EFORWOOD
Tools for Sustainability Impact Assessment

State of the art report on operational defined indicators to assess impacts of management on key EU forest environmental services

Karsten Raulund-Rasmussen, Klaus Katzensteiner, Emil Klimo, Denis Loustau, Per Gundersen, Jonathan Humphrey and Johnny de Jong

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Preface

This report is a deliverable from the EU FP6 Integrated Project EFORWOOD – Tools for Sustainability Impact Assessment of the Forestry-Wood Chain. The main objective of EFORWOOD was to develop a tool for Sustainability Impact Assessment (SIA) of Forestry-Wood Chains (FWC) at various scales of geographic area and time perspective. A FWC is determined by economic, ecological, technical, political and social factors, and consists of a number of interconnected processes, from forest regeneration to the end-of-life scenarios of wood-based products. EFORWOOD produced, as an output, a tool, which allows for analysis of sustainability impacts of existing and future FWCs.

The European Forest Institute (EFI) kindly offered the EFORWOOD project consortium to publish relevant deliverables from the project in EFI Technical Reports. The reports published here are project deliverables/results produced over time during the fifty-two months (2005–2010) project period. The reports have not always been subject to a thorough review process and many of them are in the process of, or will be reworked into journal articles, etc. for publication elsewhere. Some of them are just published as a “front-page”, the reason being that they might contain restricted information. In case you are interested in one of these reports you may contact the corresponding organisation highlighted on the cover page.

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EFORWOOD

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PD 2.2.1 STATE OF THE ART REPORT ON OPERATIONAL DEFINED INDICATORS TO ASSESS IMPACTS OF MANAGEMENT ON KEY EU FOREST ENVIRONMENTAL SERVICES

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Dissemination Level		
PU	Public	×
PP	Restricted to other programme participants (including the Commission Services)	
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)	

PD 2.2.1 State of the art report on operational defined indicators to assess impacts of management on key EU forest environmental services including carbon sequestration, protection of water quantity and quality, maintenance of soil fertility, biodiversity conservation.

Karsten Raulund-Rasmussen, Klaus Katzensteiner, Emil Klimo, Denis Loustau, Per Gundersen, Jonathan Humphrey, and Johnny de Jong

Abstract:
Criteria and indicators may be used on various levels. Here we suggest a list of indicators (9) and subindicators (37) selected primarily for use when evaluating the effect of local level forest management operations on four environmental services, i.e. carbon sequestration, water quantity and quality, soil quality and biodiversity. Each subindicator is in principle described to the operational level. Comments are given when necessary.

CONTENT

1 Introducing remarks

The indicators are selected primarily to be used to evaluate the impact of forest management on the following environmental services:

- carbon sequestration
- protection of water in quantity and quality
- conservation of biological diversity
- maintenance of soil quality

The indicators are selected so that they also allow assessment of the effects of forest management on adjacent ecosystems via processes in the system considered.

The operational indicators documented in this report come from the MCPFE list (2003)and other relevant sources, and will contribute to EFORWOOD whole forest-wood chain indicators (WCI) as described in draft set 3 (Rametsteiner, 2006) and to future indicators for SIA of forest management. (EFORWOOD Module 2 specific indicators (MSI).

The presented indicators will be used in the reviews on forest management effects on environmental services; the reviews of forest management effects will be based on existing research and written reports, and therefore data availability is not an issue in this context.

2 Carbon sequestration

Indicator	*subindicator*	*value/unit*	*Reference of indicator*	*comments*
carbon sequestration in the forest ecosystem				
	carbon in the above ground living tree compartment biomass	tons C pr ha	MCPFE (C.1.4) Eforwood WCI (16)	
	carbon in the root biomass	tons C pr ha	MCPFE (C.1.4) Eforwood WCI (16)	
	carbon in above ground living herb and bush compartment biomass	tons C pr ha	MCPFE (C.1.4) Eforwood WCI (16)	
	carbon in the forest floor	tons C pr ha	MCPFE (C.1.4) Eforwood WCI (16)	
	carbon in dead woody biomass	tons C pr ha	MCPFE (C.1.4) Eforwood WCI (16)	
	carbon in the mineral soil	tons C pr ha	MCPFE (C.1.4) Eforwood WCI (16)	
	carbon loss due to leaching of DOC	tons C pr ha		
	carbon loss due to loss of sediments	tons C pr ha		
Greenhouse gasses emissions				
	emission of methane	kg C or CO2 equivalent pr ha pr year	Eforwood WCI (22)	
	emission of nitrous oxide	kg N or CO2 equivalent pr ha pr year	Eforwood WCI (22)	

