Estimation of carbon stocks and stock changes in soil, LFH layer and deadwood in Swiss forests with Yasso07

16. November 2012

Prepared by Markus Didion, Edgar Kaufmann and Esther Thürig

Forest Resources and Management, Swiss Federal Institute for Forest, Snow and Landscape Research WSL

Commissioned by the Federal Office for the Environment FOEN

Swiss Federal Institute for Forest,
Snow and Landscape Research WSL

Summary

As a party of the United Nations Framework Convention on Climate Change (UNFCCC), Switzerland has committed to submit annual national greenhouse gas (GHG) inventories to the Climate Change secretariat. Carbon dioxide (CO_2), one of the major greenhouse gases, is removed from the atmosphere and stored as carbon (C) in living and dead biomass and in the soils of terrestrial ecosystems. In Switzerland, forests and forest soils are major C stores (Fischlin et al. 2003). As commissioned by the Swiss Federal Office for the Environment (FOEN), this report documents the ongoing research at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) on improving the accounting of temporal changes in C stored in soils, litter and deadwood (as defined in the IPCC Good Practice Guidance; IPCC 2003) on forest land. This study contributes to a strengthening of Switzerland's GHG accounting with regards to the criteria for transparency, consistency, comparability, completeness and accuracy (TCCCA; section 1.1).

Important drivers of C stock changes in soil, litter and deadwood on forest land are climate and C inputs from annually accumulating woody (e.g., deadwood, roots) and non-woody (e.g., foliage) dead organic material. Based on the network of climate stations of the Federal Office of Meteorology and Climatology MeteoSwiss and the extensive forest monitoring in the Swiss national forest inventory (NFI), relevant representative data on climate and C inputs can be easily derived. To make use of such comprehensive data, Yasso07 (Tuomi et al. 2009, 2011b), a model of C cycling in mineral soil, litter and deadwood was developed (section 2). Section 2.2 presents the implementation of Yasso07 in Switzerland that follows the approaches of UNFCCC and Kyoto Protocol (KP) signature states, including, Austria, Finland and Norway. Yasso07 was used to estimate annual sizes of soil, litter and deadwood pools since 1989 for all sites of the NFI network. The annual changes in the pool sizes were calculated for use in Switzerland's Greenhouse Gas Inventory 1990-2013 (GHGI) and the submission on the domestic forest management reference level (FMRL).

Section 3 presents the results of C stocks and C stock change for Switzerland nationally and stratified by production region and elevation class. In addition to the estimates for the GHGI until 2011 and the FMRL until 2020, results are shown for alternative forest management and climate scenarios until 2050. The comprehensive verification of the C stock and C stock change estimates showed that particularly the soil C pool size was underestimated by Yasso07. One reason for this is pyrogenic C, which contributes to the uncommonly large C stocks particularly in the Southern-Alps, and which could not be reproduced by the model (as discussed in section 4).

The verification of the C stock change estimates, which are used in the GHGI and for determining the FMRL, demonstrated that these were rather robust despite the limitations in the stock estimates. The national estimates of C stock change 2010 to 2011 to be used in the Switzerland's GHGI 2013 indicate a sink effect in soil, litter and deadwood of 0.029 Mg C $ha^{-1}a^{-1}$ (as reported in Appendix II, Table A-3d) or 0.034 Tg C a^{-1} (0.124 Tg CO_2 equivalents); national estimates were based on a forest area of 1'165'345 ha. The estimated sink effect of the soil stock change of 0.006 Mg C $ha^{-1}a^{-1}$ for 2009 to 2010 (Appendix II, Table A-3c) is comparable to the values reported by other KP parties in the summary report of the national inventories (e.g., Austria: 0.19 (source), EU15: -0.05, Finland: -0.09, Liechtenstein: -0.01; Tab. 5.2a in UNFCCC 2012).

The stock changes calculated based on C inputs from NFI data and on observed climate since the start of the first commitment period of the Kyoto Protocol in 2008 differ from the modeled estimates for the FMRL. The FMRL was constructed based on modeled projections under a business as usual scenario, which was defined on the basis of available knowledge and policies until the End of 2009. As the current data show, the assumed increase in harvesting rates overestimated observed rates of the recent years. It can be expected that the total sink effect for the period 2008 to 2012 will be smaller than the sink effect of 0.166 Mg C $ha^{-1}a^{-1}$, which was estimated based on FMRL data (section 3).

