ALTERFOR

Milestone 9 - Quality standard to be met by the up-graded DSSs

Project Title	Alternatives models and robust decision-making for future forest management
Project Acronym	ALTERFOR
Project Coordinator	Ljusk Ola Eriksson, Swedish University of Agricultural Sciences (SLU)
Scientific Coordinator	Vilis Brukas, Swedish University of Agricultural Sciences (SLU)
Project Administrator	Giulia Attocchi, Swedish University of Agricultural Sciences (SLU)
Project Duration	1 April 2016 – 30 September 2020
Project Duration in months	54
Authors, organizations (short name)	Maarten Nieuwenhuis, UCD Eva-Maria Nordström, SLU
WP No., WPL(s)	WP3, Maarten Nieuwenhuis and Eva-Maria Nordström
Date of delivery by Coordinator	31 January 2017
Date of delivery according to DoA	31 January 2017
Reviewed by (see list of abbreviations used)	
PC, PCC, PA, MSG	
Type of Deliverable	
Report	X
Demonstration	
Websites, patents, fillings, etc.	
Dissemination level	
Public	
Confidential, only members of the consortium (including the Commission Services)	X
Other	

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Contents

Abbreviations used

DSS – Decision Support System
ES – Ecosystem Service(s)
FMM – Forest Management Model
LCC – Local Case study Coordinator
OT – Owner Type
WP – Work Package

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Summary

This document sets out the (minimum) standard for the DSSs used in the ALTERFOR project. The standard relates to the capabilities of the DSSs of incorporating the following aspects:

- Variable timber and biomass pricing
- Climate change impact modelling
- Forest owner behaviour modelling
- Spatial specificity
- Ecosystem services modelling

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

1. About the ALTERFOR quality standard for DSSs

The WP3 coordinators and ES experts have prepared this quality standard. It serves as a guideline for the LCC and DSS experts in their work within each case study. Other support to the LCCs and their teams is provided by specialists active in WP1 (FMM descriptions), WP2 (framework conditions or prospective scenarios), WP4 (support to management behavioural assumptions), and ES assessments. The focus of the quality standard is to specify minimum capabilities for the DSSs used in the ALTERFOR project. The LCCs and their teams will need to make sure the DSS used by them is capable of achieving the minimum standards specified. This may require modifications and enhancements of the existing DSSs to make them suitable for use in ALTERFOR. In cases where modifications to the DSS are needed but not practically feasible, the LCC will need to outline an alternative strategy that allows for the full and comprehensive analysis of the ALTERFOR scenarios. In the following sections, all the aspects of the DSSs are highlighted for which minimum standards have been drawn up.

2. Aspects of the quality standard for DSSs

2.1. Timber Pricing

In the WP2 scenarios, information for sawlog and pulpwood price development until the end of the century is provided on a 10-year interval. The DSS needs to be able to use this price information (and linear interpolation) in the simulation/optimisation of the choice of FMMs used by different owner types (OT) over the planning horizon. Price changes should therefore be reflected in the harvest levels of OTs who are sensitive to price. The most important aspect of the WP2 prices is their trend. It is important that this trend is properly reflected in the forecasts produced for each case study. On the other hand, it might be necessary to adjust the actual price level according to local knowledge.

It should be noted that the price information in the WP2 scenarios relates to factory-gate prices. If road site or standing timber prices (which are commonly used in forest DSSs) are used in the case studies, these prices need to be modified accordingly.

No prices for harvesting residues are provided in the WP2 scenarios. The LCCs and their teams need to decide on appropriate local prices for this product, taking into account the scenario descriptions and the price trends for sawlogs and pulpwood.

2.2. Climate change impact modelling

Ideally, the DSS should be capable of modelling climate change in terms of its impact on tree growth, tree mortality and tree species suitability. The most important of these three is tree growth, as it may have a significant effect on timber production and harvest levels. In intensively managed forest mortality will not have a major impact, while species suitability and selection, and their impact of ESs, can be modelled by running the DSS multiple times.

As the WP2 scenarios identify different levels of climate change, mainly in terms of temperature rises, the DSS should be capable of modelling the effect of these intensities of climate change on tree and stand growth, either through the use of process-based models or by using empirical models that reflect the changing growing conditions.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

For DSSs that need information on climate change factors other than temperature, WP2 has indicated that they can provide information on the following variables:

Readily available variables

- monthly absolute precipitation and temperature values (averaged over 30 years around years 2000 (average 1981-2010), 2020 (2006-2035), 2050 (2036-2065), and 2085 (2070-2099))
- change in monthly value (averaged at ten year resolution for precipitation (perc. change) and temperature (abs. change), interpolated from the averages over years 2000, 2020, 2050 and 2085)

Variables that can be delivered if needed, at lowest possible time-resolution (variable-specific)

- Surface air temperatures (Tavg, Tmin, Tmax)
- Precipitation, Surface radiation (short- and longwave downwelling)
- Near-surface wind speed (east- and north-ward)
- Near-surface wind speed (total)
- Surface air pressure
- Near-surface relative humidity
- CO_2 concentration

LCCs can contact the WP2 team to discuss climate change modelling requirements and available climate data more specifically.

In the Ecosystem Services section, the impact of climate change on the risks of disease and pest outbreaks and the changed probabilities for wind and fire damage are discussed in the Regulatory Services subsection.

2.3. Behaviour modelling

The basic approach in the ALTERFOR project to reflect different forest owner types (OTs) and their potential use of different forest management models (FMMs) is the OT-FMM matrix (Table 1). In this matrix, the proportions of the forest estate owned by different OTs are identified, and for each OT, the proportions of their forests that are managed using different FMMs are quantified. In order to reflect changing conditions over time, the values in this OT-FMM matrix should be dynamic, reflecting changes in OT proportions and in the FMMs that each OT uses. For instance, forests may be inherited by city dwellers from farmers, resulting in different OT proportions, as well as changed management objectives resulting in the use of different FMMs. At the same time, within (certain) OTs, the changing market conditions (reflected by demand and prices) and the changes in climate will result in changes in the (proportions of) FMMs used. Later on in the project, alternative FMMs will also be introduced and the design of the OT-FMM matrix will need to be flexible enough to accommodate these new FMMs.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 1: Example of an OT-FMM matrix

Owner type	Area administered by the owner type	FMMs				
		Final fellings	Final fellings + fertilization	Continuous cover forestry	Coppicing	No management
"Environmentalist"	1 500 ha	0%	0%	10%	0%	90%
"Economist"	20 000 ha	50%	10%	2%	33%	5%
"High yield"	10 000 ha	10%	70%	0%	10%	10%

2.4. Spatial specificity

There are three levels of spatial specificity:

1. Locations in the landscape where certain FMMs are not allowed (e.g. clearfelling) or are mandatory (e.g. buffer zones along streams). This allows for the amalgamation of stands into larger management units, but takes zoning into account.

2. Individual stands and their locations are distinct in the models. This would allow for the recording of the management history for each stand over the planning period, and the identification of the spatial distribution of FFMs in the landscape at any point during the planning horizon, facilitating the quantification of many ESs.

3. As for level 2, but including (neighbouring) stand interactions, such as the phasing of harvesting operations, or the need for certain minimum contiguous habitat areas.

The minimum standard for ALTERFOR is level 2 but exceptions from this may occur and need to be handled from case to case, e.g., by complementary analysis using GIS software.

2.5. Ecosystem services modelling

The ES experts have developed guidelines for the assessment of a range of ES, identifying minimum standards for all ESs. These guidelines are included in Appendices 1 to 5.

Cultural services	Appendix 1, pages 9 - 16
Regulatory services	Appendix 2, pages 17 - 20
Carbon sequestration	Appendix 3, pages 21 - 32
Water	Appendix 4, pages 33 - 42
Biodiversity	Appendix 5, pages 43 - 46

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 2 is a condensed summary of the ES guidelines that shows what variables the DSSs should be able to output for the ES assessment on landscape level. Timber and biomass is also included in this table, although there are no specific guidelines for these services.

2.6. Capacity for modelling alternative FMMs

A main aspect of the ALTERFOR project is the expectation that changing market and climate conditions may lead to the adoption of new and alternative FMMs in each of the case study areas, in order to improve the provision of ESs under those changing conditions. Therefore, the DSSs should be capable of incorporating new FMMs, including all required inputs such as growth and yield models and ES provision levels. In addition, the uptake of the alternative FMM by the different OTs should be known or estimated in order to add the new FMMs into the OT-FMM matrix.

3. Future steps

As stated in the introduction, this quality standard is formulated to set the minimum capabilities needed for the DSSs to fulfil the objectives stated in the ALTERFOR project plan. However, this level is ambitious for some aspects, which means that not all DSSs are currently equipped to cope with these requirements. In some cases, development may result in improved DSSs that can achieve the standard but, since ALTERFOR is not focused primarily on DSS development but on DSS use, sufficient development may not be possible within the context of the ALTERFOR project. In such cases other, alternative solutions will need to be considered, e.g. using other models outside the DSS.

This quality standard will be disseminated to the LCCs along with an invitation to discuss with WP3 leaders (and other relevant people) how a DSS may be improved to achieve the standard or how alternative solutions may be found in the cases where the necessary DSS development is not an option. Ultimately, the WP3 leaders will need to report on the achievement (or not) of this quality standard by the DSS used in each case study in the project.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 2: Summary of ES guidelines in terms of what variables the DSSs should be able to output for ES assessment

Descriptor	Unit	Comment	Timber and biomass	Cultural services	Regulatory services	Carbon sequestra-tion	Water	Biodiversity
Tree species composition	m3/ha (per period)	Per species		x	x		x	x
Tree size diversity	m3/size class (per period)	Suggestion for size classes (diameter in cm): 1-10, 11–20, 21–30, 31-40, 41-50, 51-60, >61		x	x			x
Standing volume	m3/ha and kt/ha (per period)		x			x	x	x
Basal area	m2/ha (per period)				x			
Tree height	m (per period)	Dominant height			x			
Age	year (per period)	Mean stand age		x	x		x	
Density/openness	stems/ha or basal area (m2/ha) (per period)	Mean for stand		x	x			
Large trees	m3/ha (per period)	Per species, suggestion for size classes (diameter in cm): >30 cm, >40cm, >50cm, >60cm						x
Dead wood, logs	m3/ha and kt C/ha (per period)	Per species		x		x		x
Dead wood, stumps and roots	kt C/ha (per period)					x		
Large dead wood	st/ha (per period)	Per species, suggestion for size classes (diameter in cm): >30 cm, >40cm, >50cm, >60cm						x
Spatial fragmentation	index value per habitat or forest type (per period)	Aggregation indices are available in GIS, but this should be harmonized between LCCs			x			x
Naturalness	Hemeroby index (per period)	Hemeroby index: 0 = natural, non-disturbed forest, 0.33 = close to natural, 0.66 = semi-natural, 1 = relatively far from natural (monocultures, planta-tions)		x				
Forest edges	length of edge relative to the landscape area (per period)			x	x			
Diversity of forest stand types	no. of different stand types in the land-scape or Shannon's landscape diversi-ty/evenness index (per period)	How are stand types defined?		x				
Stand size variation	largest patch index (per period)			x				
Understory	0 (=no)/1 (=yes) or biomass (per period)			x	x			
Heterogeneity	heterogeneity index, i.e., distribution of forest stand types (per period)			x				
Final felling area	ha (per period)	For uneven-aged forests: size of contiguous harvest-ed areas. For shelterwood: two figures regarding harvested area / time period are given		x			x	x
Protected area	ha (per period)	Area as per IUCN category						x
Afforestation	age of forest cover (per period)	Concerns afforestation of non-forest land, not regeneration after final felling		x				
Residues harvested	m3 or kg/ha, and area where residues are harvested (per period)	In final felling (and thinning if possible/applicable, but these should be separated)	x	x		x		
Below ground biomass	kt C/ha (per period)					x		
Harvested wood, total	m3/ha (per period)		x			x	x	x
Volume harvested by assortments (sawlogs, pulpwood)	m3/ha and kt C/ha (per period)		x			x		
Fertilization (nitrogen and/or phosphorus)	kg/ha and area fertilized (per period)						x	

Appendix 1. Guidelines for cultural services

DRAFT 6.0

Marjanke A. Hoogstra-Klein, Geerten Hengeveld

Forest and Nature Conservation Policy group, Wageningen University, the Netherlands

1. Background

The group of Cultural Services (CS) is one of the four categories of Ecosystem Services (ES) as defined in the Millennium Ecosystem Assessment (MA) report 2005, and is defined as "*the non-material benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation and aesthetic experiences*" (MA, 2005, p.29). The key-challenge of this text is to discuss how to convert a range of biophysical measures of forests and/or forested landscapes (with potentially diverse units of measurements), as determined by the management applied to it, into a score representing the CS provided by that forest and/or forested landscape. This is not an easy task. Despite the fact that CS are consistently recognized as important, at the same time they face the problem of being characterized as "intangible", "subjective", and "difficult to quantify", either in biophysical or monetary terms (Daniel et al., 2012). This is often seen as the main reason why CS – with the exception of recreation and tourism – are often not considered in ecosystem services assessments (Feld et al., 2009; Plieninger et al., 2013).