Comments

1. Carbon cycle in forest involves four main pools, the atmosphere, biomass, harvested products and soil. As far as we include the entire forestry - wood chain (FWC), the fossil fuel pool must be also included. The assessment of the greenhouse gases balance of the FWC must account for the changes in each of these pools caused by the process involved in the FWC, i.e. modules 2-4.

2. Two methods can be used for calculating the greenhouse gases balance, the flux method and the stock method. For convenience, practicability and consistency with IPCC, we adopt the stock change approach except for the fossil carbon, where only net flux can be quantified. The stock change approach requires to quantify the **net change in stock** between two dates. In the context of the EFORWOOD project, we propose to compare the steady state value of stocks at equilibrium for each FWC scenario with the present value observed in 2006 (or another reference year). It is further assumed that the time needed for reaching the equilibrium starting from the present situation equals one rotation.

3. Sequestration needs to be defined. We propose to define it as as a net change of carbon allocation from a rapid turnover pool into a slower turn over pool. For instance, carbon is sequestered when the distribution of the entire carbon of the FWC among pools (atmosphere, forest, soil, wood products, fossile fuel) is changed between time t1 and t2 towards lower turn-over or longer residence time pools. This definition allows for the substitution of fossile fuel used by wood products use (as energy, material, ..) to be accounted for.

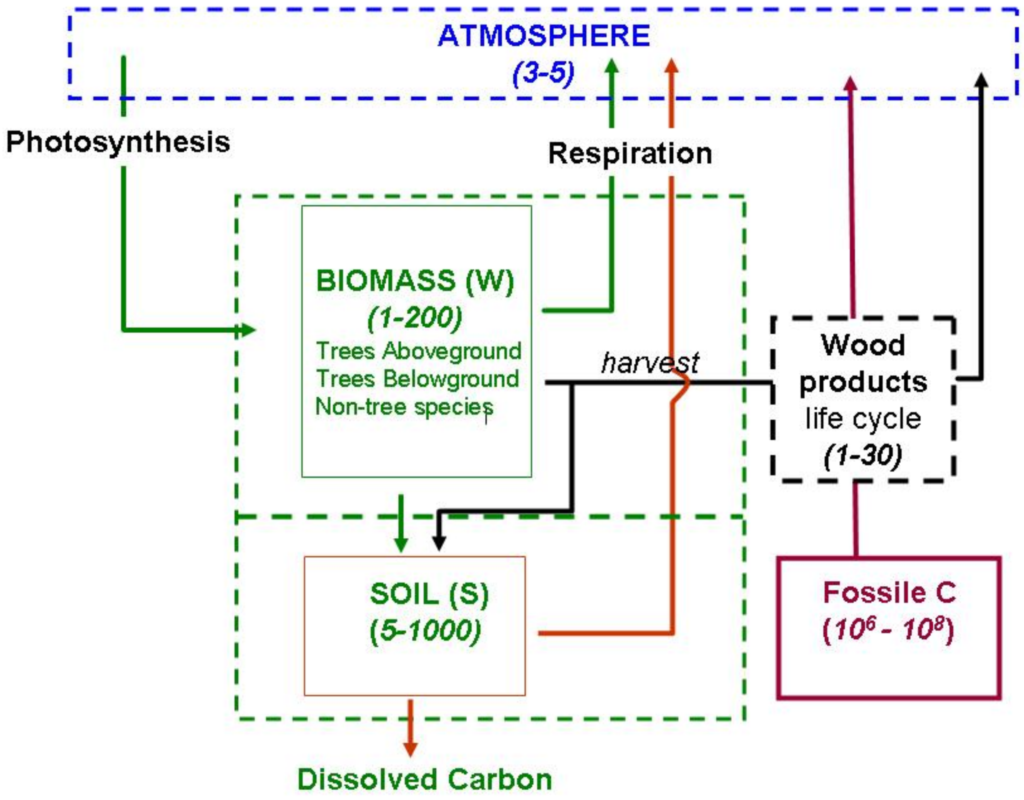

Figure 1. Sketch of the carbon cycle in the FWC. Numbers between parenthesis are approximate mean residence time of the carbon in the pool.