It is well known that large uncertainties exist for estimates of carbon stock change (Schöning et al. 2006, Luyssaert et al. 2010) and Yasso07 estimates were within reported error margins. Despite current limitations, the application of Yasso07 implies improvements in transparency, consistency and comparability over previous Swiss GHG inventories. Ongoing further development of the model will further increase its accuracy, and applications to lands converted to forest land and forest land converted to other lands as done by Norway would result in greater completeness.

Table of Contents

List of Figures

List of Tables

Glossary

Carbon pools:

- Terminology follows the IPCC Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC 2003):

  - Soil organic carbon
  - Litter
  - Deadwood

- Following the convention used by Switzerland in its previous National Inventory Reports (NIR), the reported pools are

  - Soil
  - LFH (Litter - Fermenting - Humified) layer
  - Deadwood (corresponding to *TDW* as used in Switzerland's NIR 2012 (chapter 7.3.4.8 in FOEN 2012): wood of dead trees >12 cm, lying dead wood >7 cm and dead coarse roots)
  - Total as the sum of the above pools

Dead organic matter (DOM): Term is used as defined in IPCC (2003), i.e., deadwood and litter.

Forest development scenario (FDS): Projected forest development until 2050 based on the combination of climate change and forest management scenarios.

Forest management reference level (FMRL): Mean projected C stock changes for 2013-2020 following a business as usual (BAU) harvesting scenario. This value is used for accounting for forest management in the second Kyoto-commitment period.

Greenhouse gas inventory (GHGI): Annual submissions under the UNFCCC and under the Kyoto Protocol (KP) on GHG emissions and removals in Switzerland. Includes the National inventory report (NIR).

National Forest Inventory of Switzerland (NFI; *Schweizerisches Landesforstinventar*, LFI):

- State analyses (*Zustandsauswertungen*):

  - NFI1: assumed to be representative of the year 1985
  - NFI2: assumed to be representative of the year 1995
  - NFI3: assumed to be representative of the year 2005
  - NFI4a: assumed to be representative of the year 2011

- Change analyses (*Veränderungsauswertungen*)

  - NFI12: assumed to be representative of the period 1986 to 1995
  - NFI23: assumed to be representative of the period 1996 to 2005
  - NFI34a: assumed to be representative of the period 2006 to 2011

Units of carbon measurements:

- Carbon stocks:

  - Kilogram (Kg)
  - Megagram (Mg) = 1 metric ton
  - Terragram (Tg) = 10^6 Mg

- Carbon stock changes:

  - Kilogram per hectare and year (Kg $ha^{-1}a^{-1}$)
  - Megagram per hectare and year (Mg $ha^{-1}a^{-1}$)

1 Introduction

Global climate change has been recognized as a major threat for future development in the United Nations Framework Convention on Climate Change (UNFCCC) in 1992. A major driver of climate change is the increasing concentration of greenhouse gas (GHG) emissions (IPCC 2007). As an approach to control GHG emissions, the UNFCCC provides guidelines at the national level to account for carbon and other greenhouse gases. The Kyoto Protocol (KP) to the UNFCCC sets binding targets for greenhouse gas emissions for its signature states and obliges them to an annual reporting of greenhouse gas balances in their National Inventory Reports (NIR).

As a signature state, Switzerland is required to maintain a comprehensive inventory of greenhouse gas emissions expressed in CO_2-equivalents, including emissions and removals of CO_2-eq. from Land Use, Land-Use Change and Forestry (LULUCF). CO_2 is removed from the atmosphere by photosynthesis and stored as carbon (C) in living and dead biomass and in the soils of terrestrial ecosystems. In Switzerland, forests and forest soils are major C stores (Fischlin et al. 2003). The Swiss Federal Office for the Environment (FOEN) compiles annually, among others, the data on changes in the carbon stock of forests and forest soils for Switzerland's GHG inventory. In previous GHG inventories Switzerland used a conservative approach for reporting changes in the C stock of forest soils. Switzerland intends to improve the accounting of the soil C stock and soil C stock change in future inventories and to apply the soil carbon model Yasso07 (Tuomi et al. 2009, Tuomi et al. 2011b) to estimate temporal changes in C stored in the soil in Swiss forests (FOEN 2012).