2. Cultural Services – delineation and definitions

Different subdivisions of CS exist. De Groot et al. in the MA report (2005), for example, distinguish 6 categories of CS: (1) cultural heritage and identity, (2) heritage values, (3) spiritual services, (4) inspiration, (5) aesthetic appreciation of natural and cultivated landscapes, and (6) recreation and tourism. In this document, the focus will be on the last two categories: aesthetic appreciation (or aesthetic beauty or scenic beauty) and recreation and tourism.

Analyzing the two categories, we concluded, like many other studies did, that the two are much intertwined. Many studies show that a higher aesthetic value (or scenic beauty) also affects the recreational value. In several studies (e.g. Edwards et al., 2012a), therefore, aesthetic value and recreational value are considered to be the same. Edwards et al. (2009, p. 54) argue that "*the majority of the people would prefer to visit forests with higher aesthetic value, and hence visit those sites more frequently, regardless of the particular recreational activity being pursued*". This is also the reason why Edwards et al. (2011, p. 84) conclude that "*the visual quality of a stand can act as a proxy for preferences for all major types of recreational use*". Although not all scholars agree with this interpretation (see e.g. Tahvainen et al. (2001)), we will also follow this approach.

3. Underlying assumptions

To set up the assessment framework for the aesthetic/recreational function, we had to make several decisions:

1) The focus is on the **visual characteristics** of landscapes, as other aspects of landscape experience, such as sounds and smells, etc., could not be included in the framework (Tveit et al., 2006).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

2) These visual characterists are based on **forest characteristics or forest attributes** that *"could be measured in any forest stand regardless of management regime (including unmanaged forest nature reserves)"* (Edwards et al., 2012a, p. 14). By focusing on the attributes and not on silvicultural interventions (such as thinning or harvesting) too, one can prevent overlap. As an example: the attribute "variation in tree size" implicitly relates to different silvicultural regimes[1]. This fits the focus of ALTERFOR, namely comparing different forest management models over time, hence silvicultural regimes.
3) These forest characteristics/attributes can relate to **both stand level and landscape** level. Despite that many studies have focused on preference modeling of forest *stands*, weighted for the total forest area (e.g. Pukkala et al., 1988; 1995; Silvennoinen et al., 2001; Blasco et al., 2009), many scholars are of the opinion that the single stand is only part of the scenic beauty experience. Gundersen and Frivold (2008, p. 249) formulated this as follows: "*the total preference for this experience* [preference] *is more than the sum of single stand preferences*".
4) Despite different cultures, same frame for Europe (*to be explained*)

To structure the frame, we make use of the four levels of abstraction as identified by Tveit et al. (2006): concept – dimension – attribute – indicator. Concept relates to the most abstract level of the four, and functions as an umbrella term under which different dimensions can be distinguished. These dimensions, in turn, describe different aspects of the concept (still on an abstract level), and are determined by attributes of the forests. The indicators are the most concrete level, respresenting the level at which the forest attributes can be counted and/or measured in order to determine and compare scores (Tveit et al., 2006).

4. Value of aesthetic/recreational function

For our framework, we make use of the studies of Tveit et al. (2006) and Ode et al. (2008), which are elaborate studies on the scenic quality of landscapes. We added the insights from the landscape and forestry literature on scenic beauty, specifically the work of Edwards et al. (2012a) and Giergiczny et al. (2015). Only those aspects that seem to fit (most of) the different DSSs used in the ALTERFOR project are represented in tables below. Different options for the indicators (from simple to more intricate) are presented for some of the attributes in order to make good use of the capabilities of each DSS, but at the same time offering an option for every DSS to measure the attribute. Table 1 offers those indicators to be measured on stand level. These indicators will in turn be weighted to landscape level and, together with the landscape level indicators (table 2), will form the basis of analysis of the landscape level.

[1] In another article, Edwards et al. (2012b) linked several attributes to forest management alternatives on a continuum of management regimes, and determined the recreation (i.e. aesthetic) value of that forest management alternative

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 1: Concepts, dimensions, attributes, and indicators to determine the aesthetic/recreational value on stand level

CONCEPTS	DIMENSIONS	ATTRIBUTE	INDICATOR	OUTPUT
Stewardship	Sense of care/upkeep	Amount of residue from harvesting and thinning per ha	• Absent (0), medium (0.5), high (1) or • Kg's/ha or • M3/ha	• Mean value over time • Minimum value over time • Maximum value over time
Naturalness/ disturbances	Alteration/impact	Area of final felling	Size of final felling in ha (0 if no clear cut takes place)	• Mean value over time • Minimum value over time • Maximum value over time
		Frequency of final felling	Number of years	
	Natural value	Naturalness of forest stands	Hemeroby index (0 = natural, non-disturbed forest, 0.33 = close to natural, 0.66 = semi-natural, 1 = relatively far from natural (monoculture, plantations)	• Mean value over time • Minimum value over time • Maximum value over time
	Wildernis	Amount of natural dead wood	• Absent (0), medium (0.5), high (1) or • Kg's/ha or • M3/ha	• Mean value over time • Minimum value over time • Maximum value over time
	Intrusion	Naturalness of forest edges/edge effects	Straight edges (0), combination of straight and non-linear edges (0.33), induced, but non-linear borders (0.66), inherent, natural borders (1)	• Mean value over time • Minimum value over time • Maximum value over time
Complexity	Diversity	Tree species diversity within stand	• One (0), two (0.33), three (0.66), more than three (1) or • Number of tree species in stand or • Shannon Diversity Index or • Shannon Evenness Index	• Mean value over time • Minimum value over time • Maximum value over time

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

CONCEPTS	DIMENSIONS	ATTRIBUTE	INDICATOR	OUTPUT
	Variety	Variation in tree size within stand/Age structure	• Even-aged (0), two-aged (0.5), uneven-aged (1) or • Coefficient of variation of dbh (or height or volume) of trees	• Mean value over time • Minimum value over time • Maximum value over time
	Spatial pattern	Variation in tree spacing within stand	• Regular (0), quasi regular (0.5), irregular (1) or • Clark and Evans index = the nearest neighbour index	• Mean value over time • Minimum value over time • Maximum value over time
Visual scale	Openness	Visual penetration/density of obstruction	• Number of trees per ha or • Basal area	• Mean value over time • Minimum value over time • Maximum value over time
	Visibility	Presence of understory in stand	• Present (0), not present (1) or • High (0), medium (0.5), absent (1) Or • Shrub biomass	• Mean value over time • Minimum value over time • Maximum value over time
Historicity/ imagenability	Historical richness	Age of trees in stand	• Stand age in years	• Mean value over time • Minimum value over time • Maximum value over time
	Historical continuity/place identity	Age of current land-use	Area afforested in recent decades (< x years) (0), area afforestated between x years and z years (0.5), area with forest > z years (1)	• Mean value over time • Minimum value over time • Maximum value over time
Ephemera	Seasonal change	Presence of broadleaves	• Coniferous (0), mixed (0.5), broadleaved (1) or • Percentage of broadleaves in forest stand	• Mean value over time • Minimum value over time • Maximum value over time

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Table 2: Concepts, dimensions, attributes, and indicators to determine the aesthetic/recreational value on landscape level

CONCEPTS	DIMENSIONS	ATTRIBUTE	INDICATOR	OUTPUT
Stewardship	Sense of care/upkeep	Area with residue from harvesting and thinning	Percentage of total forest landscape with thinning and/or clear-felling activities where residues have been left	• Mean value over time • Minimum value over time • Maximum value over time
Naturalness/ disturbances	Alteration/ impact	Area visually impacted by clear cuts	Percentage of total forest landscape impacted by clear cuts	• Mean value over time • Minimum value over time • Maximum value over time
	Natural value	Naturalness	Percentage of total area that is natural or close to natural according to the Hemeroby index	• Mean value over time • Minimum value over time • Maximum value over time
	Wilderness	Presence of dead wood	Percentage of total forest landscape with dead wood	• Mean value over time • Minimum value over time • Maximum value over time
	Intrusion	Presence of edges in forests	Edge density (amount of edge relative to the landscape)	• Mean value over time • Minimum value over time • Maximum value over time
Complexity	Diversity	Diversity of forest stands	• Stand richness density (number of different forest stand types in total forest landscape) or • Shannon's landscape diversity index or • Shannon's landscape evenness index	• Mean value over time • Minimum value over time • Maximum value over time

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Concepts	Dimensions	Attribute	Indicator	Output
	Variety	Size variation	• Largest patch index (percent of total forest landscape occupied by largest forest stand)	• Mean value over time • Minimum value over time • Maximum value over time
	Spatial pattern	Heterogeneity	Heterogeneity index (Hix) (distribution of forest stand types)	• Mean value over time • Minimum value over time • Maximum value over time
Visual scale	Openness	Visual penetration/ density of obstructing	Percentage of total forest landscape with forest stands with a density > r or a basal area > s	• Mean value over time • Minimum value over time • Maximum value over time
	Visibility	Understory in forest landscape	Percentage of total forest landscape with forest stands without understory	• Mean value over time • Minimum value over time • Maximum value over time
Historicity/ imageability	Historical richness	Presence of older forests	Percentage of total forest landscape with forests older than *x* years	• Mean value over time • Minimum value over time • Maximum value over time
	Historical continuity/place identity	Age of current land-use	Percentage of total forest landscape being afforested more than *z* years ago	• Mean value over time • Minimum value over time • Maximum value over time
Ephemera	Seasonal change	Presence of broadleaves	Percentage of total area with broadleaf stands and mixed forests	• Mean value over time • Minimum value over time • Maximum value over time

References

Blasco, E., Gonzalez-Olabarria, J. R., Rodriguez-Veiga, P., Pukkala, T., Kolehmainen, O., & Palahí, M. (2009). Predicting scenic beauty of forest stands in Catalonia (North-east Spain). Journal of Forestry Research, 20(1), 73-78.