4. Carbon cycle changes dramatically over the course of a rotation and we recommend therefore to calculate indicator values for the soil and biomass stocks as their **average over an entire rotation** (the “steady state value” referred to above §2).

5. A set of operational indicators must be **exhaustive** of either flux or pools or both, cover the **full lifetime of the stand** (length of the rotation), and include indication on the **t.o. rate** of each pool.

3 Protection of water in quantity and quality

Indicator	sub indicator	value/unit	reference indicator	comments
Water budget (quantity)				
	evapotranspiration of the system	mm	Eforwood WCI (18)	The loss of water from a given area during a specified time by evaporation from the soil and plant surface and by transpiration from plants. Process models may be used for management scenarios under defined site conditions. Literature sources.
	runoff coefficient	no dimension	Eforwood WCI (18)	ratio of peak runoff (surface runoff + interflow) to precipitation (rainfall intensity) Empirical value. Literature source
	Groundwater recharge	[mm]	EFORWOOD WCI (18)	Output of process models. Validity of estimates dependent on site conditions. Estimates will be good for conditions where surface runoff can be neglected.
	Snow interception	[mm] water equivalent	EFORWOOD MSI	Amount of snow stored in the canopy. Important indicator with respect to avalanche formation. Literature sources.
Quality of the water leaving the system				
	concentration of nitrate	mg N / l	Eforwood MSI	relevant indicator when evaluating effect of f.m on adjacent ecosystems
	concentration of DOC	mg C / l	Eforwood MSI	- do -
	pH	pH	Eforwood MSI	- do -
	concentration of dissolved aluminium	mg Al / l	Eforwood MSI	- do -
	concentration of heavy metals	mg Me / l	Eforwood MSI	the heavy metals should be specified
	concentration of xenobiotics	mg XB / l	Eforwood MSI	the xenobiotic should be specified

The impact of forest management upon water budget of forest stands/watersheds will be evaluated based on the terms of the **water balance equation**.

Eq. 1: The water balance of a forest stand:

$$P_0 + GW + I_{lat} - (E_s + I + T_{veg} + R + S) = \Delta SW$$

P_0.............	precipitation	E_s...........	soil evaporation
GW..........	uptake from groundwater	I................	intercepted rain evaporation
I_{lat}.............	lateral influx	T_{veg}..........	transpiration
		R............	runoff
		S.............	deep seepage
		ΔSW.........	change of soil water storage

With respect to the service 'water yield', **water use by the ecosystem** (E_s+I+T = **evapotranspiration**) is a suitable indicator. Numerous process models of different complexity and hydrological field experiments are available to estimate this term.

Response of evapotranspiration to forest management: *Leaf area, surface properties and canopy architecture determine intercepted rain evaporation. In general coniferous forests show higher intercepted precipitation evaporation than broadleaved forests – even during the growing season. Forest management (choice of tree species, thinning operations, harvesting and regeneration) has direct impact on leaf area and canopy architecture and thus on the interception process. For transpiration besides leaf area, and canopy architecture the canopy conductance is an important factor. Canopy conductance and its response to climate stress vary considerably between tree species.*

As in mountain regions one of the most important environmental services is the protective function with respect to avalanches. Thus **snow interception** is considered as an indicator which is sensitive to forest management.

Response to forest management: *Snow interception depends on canopy structure and leaf area. In general dense coniferous forests provide high interception whereas broadleaves have only minor effects*

An important service of forests is the impact upon water pathways (runoff R versus deep seepage S (=**groundwater recharge**). To account for this fact and the fact that there is a close relation between surface runoff and erosion processes, in addition the parameter '**runoff coefficient**' will be included. Model predictions for this parameter are usually poor, as mechanisms controlling macropore flow in soils (root channels, wormholes etc.) are not yet fully understood. Empirical data are however available from the literature.

