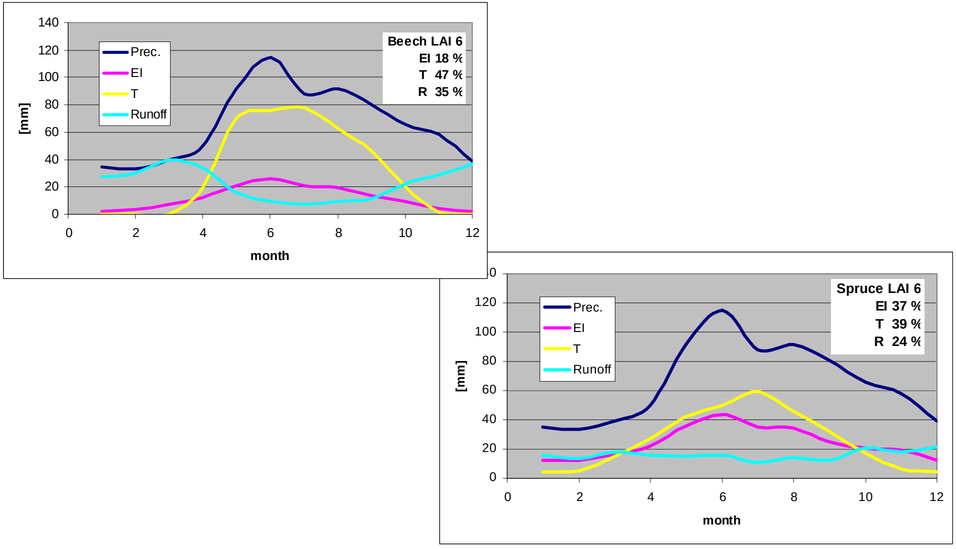


Complex, physically based hydrological models are a way to simulate all different terms of the waterbalance equation. These models are more demanding with respect to input parameters, but allow for scenario modelling under different FMA‘s and changing climatic conditions. The flowchart shows different components of the water cycle that can be modeled with the hydrological model BROOK90 (Federer 1995).

Federer, C.A. 1995. BROOK90:a simulation model for evaporation, soil water, and streamflow, . Version 3.1 Computer Freeware and documentation. USDA Forest Servics, PO Box 640, Durham NH, 03824.

Water use = f (tree species, LAI, site) → Hydrological models

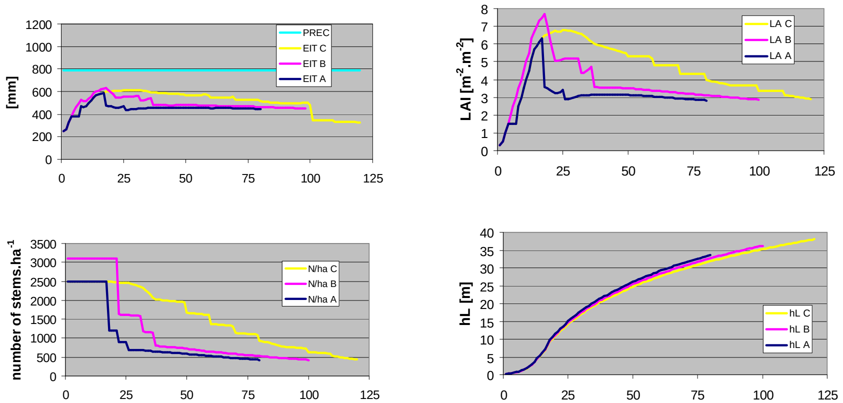
Example: Beech vs. spruce (same site conditions, similar LAI)



The example shows the different water use of spruce versus beech of similar leaf area index (LAI) under similar climatic conditions. Of the annual precipitation of 800 mm 76 percent is consumed by spruce, while beech consumes ten percent less.

Water use = f (tree species, LAI, site) → Hydrological models

Example: spruce, different rotation length (80, 100, 120 yr) & intensity of thinning



	Minimum			Average			Maximum		
Scenario	Precipitation	EIT	Water yield	Precipitation	EIT	Water yield	Precipitation	EIT	Water yield
Spruce A	587	386	153	787	453	335	1148	502	752
Spruce B		416	126		490	298		540	713
Spruce C		425	122		504	284		554	695
Beech		400	162		491	297		570	668

Both the effects of different management scenarios and wet versus dry weather conditions are shown in the example.

CONCLUSION

In this Catalogue we have gathered examples of response functions relevant for evaluation of forest management impacts on selected environmental goods and services (carbon, water, soil and biodiversity). It has not been the intention to make a complete list nor complete descriptions. In a forthcoming paper (working title: *Synergies and trade-offs between production, land expectation value and ecological services like water, carbon sequestration, biodiversity, and soil fertility in relation to forest management*) we will use several of the response functions on a virtual forest data set to illustrate use of response functions in order to quantify synergies and trade offs between the goods and services for sets of operational defined forest management alternatives.

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