Daniel, T. C., Muhar, A., Arnberger, A., Aznar, O., Boyd, J. W., Chan, K. M., ... & Grêt-Regamey, A. (2012). Contributions of cultural services to the ecosystem services agenda. Proceedings of the National Academy of Sciences, 109(23), 8812-8819.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Edwards, D., Jay, M., Jensen, F., Lucas, B., Marzano, M., Montagne, C., ... & Weiss, G. (2009). Public preferences for silvicultural attributes of European forests. Project EFORWOOD, Deliverable D, 2.

Edwards, D., Jensen, F. S., Marzano, M., Mason, B., Pizzirani, S., & Schelhaas, M. J. (2011). A theoretical framework to assess the impacts of forest management on the recreational value of European forests. Ecological Indicators, 11(1), 81-89.

Edwards, D., Jay, M., Jensen, F. S., Lucas, B., Marzano, M., Montagné, C., ... & Weiss, G. (2012a). Public preferences for structural attributes of forests: Towards a pan-European perspective. Forest Policy and Economics, 19, 12-19.

Edwards, D. M., Jay, M., Jensen, F. S., Lucas, B., Marzano, M., Montagné, C., ... & Weiss, G. (2012). Public preferences across Europe for different forest stand types as sites for recreation. Ecology and Society, 17(1), 27.

Feld, C. K., Martins da Silva, P., Paulo Sousa, J., De Bello, F., Bugter, R., Grandin, U., ... & Pärtel, M. (2009). Indicators of biodiversity and ecosystem services: a synthesis across ecosystems and spatial scales. Oikos, 118(12), 1862-1871.

Giergiczny, M., Czajkowski, M., Żylicz, T., & Angelstam, P. (2015). Choice experiment assessment of public preferences for forest structural attributes. Ecological Economics, 119, 8-23.

Gundersen, V. S., & Frivold, L. H. (2008). Public preferences for forest structures: a review of quantitative surveys from Finland, Norway and Sweden. Urban Forestry & Urban Greening, 7(4), 241-258.

Millennium Assessment (2005). Millennium Ecosystem Assessment. Washington, DC: New Island.

Ode, Å., Tveit, M. S., & Fry, G. (2008). Capturing landscape visual character using indicators: touching base with landscape aesthetic theory. Landscape research, 33(1), 89-117.

Plieninger, T., Dijks, S., Oteros-Rozas, E., & Bieling, C. (2013). Assessing, mapping, and quantifying cultural ecosystem services at community level. Land use policy, 33, 118-129.

Pukkala, T., Kellomäki, S., & Mustonen, E. (1988). Prediction of the amenity of a tree stand. Scandinavian Journal of Forest Research, 3(1-4), 533-544.

Pukkala, T., Nuutinen, T., & Kangas, J. (1995). Integrating scenic and recreational amenities into numerical forest planning. Landscape and urban planning, 32(3), 185-195.

Silvennoinen, H., Alho, J., Kolehmainen, O., & Pukkala, T. (2001). Prediction models of landscape preferences at the forest stand level. Landscape and Urban Planning, 56(1), 11-20.

Tahvanainen, L., Tyrväinen, L., Ihalainen, M., Vuorela, N., & Kolehmainen, O. (2001). Forest management and public perceptions—visual versus verbal information. Landscape and urban planning, 53(1), 53-70.

Tveit, M., Ode, Å., & Fry, G. (2006). Key concepts in a framework for analysing visual landscape character. Landscape research, 31(3), 229-255.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Appendix 2. Guidelines for regulatory services

José G. Borges

Professor at the School of Agriculture, University of Lisbon

Assessment of the contribution of FMMs to mitigate impacts of catastrophic events. Providing regulatory services in ALTERFOR

Objective:

To provide guidelines for the selection of stand and landscape level indicators to assess the contribution of FMMs to mitigate impacts of catastrophic events.

Context:

Our recent survey underlined the importance of a range of events - wildfire, windstorms, pests, snowstorms and droughts – in the ALTERFOR CSA. It highlighted further that the assessment of the contribution of each FMM to the mitigation of impacts of catastrophic events must take into account the distribution of the inventory over the CSA over the planning horizon that results from its application. This information will be influential to define effective regulatory frameworks.

The literature underlines the local specificity of models to assess the contribution of FMMs to mitigate impacts of catastrophic events. For example, this was demonstrated by research that analyzed the correlation of inventory variables over which forest managers have control (through FMMs) and a) the likelihood of occurrence of wildfires (e.g. Garcia-Gonzalo et al. 2013, Botequim et al. 2013), b) the damage caused by wildfires (e.g. Gonzalez et al. 2007, Marques et al. 2011) and c) the damage caused by windstorms (Zeng et al. 2010).

All 10 LCC reported the availability of inventory data and the possibility of using it to assess the impact of plot/stand-level FMM on the likelihood of the occurrence of catastrophic events as well as on the damage caused by them. Although the (possibility of) classification of the forested landscape into homogeneous stand-polygons is available only in 8 out of 10 CSA, all 10 LCC reported the possibility of generating landscape metrics to assess the contribution of landscape-level FMM to the mitigation of impacts of catastrophic events. Nevertheless, in concordance to the information reported in the literature, all 10 LCC reported either a) the need to consult local/national experts to both select from the inventory dataset the indicators to measure that impact and select adequate landscape metrics, or else b) the motivation to use local models for that purpose.

The proposal of research to be conducted a) builds from the survey, b) acknowledges the specificity of each CSA and c) outlines the research to be conducted to help derive information (vulnerability class / indicator) that hopefully may contribute 1) to standardize the assessment of the contribution of each FMM to the mitigation of impacts of catastrophic events, 2) to design the provision of regulatory services and 3) to facilitate the comparison across CSA and the upscaling efforts. Nevertheless, this is a tentative proposal that may benefit from local/national expertise from the CSA to be adapted further to the specificity of the LC.

Research to be conducted:

Stand-level

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

a. If no models are available to correlate inventory data with the vulnerability to a catastrophic event: consult local/national experts and for each CSA relevant catastrophic event:
    i. Select biometric **indicators** out of the CSA inventory dataset
        1. Potential biometric indicators and corresponding **metrics** based on a review of the literature:
            a. Basal area (m^2/ha)
            b. Number of trees (n/ha).
            c. Quadratic mean diameter (cm)
            d. Dominant height (m)
            e. Understory biomass (Mg/ha)
            f. Age (years) in the case of even-aged stands
            g. Distribution of tree sizes (% of Vol/ha of each size class)
            h. Species composition (% of Vol of each species/ha)
    ii. **Output.** Define (discrete) vulnerability classes, 1 to 5, with 5 corresponding to the highest vulnerability, based on specific intervals of values of relevant biometric indicators for that CSA relevant catastrophic event. These classes will be used to assess the impact of stand-level FMMs on the vulnerability of the CSA landscape unit (e.g. stand, stand-type, strata,…) to that catastrophic event over the planning horizon.

b. Else
    i. **Output.** Use the models to compute (continuous) vulnerability indicators based on the inventory data. These indicators, will be used to assess the impact of stand-level FMMs on the vulnerability of the CSA landscape unit (e.g. stand, stand-type, strata,…) to that catastrophic event over the planning horizon. For comparison purposes LCC should check with local/national experts how to translate the (continuous) vulnerability indicators based on the inventory data into discrete) vulnerability classes, 1 to 5, with 5 corresponding to the highest vulnerability.

Landscape-level

c. If no spatial indicators may be computed, for each CSA catastrophic event
    i. **Output.** Use either the distribution of area per vulnerability classes (1.b) or the distribution of area per vulnerability **indicator** (2.a) to estimate the landscape weighted average vulnerability. The latter will be used as indicator to assess the impact of landscape-level FMMs on the vulnerability of the landscape to that catastrophic event over the planning horizon.

d. Else if spatial indicators may be computed but models are not available to correlate spatial/topological data with the vulnerability to a catastrophic event:
    i. **Output.** Use approach (3.a)
    or
    ii. Consult local/national experts and for each CSA relevant catastrophic event select spatial **indicators** from the CSA database. Potential spatial indicators and corresponding **metrics** based on a review of the literature:
            a. Edge between openings and forest stands (Km)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

b. Patch size (aggregation of stands with the same inventory) (Ha)
c. Patch configuration $(2\sqrt{\pi}\,\sqrt{Area})/\sqrt{Perimeter})$

Output. Define (discrete) vulnerability classes, 1 to 5, with 5 corresponding to the highest vulnerability, based on specific intervals of values of each spatial indicator for that CSA relevant catastrophic event. These classes will be used – in conjunction with the vulnerability of the CSA landscape unit (e.g. stand, stand-type, strata,…) - to assess the impact of landscape-level FMMs on the vulnerability of the CSA landscape to that catastrophic event over the planning horizon

e. Else if spatial indicators may be computed and models are available to correlate spatial/topological data with the vulnerability to a catastrophic event
   i. **Output.** Use the models to compute (continuous) vulnerability indicators based on both the inventory and the spatial/topological data. These indicators, will be used to assess the impact of landscape-level FMMs on the vulnerability of the CSA landscape to that catastrophic event over the planning horizon. For comparison purposes CSA should check with local/national experts how to translate the (continuous) vulnerability indicators based on the inventory data and the spatial/topological data into discrete) vulnerability classes, 1 to 5, with 5 corresponding to the highest vulnerability.

Final remarks: 1) the value of a biometric variable evolves over the temporal horizon (e.g. rotation, cycle) associated to the development a stand-level prescription within a FMM. Thus the value of a regulatory services stand-level indicator will evolve over the same period. 2) The value of a regulatory services landscape-level indicator will evolve thus also over the planning horizon.

Literature cited

BOTEQUIM, B., J. GARCIA-GONZALO, S. MARQUES, A. RICARDO, J. G. BORGES, M. TOMÉ, AND M. M. OLIVEIRA 2013. Developing wildfire risk probability models for Eucalyptus globulus stands in Portugal*. iForest - Biogeosciences and Forestry* 6:217-227

GARCIA-GONZALO J., ZUBIZARRETA-GERENDIAIN A., RICARDO A., MARQUES S., BOTEQUIM B., BORGES J. G., OLIVEIRA M. M. , TOMÉ M. AND PEREIRA, J.M.C. 2012 Modelling wildfire risk in pure and mixed forest stands in Portugal. *Allgemeine Forst und Jagdzeitung (AFJZ) – German Journal of Forest Research* 183 (11/12): 238-248

GONZÁLEZ J.R., TRASOBARES A., PALAHÍ M., PUKKALA T., 2007. Predicting tree survival in burned forests in Catalonia (North-East Spain) for strategic forest planning. *Annals of Forest Science* 64, 733-742

MARQUES, S., J. GARCIA-GONZALO, J. G. BORGES, B. BOTEQUIM, M. M. OLIVEIRA, J. TOMÉ AND M. TOMÉ. 2011. Developing post-fire *Eucalyptus globulus* Labill stand damage and tree mortality models for enhanced forest planning in Portugal. *Silva Fennica* 45: 69-83

ZENG H., GARCÍA-GONZALO J., PELTOLA H., KELLOMÄKI S., 2010. The effects of forest structure on the risk of wind damage at a landscape level in a boreal forest ecosystem. *Annals of Forest Science* 67(1):

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

ALTERFOR

Appendix 3. Guidelines for carbon sequestration

Kevin Black (PhD Ecology, MSc GIS and Remote sensing)
Forestry Division
Director FERS Ltd
mob: +353 86 333 6475
www.fers.ie

Contents

Introduction

Following the meeting in Zvolan it was agreed to limit the scope of the C sequestration DSS used by LCCs to only include the following pools:

- Above and below ground biomass
- Deadwood
- Harvested wood product

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Development of harmonised models for litter and soils would not be possible unless one modelling approach is adopted. In addition, the contribution of these pools to overall C sequestration is relatively small.