Response of groundwater recharge to forest management: *As groundwater recharge directly depends on precipitation and water use of the forest (surface runoff in many instances may only play a minor role), all management impacting evapotranspiration will have a direct effect on water surplus.*

Response of the runoff coefficient to forest management: *In general forests show small runoff coefficients compared to other land use types. While during rainfall with peak intensities canopy interception provides only a minor contribution to water retention, ground surface roughness and macropores cause a decrease and delay of runoff. Harvesting practices (and forest grazing) causing soil compaction will increase the runoff coefficient.*

Definitions: Definitions are adapted from textbooks (e.g. Dingman, 2002) and glossaries of hydrologic terms (e.g. USGS).

Precipitation: Any form of water, such as rain, snow, sleet, or hail that falls to the earth's surface.

Interception: The process and the amount of rain or snow stored in the plant canopy.

Evaporation: The physical process by which a liquid or solid substance is transformed to the gaseous state.

Transpiration: Process, in which water is absorbed by the root systems of a plant, moves up through the plant, passes through pores (stomata) in leaves, and then evaporates into the atmosphere as water vapour.

Evapotranspiration: The loss of water from a given area during a specified time by evaporation from the soil and plant surface and by transpiration from plants.

Runoff: Flow of water across the land surface as surface runoff or interflow.

Interflow: Lateral flow of water through the upper soil layers to a ditch, stream, etc.

Runoff Coefficient: Ratio of peak runoff (peak streamflow per unit area) to precipitation (rainfall intensity). The runoff coefficient is a function of infiltration rate, surface cover, and rainfall intensity. The coefficient is usually used for the rational method – a simple rainfall-runoff model. Empirical values are available from literature.

Quick flow (event flow, storm flow, direct flow): Water that enters streams promptly in response to individual water input events

Base Flow: the part of stream flow that is attributable to persistent, slowly varying sources (e.g. discharge of groundwater). This part of stream flow is not attributable to short-term surface runoff, precipitation, or snow melt events.

4 Maintenance of soil quality

Indicator	sub indicator	value/unit	Reference indicator	comments
Maintenance of the production capacity				
	available nutrient stock	kg nutrient per ha	MCPFE (C2.2) Eforwood WCI (21)	the indicators (one for each relevant nutrient / N, P, Ca, Mg and K etc.) are especially relevant for assessment of effects of very intensive harvesting on sensitive soils. Change in stocks may be modelled.
	soil compaction related to forest management	soil density, kg l^{-1}	Eforwood WCI (21)	
	C/N of forest floor		Specification of MCPFE 1.4 Eforwood WCI (21)	indicator on potential mineralization rate
	humus morphology	class variable to be defined	specification of MCPFE 1.4	indicator on potential mineralization rate
	forest floor pH	pH	specification of MCPFE 1.4 Eforwood WCI (21)	indicator on potential mineralization rate
Protective functions				
	soil erosion related to forest management (sediment transport)	tons/ha	Eforwood WCI (21)	
	soil acidity	pH in seepage water	Eforwood WCI (21)	

The nutrient balance is a very crucial factor for the long term productivity and change in nutrient stock can be one derived indicator. Several forest management operations have documented effects on the nutrient stock, e.g. leaching following clear cutting, very intensive harvesting, soil preparation, and choice of tree species. Changes in nutrient stock can be determined historically or retrospectively. Another way is the nutrient balance approach relying on estimates of all inputs to the system and all outputs from the system. Inputs are elements coming from out of the system sources like dissolved in precipitation, dust, fixation and fertilisation whereas output are leaching, harvesting and evaporation. For all elements except nitrogen important inputs also comes from chemical weathering of the soil minerals. In fact, fertile soils are fertile because the release elements in sufficient amounts to compensate the outputs. Modelling is often used as part of the nutrient balance approach.

Release of elements due to mineralization of organic matter is also a very important factor for the nutrient cycle. Therefore indicators like the C/N-ration of the forest floor, pH and forest floor morphology are included.

As a consequence of biological activity soils in the long term turn acid in humid climates. Forest management operations like harvesting and tree species accelerate the soil acidification.