Following a review of individual LCCs capacity to develop such a DSS, it is evident that most groups can deliver a biomass estimate. Development of capacity to estimate deadwood and HWP would be possible based on guidance provided by the ES expert. This document outlines a proposed approach for deadwood and HWP estimations and guidelines on how biomass pools (but no guidance for coppices) can be estimated if LCCs do not have sufficient capacity.

Biomass (AB and BG)

Most groups have capacity to estimate this pool. The following basic approaches are applied:

- Select basic approach i.e. gains and losses versus stock change (see section 2 of IPCC guidelines http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf). For modelling purposes the gains loss approach is easier. To determine this one would need
  - Biomass growth (above and below ground, G_{gain})
  - Losses (G_{loss}) due to:
    - harvest ($L_{harvest}$)
    - mortality ($L_{mortality}$)
  - Transfer of C from biomass to harvest or deadwood pools.

    $$\Delta CGw = G_{gain} - G_{loss} \quad (1)$$

    where G_{gian} G_{loss} are biomass gains and losses (t C/ha/yr)

Biomass gains

- Estimate aboveground biomass (AB) growth based on:
- Biomass expansion factors (**BEF_I**)[2] using volume increment per ha per yr (IV) and biomass C expansion factor for increment (BEF_I):

  $$AB = I\,V \times BCEF_I \quad (2)$$

  If a group does not have their own BEF_I value use aboveground C stock BEFs (BEFt), wood density (D) or carbon fraction (CF) values for specific species then IPCC default values can be used (see Table 4.5 in the link http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf)

  or
- Use of biomass algorithms based on mean tree DBH and or height

  or
- Use of stand biomass volume curves to convert standing or cumulative volume to aboveground biomass
- Below ground biomass (BG) using:

[2] **Please note** different BEFs are used depending if a stock change (biomass stock) or gains loss approach (biomass increment) is adopted (section 2.2 in http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_02_Ch2_Generic.pdf and http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf) Use BEFI for increment

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

- Total biomass (Gw) and root ratios (R):

$$Gw = IV \times BCEF_I \times (1 + R) \quad 3$$

$$BG = Gw - AG \quad 4$$

If data are not available, use the default R values provided by the IPCC see Table 4.5 in the link http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf)

- Biomass algorithms or relationships between aboveground and below ground biomass

Biomass losses

- Harvest losses ($L_{harvest,}$ tC per ha per yr)can be derived from volumes removed during thinning or clearfell operations (H, m^3 per ha per yr) based on:
- $L_{harvest} = H \times BCEF_S \times (1 + R) \times CF$ 5a

  where CF is a carbon fraction (use 0.5 as default if no specific values are available) or
- Biomass algorithms or relationships between timber volume and total biomass. For Ireland we use a algometric equation

(if no $BCEF_S$ values are available use Volumes BEF_t and D values, see Table 4.5 http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf).

If volumes removed are under bark values apply and expansion factor of 1.15 to get volumes over bark.

Note: These C pools need to be reallocated to harvested wood product and deadwood pools. To do this one can assume that stump and root biomass and harvest residue is transferred to the deadwood pool (see $DW_{inflows}$).

- Mortality losses ($L_{mortality}$, tC per ha per yr); This is not always evidently available in stand based modelling processes but all volume increment curves underlie some morality function. This can be expressed as a percentage of standing stock or volume on an annual bases (Mvol):
- $L_{mortality} = Mvol \times BCEF_S \times (1 + R) \times CF$ 5b
- Biomass algorithms can also be used directly to calculate mortality losses based on annual mortality rates, DBH, tree number etc.

  Note that some of this pool is also re-allocated to the deadwood pool by assuming that all dead timber, roots and stumps are transferred to the $DW_{inflows}$.

Deadwood

The following section attempts to provide the simplest but relatively accurate model for all LCC to model deadwood stocks and stock changes. LCC should use their own model if they have capacity to use more complex model which better reflect the FMM used.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Model description

Deadwood C stocks (DW) comprise of dead logs and roots (including stumps) categories which accumulate and decompose at different rates (Default uses 2 categories) over time. This uses the same concept at eh IPCC harvested wood product estimation but there are some modifications to specifically address deadwood dynamics.

- Deadwood (DW) categories (*j*) be estimated using a C flow model:

$$DW_{ij+1} = e^{-k} \times DW_{ij} + \left[\frac{(1-e^{-k})}{k}\right] \times Inflow_{ij} \quad 6$$

$$\Delta DW_{ij} = DW_{ij+1} - DW_i \quad 7$$

Where:

i = year

j = DW category default (logs and roots (including stump))

DW_{ij} = the carbon stock in the particular DW category (root, logs, stumps) at the beginning of year *i*, kt C. This is equivalent to the deadwood stock, which is useful for biodiversity DSS.

k = decay constant of first-order decay for DW category given in units yr^{-1} (*k* = ln(2)/HL, where HL is half-life of the log or roots (including stumps) in the DW pool in years (see below). Different half-lives can be applied by LCC depending on specific case studies and FMMs. There are 2 categories as default but LCCs can use more than 2 categories if inflows and half-life information for those categories are available.

$Inflow_{ij}$ = the inflow to the particular DW category during year *i*, kt C yr^{-1}

ΔDW_{ij} = carbon stock change of the DW category during year *i*, kt C yr^{-1}

The model described by eq 6 does not include fragmentation processes resulting in an overestimation of the DW pool and underestimation of DW losses (Bond-Lamberty and Gower, 2008). These authors suggest a four pool model for each category to include fragmentation constants. This may be too complicated to adopt across the whole project. However, comparison of one pool (eq6) versus four pool models suggest that fragmentation can account for an addition loss of 10 to 30% of the CDW pool per year. This fraction is transferred to litter soil processed, which are not included in out model framework. However, a correction to the one pool model is required by applying a fragmentation loss fraction (FF, default of 0.85, i.e. 15% per year) to the DW_{ij} value in eq6, which can be rewritten as

$$DW_{ij+1} = e^{-k} \times [DW_{ij} \times \mathrm{FF}] + \left[\frac{(1-e^{-k})}{k}\right] \times [Inflow_{ij} \times FF] \quad 6a$$

Half-lives, decay and fragmentation constants

Default half-lives of 12 years for logs, 19 years for all roots and 14 for stumps can be applied (Olajuyigbe et al, 2011). The default half-life for logs is similar to values reported for other studies for Norway spruce (Lundmark et al, 2006, Yatskov et al. 2003). The half-life for a range of broadleaf species in New Zealand varies from 13 to 47 years (Beets et al., 2008), so longer half-lives may be needed for broadleaf species.

A weighted mean half-life for combined stumps and roots can be applied assuming a stump ratio of 0.3 (i.e. stump represent 30% of the total root and stump mass, Olajuyigbe et al, 2011). Roots in this case are all roots greater than 10cm diameter. This equates to a half-life of 17.5 years. These decay constants roots agree with those published for a range of conifer species in Canada (Chen et al., 2001) and Europe (Lundmark et al., 2016), but LCCs are encouraged to use their own constants if available.

Consideration of adjustment of these half-lives can be considered if we want to model climate change effects on decomposition. Site mean annual temperature is known to influence DW decay rates. Global data sets suggest a normalised respiration rate at 10 degC (Q10) of 2.53 (Mackensen et al., 2003), or 2.4 (Chambers et al., 2000), so it may be appropriate to apply this to case studies where temperatures significantly different from those used in here where mean temperature are 10 degrees C or for the IIASA climate change scenarios. This could be achieved by multiplying the decay constant by $Q_{10}^{(T-T^*)/10}$, where T is the MAT of the site and T* is the MAT of the sites. In the default example presented by Olajuyibge, 2011, T* =10C).

Inflows

- DW Inflows (*Inflows*, tC per ha per hr)) is assumed to come from harvest residue log (HR_{logs}), mortality log inputs (M_{logs})

$$Inflow = HR_{logs} + M_{logs} \quad 8$$

- $HR_{logs} = (H \times D \times CF) \times HF$ 9

where H and CF are derived as specified in eq 5, D is the specific density (t/m3) (for default values see Table 4.5 in IPCC guidelines http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/4_Volume4/V4_04_Ch4_Forest_Land.pdf), CF is a C fraction use 0.5 as default and HF is the harvest fraction left on site.

- HF can be user defined or a default estimate can be provided using the following function based on mean tree volume (MTV, m3):
  - $F = [(4 - (3.8 \times \ln MTV)) \times 0.9] \div 100,$ 10

Then if F<3 then HF=F else HF=0.03

(Eq 8 is derived from commercially harvested forests in Ireland, case study specific functions can be developed).

- $M_{log} = Mvol \times D \times CF$ 11

- DW inflows for roots ($Inflow_{roots}$) is derived from inputs of roots and stumps from harvest residue (HR_{roots}) and mortality (M_{roots}) can be estimated as:
  - $HR_{root} = H \times BCEF_s \times R \times CF$ 12
  - $M_{root} = Mvol \times BCEFs \times R \times CF$ 13

The R values used in this equation are the same used for below ground biomass.

DW

The model is recursive so requires an initial C stock (DW_{ij}).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

- If the FMM is initiated from year one on previously un-forested land, then it is plausible to assume that DW_i is zero. However, a complication arises on older and successive rotation forests where the initial stock would be large. Exclusion of this initial stock in the calculation (eq 6) would lead to overestimation of the stock change and hence sequestration potential on the DW pool.
- For reforested FMMs (forest re-established on forest land) the DW_i can be estimated based on either:
  - the mean stock for each DW category (logs and roots) and for the particular FMM based on national forest inventory statistics or
  - A mean or look up DW_i value over 3 successive rotations for that particular FMM (see example spreadsheet provided)
- If a FMM is initiated during a second or later rotation the DWi can be derived from an age class lookup table (see example spreadsheet, DWi look up).

Validation of DW model

It would be advisable for LCCs to validate the DW model for each FMM by comparing forest inventory data of published DW C stocks to model outputs (see blue box (columns Z:AF) in example spreadsheet). If the model does not fit the outputs for FMM the half-life and fragmentation assumptions can be altered or parameters can be resolved using case study specific information.

Harvested wood products

Harvested wood product sequestration can occur in two ways:

- Storage in HWP carbon stocks; This is based on the storage of C in wood products coming from harvest.
- The substitution approach is based on life cycle analysis and it recognises the added potential of energy substitution of energy demanding products such as steel or cement or fossil fuel energy production. Regardless of the approach adopted, the DSS would require a base line against which addition substitution can be measured (Oliver et al. 2014).

It is recommended that the HWP modelling framework should be done using at least 3 ES specific scenarios:

- **Business as usual (BAU):** Since HWP removals of CO_2 need to be additional a BAU HWP sequestration baseline is required for each FMM. This should be based on the current wood utilisation of product from the FMM output in the study case area. The HWP calculator provided (see attachments) can facilitate the allocation of harvest into HWP categories in order to estimate long term HWP sequestration.
- **High fuelwood demand scenario:** This in essence is the IIASA climate change scenario, where all non sawnwood assortments (and sawnwood in some FMMs) are allocated to energy production and fossil fuel replacement. It is documented that this type of scenario will represent a low product substitution scenario because of the lower CO_2 saving substitution value for fuel replacement by wood biomass (Oliver et al. 2014). In the case of the Italian

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

LCCs, the FMMs assume all wood is allocated for fuel use, so this is also the baseline scenario.

- **High substitution value scenario:** in this case some sawnwood is allocated to substitute energy intensive products such as cement, steel and construction. This is determined by the suitability of the product to be used for these types of products. For example, low grade and strength timber would not be suitable for such applications, but some FMMs can produce timber for such product substitutions. A solution id to assign a percentage of the sawnwood assortments to this category case by case basis using LCCs expertize with assistance from stakeholders.

Substitution concepts

Life cycle analysis of wood products provides a way of measuring the CO_2 savings that can be made by use of wood products and replacement of high CO_2 emission potential products such as energy, cement etc. (Oliver, 2014). The overall concept is avoidance of emissions by replacement of process or products using wood as a substitution (Stare and O Connor, 2010). The common approach is the use of displacement factors to estimate emissions saving due to product substitution above a BAU scenario.

A displacement factor (DF) is an index of the efficiency with which the use of biomass reduces net GHG emissions. It measures the emission reduction per unit of wood used, ranging from -2.3 to 15 tC/t C of wood, with typical values 1-3tC per tC wood used for replacement. The DFs are based on all manufacture, transport and processing emission and removal over an entire life cycle, but this is usually 100-300 years. The system boundary for most reported DFs include all processes from energy for production of material, process emissions, biomass residues for energy, end-of-life management, but exclude HWP stocks and C dynamics in forests (Stare and O Connor, 2010; Smyth et al. 2016, Oliver et al. 2016, Lundmark et al., 2014)). A database of DFs and long term C storage potentials of wood products will be provided by the ES expert (see HWP parameters in example spreadsheet). All of the selected DFs exclude C capture by the forest ecosystem and HWP stocks. This is done to ensure that there is no double counting of CO_2 in the DSS. Most of the DFs in the database are based on a life cycle time of 100 years, so this can be used as the default.

Modelling substitution using wood product poses spatial and temporal scaling issues, which are complicated. One would have to assume that all products are utilised globally so the emission reduction are difficult to assign to a region because of global nature of the timber trade. However, the HWP tool provided can facilitate regional specificities. The emission savings are a function of both instant reduction of emissions due to energy use reductions or replacements and long term storage in wood products. However, a common and easiest approach is to allocate the emission saving is once off for the 100 year period, with the exception of fuel and energy production since emissions savings due to fossil fuel replacement are instant.

Proposed approach

HWP C stocks: Model description

HWP stock change values (ΔCW, t CO2) are calculated for each semi-finished wood category (j) based on wood product inputs (W*inflow*$_{.j}$) and initial harvested wood product on the C pool (CW_j)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

$$CW_{ij+1} = e^{-k} \times CW_{ij} + \left[\frac{(1-e^{-k})}{k}\right] \times WInflow_{ij}$$ 15

$$\Delta CW_{ij} = CW_{ij+1} - CW_i$$ 16

Where:

i = year

j = CW semi-finished category; default (paper/pulp, wood-based panels, sawnwood)

CW_{ij} = the carbon stock in the particular CW category at the beginning of year *i*, kt C.

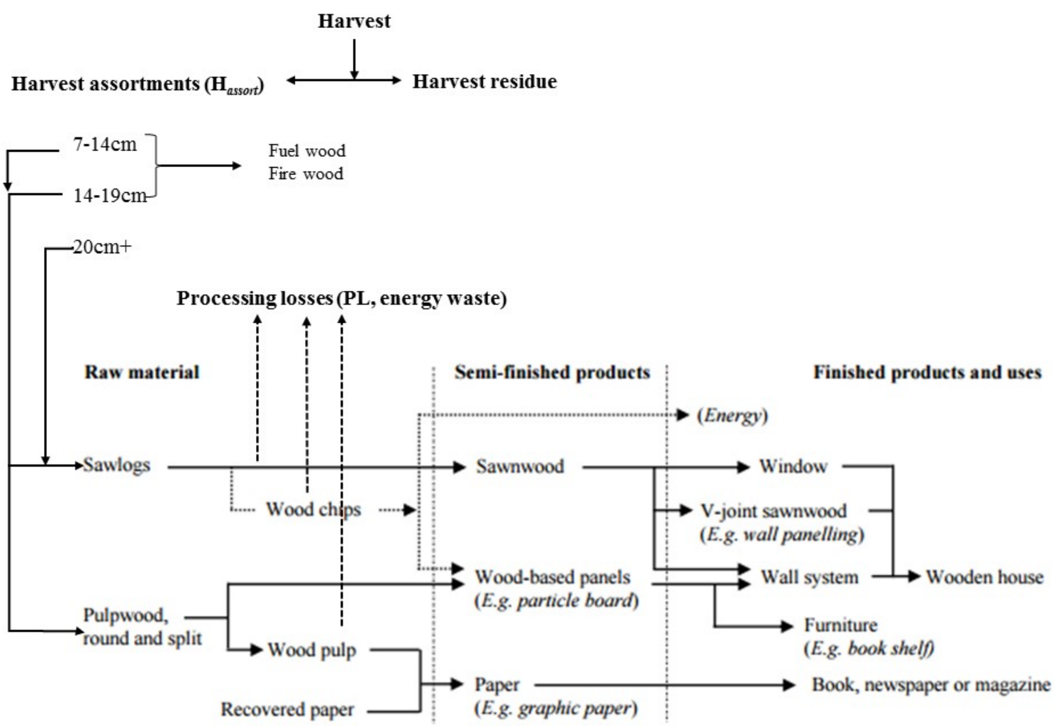
k = decay constant of first-order decay for DW category given in units yr^{-1} (*k* = ln(2)/HL, where HL is half-life of the wood category (see example spreadsheets (HWP parameter sheet table 2) and http://www.ipcc-nggip.iges.or.jp/public/kpsg/pdf/KP_Separate_files/KP_Chapter_2_Methods_Estimation_Measurement_Monitoring_Reporting.pdf. Section 2.8)

$WInflow_{ij}$ = the inflow to the particular HWP category during year *i*, kt C yr^{-1}

ΔCW_{ij} = carbon stock change of the HWP category during year *i*, kt C yr^{-1}

Harvest inputs (Winflow)

The inflow of wood from harvest into a particular semi-finished product is based on harvest residue loss, wood use for fuel of heat, and harvest assortment (as derived for each FMM, see example file HWP parameters spreadsheet). The diagram below shows the wood flow schema.



Therefore, the inflow of wood into the semi-finished categories (j, i.e. pulp and paper, wood-based panels, sawnwood) can be expressed as:

$$WInflow_{ij} = H_{productij} \times PL \times D \times CF$$ 17

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

- PL is the processing loss fraction expressed as a function of processing wood left in product after losses due to waist, heat or energy use by the mills (see table 3 HWP parameter sheet in file attached). A default value of 0.5 can be used (Lundman et al., 2014), but each country derived specific values or use on FAO and EUROSTAT data using industrial Roundwood and Roundwood harvest values.
- D and CF are density and carbon fractions for wood products (See table 5 HWP parameters file, taken from http://www.ipcc-nggip.iges.or.jp/public/kpsg/pdf/KP_Separate_files/KP_Chapter_2_Methods_Estimation_Measurement_Monitoring_Reporting.pdf. Section 2.8)

Wood allocated to specific semi-finished product categories ($H_{product(j)}$) in a given year (i) is based on the sum removed harvests (m3, overbark as produced by the FMMs) allocated to all assortment categories (AF_h) and assortments allocation to each semi-finished products (FsF*P*). This value should agree with the harvest (H) and harvest residue losses used for biomass estimations (see eq 5a, 9 and 10) to ensure model consistency. Therefore, harvest allocated to semi-finished product category ($H_{productj}$, m^3 ha) for a given year (*i*) can be estimated as:

$$H_{productij} = \sum_h [H_{\ i} \times (1 - HF_i) \times AF_{h,i} \times (FsFP_{h,j})] \qquad 18$$

- Where HF is derived from eq 10
- AF_{ih} is the assigned fraction of harvested wood removed from site that is allocated to each assortment (h,) for each FMM harvest year i)
- FsFP is the fraction of each wood assortment (h) assigned to each semi-finished product(j), (user defined, see HWP parameter sheet Table 1 attached).

CWi

The C pools in wood products at the beginning of the year can be h=based on the same principles and assumptions used for the DWi pools (see above and example spreadsheet). However, the CWi for successive rotation crops should only be based on the mean HWP stock aver a 100 year period (see e.g. spreadsheet). This is done to ensure time scale consistency with substitution and HWP stock approaches.

Product substitution for fossil fuel energy

Emissions saving due to substitution of fossil fuel (Psub(ff) replacement categories (j) are a function of harvested wood allocated to energy (H_{energy}) replacement in a given year (i), density and carbon fractions of wood (D and CF see eq17), the ratio of fuel category being replaced over the total fossil fuel being replaced (Fmix(j)) and displacement factors (DF_j) for 3 basic fossil fuels being replaced being replaced (gas, oil, coal, see HWP parameters sheet in example provided):

$$Psub(ff)_{i,j} = H_{energy(i)} \times D \times CF \times F_{mix(j)} \times DF_j \qquad 19$$

And

$$H_{energy(i)} = \sum_h [H_i \times (1 - HF_i) \times AF_{ih} \times FsubE_h] \qquad 20$$

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Where FsubE is the fraction of each wood assortment (h) assigned to a fossil fuel energy replacement (Table 8 in HWP parameters file attached file)

Product substitution for products

Emissions saving due to product substitution (Psub(P)) categories (j) are a function of wood used in semi-finished or finished products (*Hsubs*) displacement factors (DF_j) for product categories being replaced, density and carbon fractions (D and CF as used in eq 17 and 19) and processing loss fractions (PL as used in eq 17).

$$Psub(P)_{i,j} = H_{subs(i,j)} \times D \times CF \times PL \times DF_j \quad (21)$$

And

$$H_{subs(i,j)} = \sum_h [H_i \times (1 - HF_i) \times AF_{ih} \times FsubP_{h,j}] \quad (22)$$

Where FsubE is the fraction of each wood assortment (h) assigned to a fossil fuel energy replacement

To simplify the process generalised DF for sawnwood and wood based panel (semi-finished products) are provided together with the DF for more efficient replace products, such as cement. These are done separately so that LCC can allocate their own harvest flows into more or less efficient replacement products depending on wood quality, local requirements etc.