5 Biodiversity

Indicator	sub indicator	value/unit	Reference indicator	comments
Dead wood (biomass) in the ecosystem				
	standing dead wood	m^3/ha	MCPFE 4.5 Eforwood WCI (16)	
	laying coarse woody debris	m^3/ha	MCPFE 4.5 Eforwood WCI (16)	
	laying fine woody debris	m^3/ha	MCPFE 4.5 Eforwood WCI (16)	
	thickness of forest floor	cm	MCPFE 4.5	
Presence of wetland				
	Part of area wetland	%	Eforwood MSI	
	Part of area open water	%	Eforwood MSI	
	Ditching	no/yes	Eforwood MSI	
Authenticity				
	Area of Old-growth forest	ha	MCPFE 4.3 Eforwood WCI (23)	
	Tree species composition	No. of species/ha	MCPFE 4.1 Eforwood MSI	
	Forest continuity	ha	MCPFE 5.1 Eforwood MSI	Long term continuity of natural disturbances or specific cultural disturbances. Continuity of tree cover, dead wood and/or big trees

We consider that deadwood is one of the best indicators of biodiversity as the relationship between deadwood volume and dependent flora and fauna is well known for most forest types (Humphrey et al. 2004). In addition data on deadwood are collected in most EU countries through National Forest Inventories. However, only a fraction of the potential deadwood measures can be included. We suggest that the focus should be on hard and thick (>10 cm diameter) deadwood as this gives the best indicator of change, as changes in value can be detected over relatively short time scales. The unit of measurement should be m^3/ha, which is the most common value used in studies of the relation between biodiversity or different species and abundance of dead wood.

Area of old growth forest is also recorded in NFIs. Old growth areas are of high value for biodiversity in the majority of European Forest Types (Larsson 2001). There are various definitions of old growth. Here we present two suggestions: 1. “Naturally regenerated forest

on unmanaged forest land or on old overgrown pastures. The forest has long continuity or consists of the first tree generation in a natural expansion area. The old-growth forest might have been affected by some cutting, but systematic forestry has never occurred. The area is not affected by fertilizing, drainage, soil scarification or similar activities." (Nordic council of ministers, Anon 1994). 2. "Old growth forest stands are stands in primary or secondary forests that have developed the structures and species normally associated with old primary forest of that type have sufficiently accumulated to act as a forest ecosystem distinct from any younger age class".
(Convention on Biodiversity http://www.biodiv.org/programmes/areas/forest/definitions.asp).

Number of tree species is a good indicator which is easy to measure. The diversity of tree species within a stand is closely related to biodiversity of other species groups. For example, Humphrey et al (2000) found a positive link in UK forests between fungal species-richness and the number of deciduous trees species.

Forest continuity (historical continuity) of habitat features and natural and cultural disturbances are closely related to biodiversity. Old-growth forests always have long continuity, but there are a number of other habitats which not can be defined as old-growth forests but have long continuity of tree-cover and important structures, and therefore are important for the biodiversity. Forest continuity is defined as forests with long continuity of tree-cover and important structures (dead-wood, old trees, big trees etc.), or with continuity of natural disturbances (fire, flooding etc), or specific cultural disturbances (pollarding, grazing etc).

Several others potential indicators were discussed, such as number of red-listed species, area of protected forest, presence of wetland area in the forest, authenticity or area of natural forests. Number of red-listed species is difficult to use because it is difficult to translate a specific number into a conservation value. A high number of red-listed species may indicate a very biodiversity-rich area but also an intensive forestry causing many threatened species. Another problem is that the number of specialised or rare species varies naturally among different forest types and in different areas of Europe. Area of protected forest does not tell us anything about the conservation value of the area, but of the political ambition, or maybe about the conservation strategy of the country. Instead of authenticity or natural forests we suggest area of old-growth forests, which we consider as a good indicator of biodiversity in the boreal region and in many other parts of Europe, especially mountainous areas. Presence of wet forest is probably a good indicator. However, if we include that habitat as an indicator, there are several other important forest habitats which also should be included. To make the list short and simple we suggest to instead include area of old-growth forest and area of forest with long continuity.

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