Example of outputs

The paper published by Lundman et al., 2014, makes a comparison of forest, deadwood, litter, wood stocks and product substitution stock for 2 different FMM (i.e. clearfell plantations (CF) and continuous cover (CCF) systems. Surprisingly, the results suggest a larger net C removal for CF systems because of a larger increase in biomass HWP stocks and substitution products. (See Figures below). Similar types of analysis can be done for different FMMs in the ALTERFOR project based on different wood use scenarios

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

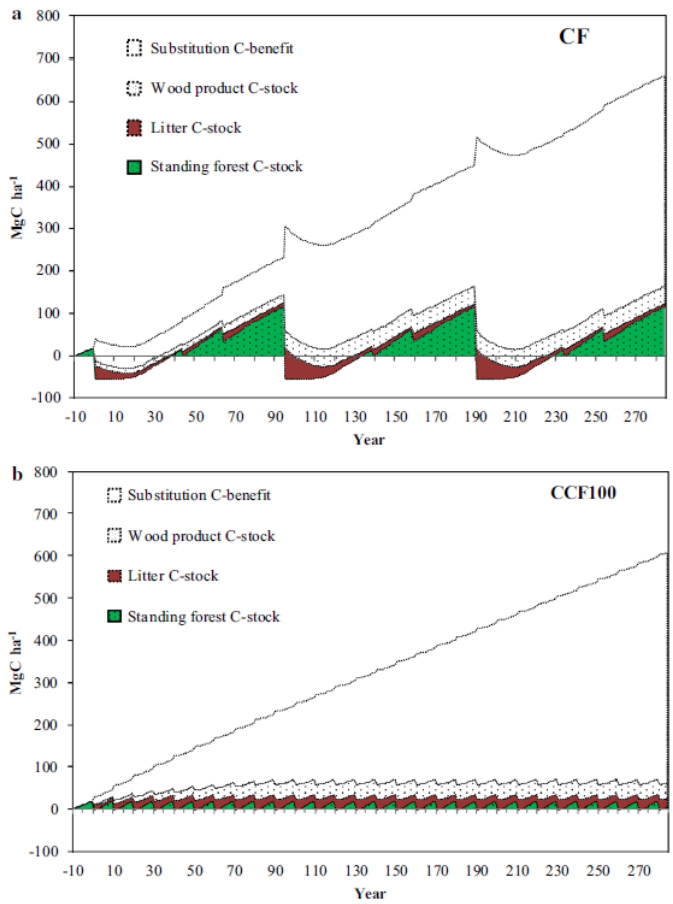


Fig. 2 Cumulative total carbon balances in **a** *CF* and **b** *CCF100* scenarios over 285 years assuming an average substitution effect of 0.90 Mg CO_2-eqv for each cubic meter of harvested stem-wood

References

Bond-Lamberty et al., 2008. Decomposition and Fragmentation of Coarse Woody Debris: Re-visiting a Boreal Black Spruce Chronosequence Ecosystems (2008) 11: 831–840

Chambers, J.Q., Higuchi, N., Schimel, J.P., Ferreira, L.V., Melack, J.M., 2000. Decomposition and carbon cycling of dead trees in tropical forests of the central Amazon. Oecologia 122, 380–388.

Chen, H., Harmon, M.E., Griffiths, R.P., 2001. Decomposition and nitrogen release from decomposing woody roots in coniferous forests of the Pacific Northwest: a chronosequence approach. Canadian Journal of Forest Research 31, 246–260.

IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National

Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds).Published: IGES, Japan.

Lundmark et al., 2010 Comparison of carbon balances between continuous-cover and clear-cut forestry in Sweden Ambio 2016, 45(Suppl. 2):S203–S213

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Mackensen, J., Bauhus, J., Webber, E., 2003. Decomposition rates of coarse woody debris—a review with particular emphasis on Australian tree species. Australian Journal of Botany 51, 27–37.

Oliver et al,. 2014 Carbon, Fossil Fuel, and Biodiversity Mitigation With Wood and Forests. Journal of Sustainable Forestry, 33:3, 248-275, DOI: 10.1080/10549811.2013.839386

Olajuyigbe et al, 2011. Stocks and decay dynamics of above- and belowground coarse woody debris in managed Sitka spruce forests in Ireland. Forest Ecology and Management, 262:1109-1118

Sathre, R., and J. O'Connor. 2010. Meta-analysis of greenhouse gas displacement factors of wood product substitution. Environmental Science & Policy 13: 104–114.

Smyth et al., 2016. Estimating product and energy substitution benefits in national-scale mitigation analyses for CanadaGCB Bioenergy (2016), doi: 10.1111/gcbb.12389

Yatskov, M., Harmon, M.E., Krankina, O.N., 2003. A chronosequence of wood decomposition in the boreal forests of Russia. Canadian Journal of Forest Research 33, 1211–1226.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Appendix 4. Guidelines for water

Davide Zoccatelli and Marco Borga

Starting from the CICES[1] classification, we have identified the following five water-related ecosystem services:

1. **Provision of surface water for drinking\non-drinking purposes**: collected precipitation, abstracted surface water from rivers, lakes and other open water bodies for drinking, domestic use (washing, cleaning and other non-drinking use), irrigation, livestock consumption, industrial use (consumption and cooling) etc.;
2. **Flood protection**: flood protection by appropriate land coverage;
3. **Hydrological cycle and water flow maintenance**: capacity of maintaining baseline flows for water supply and discharge; e.g. fostering groundwater; recharge by appropriate land coverage that captures effective rainfall; includes drought and water scarcity aspects;
4. **Mass stabilization and control of erosion rate; Buffering and attenuation of mass flow**: erosion / landslide / gravity flow protection; vegetation cover protecting/stabilising terrestrial, coastal and marine ecosystems, coastal wetlands, dunes; vegetation on slopes also preventing avalanches (snow, rock), erosion protection of coasts and sediments by mangroves, sea grass, macroalgae, etc.
5. **Chemical condition of freshwaters**: maintenance / buffering of chemical composition of freshwater column and sediment to ensure favourable living conditions for biota e.g. by denitrification, re-mobilisation/re-mineralisation of phosphorous, etc.

We have separated ES evaluation at stand-level into two levels: basic and advanced. For the **basic level** we have selected ES indicators based on the MAES project[2] and related publications (Maes *et al.* 2013). We have identified a list of DSS outputs that can be related with these indicators. In the basic level the CS can report the variation of raw DSS outputs, but the net contribution on the indicator is not quantified. On the other hand, the **advanced level** of ES evaluation is based on the application of additional models. The models suggested come from the InVEST package[3] and allow to quantify the changes on ES indicators. These models are simplified enough to be used within a heterogeneous group of DSS, but are solid and have been used in a large number of scientific publications. One restriction is that in the InVEST application the spatial location of the FMMs is explicit. In the coming discussion please mention if local DSS already produce outputs that can be used as indicators for some of the ES.

The last chapter describes how to move from stand-level FMM to the **landscape scale**. In the most simplified analysis, the landscape scale is just as an aggregation of alternative FMM. For a more complete analysis, considerations are made on how the spatial distribution is influencing the ES indicators and their value.

STAND SCALE – BASIC LEVEL

In Table 1 we summarize the indicators and related DSS outputs for each ES considered. For a short description of the relations outlined in Table 1, we refer to Appendix 4A. If the DSS do not include any of the output suggested, the LCC are invited to describe which one of their outputs could be related with the indicators.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

__Table 1:__ Basic level, indicators related with stand-level DSS outputs.

Ecosystem service	Indicators	Possible related DSS output
1 - water yield	Total supply of water per forest area; Evapotranspiration;	**Harvesting**[4] [% of cover removed]: generally increases yield; **Species**: moving from deciduous to evergreen could reduce yield;
2 – flood protection	Quickflow amount; Runoff time; Number of floods;	**Road density** [density]: increases runoff peak; **Harvesting**[% of cover removed]: decreases interception and increases flood risk; **Intensive grazing**: may increase runoff production; **Burning**: may increase runoff production;
3 – Water flow maintenance	Water storage\delivery capacity of the soil; Water distribution along the year;	**Harvesting** [% of cover removed]: generally increases low flows;
4 –erosion control	Erosion protection; Annual amount of sediment removed;	**Harvesting** [% of cover removed]: generally erosion is not directly related with the silvicultural system, except for harvesting in susceptible areas or causing large disturbances; **Road density** [density]: increases erosion; **Burning** [% of area affected]: increases erosion; **Grazing**: increases erosion;
5 – chemical conditions	Water quality; Concentration of Nitrogen, Phosphorus; Concentration of toxic elements;	**Applied chemicals** [kg/ha/year]: potentially increases nutrients, toxins; **Harvesting** [% of cover removed]: increases nutrient leaking, based on intensity; **Burning** [% of area affected]: increase nutrients and other water quality parameters; **Species**: broadleaves are generally associated with less nitrogen leak than conifers; **Age**: minimum of nutrients leak when forest reaches maturity. Increases for old-growth forests;

[4] With *harvesting* in the following tables we describe all different operations involving trees removal

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

STAND SCALE – ADVANCED LEVEL

In Table 2 for each ES we suggest additional models that may be applied in order to quantify changes in ES indicators. The main parameters influenced by DSS outputs are also described. For a better description of these models see the *4A-2* appendix.

Table 2: *The table below reports the suggested models, the output that can be used as indicator for the ES, the specific model parameters that are influenced by the FMMs, and the possible DSS outputs needed to evaluate those parameters.*

ECOSYSTEM SERVICES	MODEL NAME	ES INDICATOR (output)	FMM-related model parameters	POSSIBLE related DSS Outputs
1 – water yield 2 – flood protection 3 – Water flow maintenance	**Seasonal Water Yield Model**	Annual runoff Annual quickflow Annual baseflow	Curve number Monthly crop factor	Percentage of soil cover by shrubs and litter; Area cover by forest roads; Leaf area index; Vegetation height;
4 – erosion control	**Sediment Delivery Ratio Model**	Annual sediment lost	Crop management factor	Fraction of soil cover by vegetation
5 – chemical conditions	**Nutrient delivery ratio model**	Total nutrient export	Nutrient loading; Maximum retention efficiency; Retention length values;	Species composition; Age distribution;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

LANDSCAPE SCALE

To evaluate ES at landscape scale, we can include different considerations:

- **Net combination of stand-level indicators**. This is the most basic landscape evaluation. Combining ES change across alternative FMMs, we can see how the ES basket changes and what is the overall trend.
- **Individuation of critical areas**. The most important variation of the ES often comes from critical areas, where the impact is stronger. Mapping the change of ES across these areas can help to quantify the overall change. Note that the advanced approach already includes these considerations.
  - **Water yield:** humid areas, riparian areas;
  - **Flood protection:** headwater catchments and riparian areas;
  - **Water flow maintenance:** headwater catchments and infiltration areas;
  - **Erosion control:** floodplains, alluvial fans, riparian areas, unstable (steep) terrains;
  - **Chemical conditions:** riparian areas;
- **Integration with other indicators.** The flow of services could also be integrated with indicators describing the beneficiaries (supply, demand, benefiting areas), and their distribution in space. **[note that this list is not exhaustive]**
  - **Water yield:** water abstraction for drinking, agriculture, hydropower;
  - **Flood protection:** flood vulnerability and exposure map;
  - **Water flow maintenance:** draught vulnerability and exposure map; benefit to the ecosystems;
  - **Erosion control:** sediment removed from dams, lakes, rivers; water purification
  - **Chemical conditions:** cost of water purification;

REFERENCES

Allen, R. G., L. S. Pereira, D. Raes and M. Smith (1998). *Crop evapotranspiration-Guidelines for computing crop water requirements-FAO Irrigation and drainage paper 56.* FAO, Rome 300(9): D05109.

Barten, P., J. Jones and G. Achterman (2008). *Hydrologic effects of a changing forest landscape (180pp)*, Washington, DC: National Academies Press.

Bartsch, K. P., H. Van Miegroet, J. Boettinger and J. P. Dobrowolski (2002). *Using empirical erosion models and GIS to determine erosion risk at Camp Williams, Utah.* Journal of soil and water conservation 57(1): 29-37.

Bent, G. C. (2001). *Effects of forest-management activities on runoff components and ground-water recharge to Quabbin Reservoir, central Massachusetts.* Forest Ecology and Management 143(1): 115-129.

Best, A., L. Zhang, T. McMahon, A. Western and R. Vertessy (2003). *A critical review of paired catchment studies with reference to seasonal flows and climatic variability.* MDBC Publication 11(03).

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Boegh, E., R. Poulsen, M. Butts, P. Abrahamsen, E. Dellwik, S. Hansen, C. B. Hasager, A. Ibrom, J.-K. Loerup and K. Pilegaard (2009). *Remote sensing based evapotranspiration and runoff modeling of agricultural, forest and urban flux sites in Denmark: From field to macro-scale.* Journal of Hydrology 377(3): 300-316.

Buttle, J. M. (2011). *The effects of forest harvesting on forest hydrology and biogeochemistry*. Forest Hydrology and Biogeochemistry, Springer**:** 659-677.

Cebecauer, T. and J. Hofierka (2008). *The consequences of land-cover changes on soil erosion distribution in Slovakia.* Geomorphology 98(3): 187-198.

Chou, W.-S., T.-C. Lee, J.-Y. Lin and S. L. Yu (2007). *Phosphorus load reduction goals for Feitsui Reservoir watershed, Taiwan.* Environmental monitoring and assessment 131(1): 395-408.

Díaz, M. F., S. Bigelow and J. J. Armesto (2007). *Alteration of the hydrologic cycle due to forest clearing and its consequences for rainforest succession.* Forest Ecology and Management 244(1): 32-40.

Endreny, T. A. and E. F. Wood (2003). *WATERSHED WEIGHTING OF EXPORT COEFFICIENTS TO MAP CRITICAL PHOSPHOROUS LOADING AREAS1*, Wiley Online Library.

Erdogan, E. H., G. Erpul and İ. Bayramin (2007). *Use of USLE/GIS methodology for predicting soil loss in a semiarid agricultural watershed.* Environmental monitoring and assessment 131(1-3): 153-161.

Feller, M. (2009). *Deforestation and nutrient loading to fresh waters.* Encyclopedia of inland waters. Elsevier 6492.

Feller, M. C. (2005). *Forest harvesting and streamwater inorganic chemistry in western North America: a review1.* Journal of the American Water Resources Association 41(4): 785.

Folly, A., M. Bronsveld and M. Clavaux (1996). *A knowledge-based approach for C-factor mapping in Spain using Landsat TM and GIS.* International Journal of Remote Sensing 17(12): 2401-2415.

Forestry_Commission (2011). *Forests and Water. UK Forestry Standard Guidelines.* Forestry Commission, Edinburgh.

Guillemette, F., A. P. Plamondon, M. Prévost and D. Lévesque (2005). *Rainfall generated stormflow response to clearcutting a boreal forest: peak flow comparison with 50 world-wide basin studies.* Journal of Hydrology 302(1): 137-153.

Hamilton, L. S. (2008). *Forests and water*, FAO.

Harmel, D., S. Potter, P. Casebolt, K. Reckhow, C. Green and R. Haney (2006). *Compilation of measured nutrient load data for agricultural land uses in the United States1*, Wiley Online Library.

Hubbart, J. A., T. E. Link, J. A. Gravelle and W. J. Elliot (2007). *Timber harvest impacts on water yield in the continental/maritime hydroclimatic region of the United States.* Forest Science 53(2): 169-180.

Jeje, Y. (2006). *Export coefficients for total phosphorus, total nitrogen and total suspended solids in the southern Alberta region.* Alberta Environment and Sustainable Resource Development.

Lewis Jr, W. M. (2002). *Yield of nitrogen from minimally disturbed watersheds of the United States*. The nitrogen cycle at regional to global scales, Springer: 375-385.

Lin, J. P. (2004). *Review of published export coefficient and event mean concentration (EMC) data*, DTIC Document.

Maes, J., A. Teller, M. Erhard, C. Liquete, L. Braat, P. Berry, B. Egoh, P. Puydarrieux, C. Fiorina and F. Santos (2013). *Mapping and Assessment of Ecosystems and their Services.* An analytical framework for ecosystem assessments under action 5: 1-58.

Martin, A., J. T. Gunter and J. L. Regens (2003). *Estimating erosion in a riverine watershed bayou liberty-tchefuncta river in louisiana.* Environmental Science and Pollution Research 10(4): 245-250.

May, L., W. A. House, M. Bowes and J. McEvoy (2001). *Seasonal export of phosphorus from a lowland catchment: upper River Cherwell in Oxfordshire, England.* Science of the total environment 269(1): 117-130.

Mayer, P. M., S. K. Reynolds, M. D. McCutchen and T. J. Canfield (2007). *Meta-analysis of nitrogen removal in riparian buffers.* Journal of environmental quality 36(4): 1172-1180.

Morgan, R. P. C. (2009). *Soil erosion and conservation*, John Wiley & Sons.

NRCS, U. (2004). *National Engineering Handbook: Part 630—Hydrology.* USDA Soil Conservation Service: Washington, DC, USA.

Ohte, N. and N. Tokuchi (2011). *Hydrology and biogeochemistry of temperate forests*. Forest Hydrology and Biogeochemistry, Springer: 261-283.

Osborne, L. L. and D. A. Kovacic (1993). *Riparian vegetated buffer strips in water-quality restoration and stream management.* Freshwater Biology 29(2): 243-258.

Özhan, S., A. N. Balcı, N. Özyuvaci, A. Hızal, F. Gökbulak and Y. Serengil (2005). *Cover and management factors for the Universal Soil-Loss Equation for forest ecosystems in the Marmara region, Turkey.* Forest Ecology and Management 214(1): 118-123.

Panagos, P., C. Ballabio, P. Borrelli, K. Meusburger, A. Klik, S. Rousseva, M. P. Tadić, S. Michaelides, M. Hrabalíková and P. Olsen (2015a). *Rainfall erosivity in Europe.* Science of the total environment 511: 801-814.

Panagos, P., P. Borrelli, K. Meusburger, C. Alewell, E. Lugato and L. Montanarella (2015b). *Estimating the soil erosion cover-management factor at the European scale.* Land Use Policy 48: 38-50.

Pärn, J., G. Pinay and Ü. Mander (2012). *Indicators of nutrients transport from agricultural catchments under temperate climate: A review.* Ecological Indicators 22: 4-15.

Perrone, J. T. (1997). *Hydrologie Modeling of an Agricultural Watershed in Quebec Using AGNPS*, McGill University.

Pike, R. G., M. C. Feller, J. D. Stednick, K. J. Rieberger and M. Carver (2010). *Water quality and forest management*. Compendium of forest hydrology and geomorphology in British Columbia. RG Pike, TE Redding, RD Moore, RD Winker, & KD Bladon (editors). BC Ministry of Forests and Range, Forest

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Science Program, Victoria, BC, and FORREX Forum for Research and Extension in Natural Resources, Kamloops, BC. Land Management Handbook, Citeseer.

Ruhoff, A. L., B. S. P. Souza, E. Giotto and R. S. Pereira (2006). *Avaliação dos processos erosivos através da equação universal de perdas de solos, implementada com algoritmos em legal.*

Shrestha, S., F. Kazama and L. T. Newham (2008). *A framework for estimating pollutant export coefficients from long-term in-stream water quality monitoring data.* Environmental Modelling & Software 23(2): 182-194.

Sidle, R. C., A. D. Ziegler, J. N. Negishi, A. R. Nik, R. Siew and F. Turkelboom (2006). *Erosion processes in steep terrain—truths, myths, and uncertainties related to forest management in Southeast Asia.* Forest Ecology and Management 224(1): 199-225.

Silva, A. M. d., L. Casatti, C. A. Alvares, A. M. Leite, L. A. Martinelli and S. F. Durrant (2007). *Soil loss risk and habitat quality in streams of a meso-scale river basin.* Scientia Agricola 64(4): 336-343.

Stednick, J. D. (2010). *Effects of fuel management practices on water quality.*

Tipping, E., E. Rowe, C. D. Evans, R. T. Mills, B. A. Emmett, J. Chaplow and J. R. Hall (2012). *N14C: A plant–soil nitrogen and carbon cycling model to simulate terrestrial ecosystem responses to atmospheric nitrogen deposition.* Ecological Modelling 247: 11-26.

Van Dijk, A. I., M. Van NOORDWIJK, I. R. CALDER, S. L. BRUIJNZEEL, J. SCHELLEKENS and N. A. CHAPPELL (2009). *Forest–flood relation still tenuous–comment on 'Global evidence that deforestation amplifies flood risk and severity in the developing world'by CJA Bradshaw, NS Sodi, KS-H. Peh and BW Brook.* Global Change Biology 15(1): 110-115.

Wischmeier, W. H. and D. D. Smith (1978). *Predicting rainfall erosion losses-A guide to conservation planning.* Predicting rainfall erosion losses-A guide to conservation planning.

Zhang, H. and K. Hiscock (2011). *Modelling the effect of forest cover in mitigating nitrate contamination of groundwater: A case study of the Sherwood Sandstone aquifer in the East Midlands, UK.* Journal of Hydrology 399(3): 212-225.

Zhang, X., X. Liu, M. Zhang, R. A. Dahlgren and M. Eitzel (2010). *A review of vegetated buffers and a meta-analysis of their mitigation efficacy in reducing nonpoint source pollution.* Journal of environmental quality 39(1): 76-84.

Zhou, P., O. Luukkanen, T. Tokola and J. Nieminen (2008). *Effect of vegetation cover on soil erosion in a mountainous watershed.* Catena 75(3): 319-325.

Zobrist, J. and P. Reichert (2006). *Bayesian estimation of export coefficients from diffuse and point sources in Swiss watersheds.* Journal of Hydrology 329(1): 207-223.

APPENDIX 4A: effect of forest management on water ES

Below we provide a short literature of the relations between ES indicators and DSS outputs summarized in Table 1 for the basic Stand-level analysis:

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

1 - WATER YIELD

Harvesting and thinning: water yield increases after harvesting and thinning, and returns to its previous value as the canopy closes. The change is stronger in clear-cut areas since, in the other cases, the increased transpiration of remaining trees can partially compensate the increased water yield (Hubbart *et al.* 2007).

Age: because of their lower evapotranspiration, mature forests may generate more water yield than developing ones (Barten *et al.* 2008);

Species: evergreen have higher evapotranspiration in winter than deciduous trees. If water is available during this season, annual yield can be reduced when moving from deciduous to evergreen (Ohte and Tokuchi 2011);

2 – FLOOD PROTECTION

Activities that reduce soil infiltration and increase connectivity can increase surface runoff, such as **creation of roads, forest landings, intensive grazing** (Hamilton 2008) or **forest fire** (Stednick 2010);

Harvesting decreases interception and transpiration, increasing – especially in clear cut areas (Hubbart *et al.* 2007) – soil water content, runoff and generally flood risk. The change in flood frequency is stronger for smaller localized floods (Van Dijk *et al.* 2009). The overall effect is mixed depending on climate, but generally flood risk increases with harvesting intensity (Guillemette *et al.* 2005);

3 – WATER FLOW MAINTAINANCE

Harvesting: after forest operations groundwater recharge increases, and water table rises (Bent 2001; Díaz *et al.* 2007) generally resulting in increased low flows (Best *et al.* 2003);

4 – EROSION CONTROL

Forest harvesting: tree harvesting alone does not substantially contribute to sediment fluxes, unless severe and widespread disturbance occur (Sidle *et al.* 2006). In prone areas, **site preparation** can result in increased erosion (Stednick 2010). Clear cut in steep areas also increases the risk of landslides (Sidle *et al.* 2006)

Roads and trails construction, stream crossing: increases soil erosion, with a peak shortly after harvesting (Barten *et al.* 2008);

Burning: fire reduces soil cover and soil infiltration, loose soil is quickly removed from the catchment during storms (Stednick 2010);

Grazing: intense grazing can remove soil cover, increase compaction and cause erosion (Barten *et al.* 2008).

5 – CHEMICAL CONDITIONS

Applied chemicals: potentially increases nutrients, toxins (Pike *et al.* 2010);

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Harvesting: decreasing nutrient uptake by plants increases nutrients concentration in aquatic ecosystems up to 7 years later (Feller 2005; Feller 2009). The effect depends on the harvest rate and on local climate, with more

For the effect of harvesting on specific chemical elements see (Feller 2005).

Burning: increased nutrients (phosphate, sulphate), sediment, dissolved solids, dissolved oxygen and generally reduced water quality; (Pike *et al.* 2010)

Species: generally agreed that broadleaves have higher N uptake and need higher N concentration to leak (Tipping *et al.* 2012). Nitrogen-fixing species can be a problem if largely present in vulnerable areas (Forestry_Commission 2011)

Age: concentration of most nutrients in aquatic ecosystems decreases down to a minimum for mature forests, and then increases up to an equilibrium for old-growth forests (Buttle 2011).

Grazing: overgrazing could cause bacterial contamination of water, but following best management practices the effect should be limited (Stednick 2010)

APPENDIX 4B: literature and data source for additional modelling

Sediment Delivery Ratio Model

The model suggested is an application of the RUSLE (Revised Universal Soil Loss Equation). This is a widely used method describing soil loss from surface runoff, but does not include processes such as gully erosion, landslides or streambank erosion. If these processes are dominant in the case study area, other models should be applied.

Model parameters and how to define them

- Digital Elevation Model (DEM): http://asterweb.jpl.nasa.gov/gdem-wist.asp has 30m resolution.
- Rainfall erosivity index (R): factor that depends on the intensity and duration of rainfall in the area analyzed. Information can be found at:
    - http://www.fao.org/docrep/t1765e/t1765e0e.htm
    - Panagos *et al.* (2015a) provides a map for Europe;
    - Updated values could be computed for climate change scenarios;
- Soil erodibility (K): susceptibility of soil particles to detachment.
    - Global data is provided by FAO in the Harmonized World Soil Database http://www.iiasa.ac.at/Research/LUC/External-World-soil-database/HTML/;
    - The SOTER project provided data for central Europe;
- Support practice (P) and Crop management (C): P accounts for effects of terracing and plowing. C is suggested to be related with the fraction of soil coverage by vegetation (Maes *et al.* 2013; Panagos *et al.* 2015b). Additional information can be found in:
    - http://www.omafra.gov.on.ca/english/engineer/facts/12-051.htm#t5
    - http://www.fao.org/docrep/T1765E/t1765e0c.htm
    - http://eusoils.jrc.ec.europa.eu/content/cover-management-factor-c-factor-eu
    - http://eusoils.jrc.ec.europa.eu/content/support-practices-factor-p-factor-eu

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

- Literature on forest applications: (Wischmeier and Smith 1978; Folly *et al.* 1996; Perrone 1997; Bartsch *et al.* 2002; Martin *et al.* 2003; Özhan *et al.* 2005; Ruhoff *et al.* 2006; Erdogan *et al.* 2007; Silva *et al.* 2007; Cebecauer and Hofierka 2008; Morgan 2009)

DSS output that could be related with parameters

- Fraction of soil covered by vegetation can be used to estimate the crop management factor (Zhou *et al.* 2008; Panagos *et al.* 2015b)

Seasonal Water Yield Model

As reported in Table 2, the output from this model can be used as indicators for different ecosystem services. The model is an application of the SCS Curve number, and divides the water input into quickflow, baseflow, evapotranspiration.

Model parameters and how to define them

- Digital elevation model (DEM): http://asterweb.jpl.nasa.gov/gdem-wist.asp has 30m resolution.
- Monthly precipitation: local information can be used where available; http://www.worldclim.org/ for current climate; monthly precipitation for future climate will be provided with the scenarios.
- Number of rain events in each month: some information can be found at https://datahelpdesk.worldbank.org/knowledgebase/articles/902061-climate-data-api or from local climate statistics;
- Curve Number: parameter describing the susceptibility of a landuse to generate runoff;
    - A description can be found at NRCS (2004)
      Where the hydrologic soil groups are based on soil depth and transmissivity, while hydrologic conditions are related with the amount of soil cover by litter and shrubs (grazing, burning could be considered);
- Potential monthly Evapotranspiration for a particular FMM
    - Monthly crop factor K: Depends on aerodynamic resistance (plants height); Albedo (ground cover, wetness); Canopy resistance (leaf area, species). Allen *et al.* (1998) reports values for crops and a method for the estimation; http://www.fao.org/docrep/X0490E/x0490e0a.htm describes the method. If there are local estimations of evapotranspiration they can be used for calibration; Boegh *et al.* (2009) describes the calculation of K for forests;
    - Reference Evapotranspiration for a month ET_0:
        - http://www.cgiar-csi.org/data/global-aridity-and-pet-database for current climate
        - Data from http://www.worldclim.org/ can be used to calculate ET_0 if not available;
        - Other methods such as Holdridge equation can be used for future climates;

DSS output that could be related with parameters

- Curve number parameter can be estimated with the amount of soil cover by litter and shrubs, the area cover by forest roads;

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

- Leaf area index and vegetation height can be used to estimate the monthly crop factor;

Nutrient delivery ratio model

The model uses a mass balance approach to describe the nutrient source and their transport to the stream. A spatially distributed approach is used, evaluating the effect of the position of harvested area or buffer zones.

Parameters and how to define them

- Nutrient runoff proxy: comes from the Seasonal Water Yield Model
- Nutrient loading (export coefficient) for nitrogen and phosphorus:
    - NatCap database
    - Pärn *et al.* (2012) and Harmel *et al.* (2006) for agricultural land;
    - Literature, mostly focused on forest areas: (Osborne and Kovacic 1993; May *et al.* 2001; Lewis Jr 2002; Endreny and Wood 2003; Lin 2004; Jeje 2006; Zobrist and Reichert 2006; Chou *et al.* 2007; Shrestha *et al.* 2008; Zhang and Hiscock 2011)
- Maximum retention efficiency for each LULC class
    - Pärn *et al.* (2012) for agricultural land
    - Mayer *et al.* (2007) and Zhang *et al.* (2010) for riparian areas
    - See literature above on nutrient loading for forest areas;
- Retention length values0
    - Mayer *et al.* (2007) and Zhang *et al.* (2010) for riparian areas;
- Subsurface parameters:
- Pärn *et al.* (2012) for agricultural land

DSS output that could be related with parameters

- Nutrient loading and retention efficiency are related with forest age and species composition;
- Point source of nutrients if present.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Appendix 5. Guidelines for biodiversity

Adam Felton, Matts Lindbladh, Miguel Bugalho & Ljusk Ola Eriksson

Biodiversity assessment suggested common standards

Regionally relevant forest biodiversity goals need to be sourced for the LC from government, ENGO, and forest certification agencies. Forest certification standards may provide a standardized means of comparison across LCCs (i.e. FSC, PEFC). These should address the three biodiversity proxies indicated in the guidelines, and quantified where possible by the DSS; tree species composition, forest structures, and spatial-temporal disturbance patterns. The specifics of the biodiversity goals will of course vary (to some extent) among the countries participating in ALTERFOR. Despite this variation, we (ES leaders) can still provide the following guide as a means of indicating the expected type of output we think we should be aiming to extract from the DSS (or from regulations (e.g. clearcut sizes)). These biodiversity goals are important for evaluating the DSS output **for each stand level FMM that was described in the WP1 FMM questionnaires**.

LCCs will quantify the biodiversity proxies listed below for all relevant FMMs, both at the stand and where possible, the landscape scale. As the DSS vary in their capabilities among participating countries, we indicate a minimum level output that we believe every country should readily be able to provide, using a "*", and a higher level goal that we think every country should aim for, using "**". Please see details provided below. If you feel there is an important determinant of forest biodiversity that is important but currently missing from this assessment, and is relevant to DSS output, please speak up. The time to adjust the approach is now.

The first section of the table is labelled as "stand scale / landscape" to indicate that these assessments can first be made for stand level FMMs, but are also often relevant for the landscape scale, hence the "/ landscape". These stand level outcomes can often be scaled up to the landscape, depending on the proportion of stand scale FMMs within the case study area as a whole. This is the simplest and most feasible landscape scale assessment possible in ALTERFOR that we think all LCC should be able to manage. Further down in the table we provide a "landscape scale" section, in which we focus solely on those considerations that do not apply to individual stand level FMMs. These assessments often require spatially explicit analysis beyond the current capabilities of many of the DSS, or will require information not currently available (e.g. spatial explicit GIS data). The extent to which these more complicated landscape scale assessments are to be pursued as part of ALTERFOR, is yet to be decided. Also, please see these suggested approaches as very tentative and requiring further input. Each country should of course pursue the most beneficial approach possible with the tools available. Once we get agreement regarding what each LCC will be able to do, we will be in a better position to harmonize across the LCs.

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Note that here we primarily focus on DSS relevant output. Other aspects, such as the amount of protected forest area within the LC, will of course be relevant to interpreting biodiversity outcomes. We also expect that aspects like the amount of deciduous forest, coniferous forest, older vs. younger production forest, etc., can be derived from FMM descriptions and details regarding the proportion of different FMMS within a landscape.

Biodiversity proxies	Specific Indicator	metric	unit	STAND FMM VALUE CALCULATED	Landscape FMM VALUE CALCULATED
Stand scale /landscape					
tree species composition / Diversity	*Tree species proportion The biodiversity goals should then able differentiation between tree species of higher or lower importance for biodiversity (e.g. native vs. introduced, oak vs. spruce)	Volume per hectare	$m^3 ha^{-1}$	*Max volume achieved for each tree species *Proportion of each tree species at time of harvest **Shannon index / evenness at time of harvest	*Value per period
Forest structures					
-Dead wood	*Total Dead wood for each tree species **Dead wood above minimum size thresholds; to start we suggest (>10cm diameter; >30cm diameter (or dbh if standing))	Volume per hectare	$m^3 ha^{-1}$	*Mean value for rotation **Max & min value for rotation	*Value per period **Value period

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.

Biodiversity proxies	Specific Indicator	metric	unit	STAND FMM VALUE CALCULATED	Landscape FMM VALUE CALCULATED
-large trees	*Large living trees (for each tree species) above minimum size thresholds; to start we olds; to start we suggest (>30 cm dbh; >40cm dbh; >50cm, >60cm)	Volume per ha; Stems per ha	$m^3 ha^{-1}$ # ha^{-1}	*Mean value for rotation **Max & min value for rotation	*Value per period
-Structural diversity	**Vertical structural diversity: volume of trees categorized by seven dbh size categories; to start we suggest (1-10, 11–20, 21–30, 31-40; 41-50; 51-60; >61)	Volume per size category Stems per ha	m^3 size category	** Gini coefficient (see Lexerød & Eid 2006); Max & min value for rotation.	** Gini coefficient (see Lexerød & Eid 2006); average of stand values per period
disturbance	Frequency of final felling disturbance. Most relevant to even-aged stands.	time	years	*Mean value for FMM	N/A
	Area of final felling (for uneven-aged forests, size of contiguous harvested areas). For “femel” / shelterwood, two figures regarding harvested area / time period are likely necessary.	area	ha	N/A	*Value per period
	The proportion of volume removed per harvest (particularly relevant to uneven-aged /continuous cover forestry)	Percentage	%	*Mean value for FMM	N/A

This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement No 676754.

Biodiversity proxies	Specific Indicator	metric	unit	STAND FMM VALUE CALCULATED	Landscape FMM VALUE CALCULATED
- protected area	Area of protected area as per IUCN category	area	ha	N/A	**protected area per period per IUCN category I-IV
-Spatial Fragmentation	Extent to which highest value or ranked habitats/forest types for consistency with biodiversity goals are aggregated or dispersed in the landscape			N/A	**Value per period per habitat/forest type. (*Aggregation indices should be available in GIS programs, with common approaches used for harmonization between LCCs*.)

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 676754.