Yasso07 is currently used by three KP signature states Austria, Finland and Norway to obtain estimates of change in the soil C stock to be reported in their NIRs. The model is also applied in research on the contribution of the soil C pool to regional and global carbon balances (Johnson et al. 2010, Thum et al. 2011). One of the strengths of Yasso07 is to model C dynamics in soil and litter based on readily available data on C inputs from dead organic matter and on climate. For forest lands, such C input data can be derived from forest inventories that are carried out by many countries. Since 1985 Switzerland maintains a comprehensive forest inventory that provides accurate data for applying the Yasso07 model.

The purpose of this report is twofold: first, to document the implementation of Yasso07 in Switzerland for estimating temporal changes in the C stocks of litter, dead wood and soil in Swiss forests; second, to present and discuss the estimates of these C stocks and C stock changes obtained with Yasso07 that are to be used in the upcoming GHG inventory. The report is structured to parallelly report on deliverables for both items, including data prepared for the GHGI 2013 and for determining Switzerland's Forest Management Reference Level (FMRL), which is used for accounting of forest management in the second Kyoto commitment period.

1.1 TCCCA criteria and verification: specific information for UNCFFF/KP reviewers

The report addresses the criteria for transparency, consistency, comparability, completeness and accuracy (TCCCA) and documents comprehensively the verification of the produced data:

Transparency is achieved by detailing the various data sets that were used and by providing relevant references and links to software that was applied. The methodology is described in detail to ensure that results can be reproduced. See sections 2.1 to 2.4.

Consistency is obtained by relying on data sources that are maintained in a consistent manner and that will be available in the future. It was ensured that the methods were applied consistently and that results are reported correspondingly, including data per unit area that is independent of temporal changes in the underlying forest area. See sections 2.3 and 2.4.

Comparability is achieved by applying the Yasso07 model that is also used in several other KP parties. An approach was developed to further increase the comparability by reporting carbon in individual pools as defined in Good Practice Guidance for LULUCF (IPCC 2003). Following the recommendation in IPPC (2003), the changes in C stocks were calculated from C stocks that were averaged over three years. See sections 2.1 and 2.2 and Appendix I for methods, 3.3 for results and 4.3 for discussion.

Completeness is reached by calculating annual estimates since 1989 for the litter, deadwood and soil pools for all 15 forest regions in Switzerland. See sections 2.3, 2.4 for methods and 3.1 for results.

Accuracy is obtained by employing reliable and accurate data and a methodology that is applied by other countries and in research. All results were verified with independent data and deviations were identified and discussed. See sections 2.5 for methods, 3.2 for results and 4.1 for discussion.

For a transparent and comprehensive **verification**, all chapters of this report include a section on verification. The independent data that were used for verifying are described in detail in chapter 2 on methods. Section 3.2 on verification of the C stock and C stock change estimates presents all data in the same format as the verification data and shows results together with independent data. The accuracy and deviations of estimates from independent data are discussed in the corresponding chapter.

For transparency reasons, the results presented in the body of this report are based on not averaged annual C stocks. The changes in C stocks that were calculated from averaged C stocks (cf. IPCC 2003) and used for submission to the GHGI and for determining the FMRL are presented concisely in Appendices II and III.

2 Methods

2.1 Yasso07

Yasso07 (Tuomi et al. 2009, 2011b) and its predecessor Yasso (Liski et al. 2005) are models of C cycling in mineral soil, litter and deadwood. The models were developed for general application with low parameter and input requirements. For estimating stocks of organic C in mineral soil up to a depth of ca. 100 cm and the temporal dynamics of the C stocks, Yasso07 (henceforth Y07) requires information on C inputs from dead organic matter (i.e., non-woody inputs, incl. foliage and fine roots, and woody inputs, incl. standing and lying deadwood and dead roots) and climate (temperature, temperature amplitude and precipitation); for detailed information on input data see section 2.3. Decomposition of the different types of C inputs is modeled based on their chemical composition, size of woody parts and climate (Tuomi et al. 2009, 2011a, 2011b). Decomposition rates of C that is either insoluble (N), soluble in ethanol (E), in water (W) or in acid (A) and flows of C between these four compartments and to a more stable humus compartment (H) and out of the soil (Fig. 1; Tuomi et al. 2011b) were derived from a global data set (Tuomi et al. 2009, 2011a).

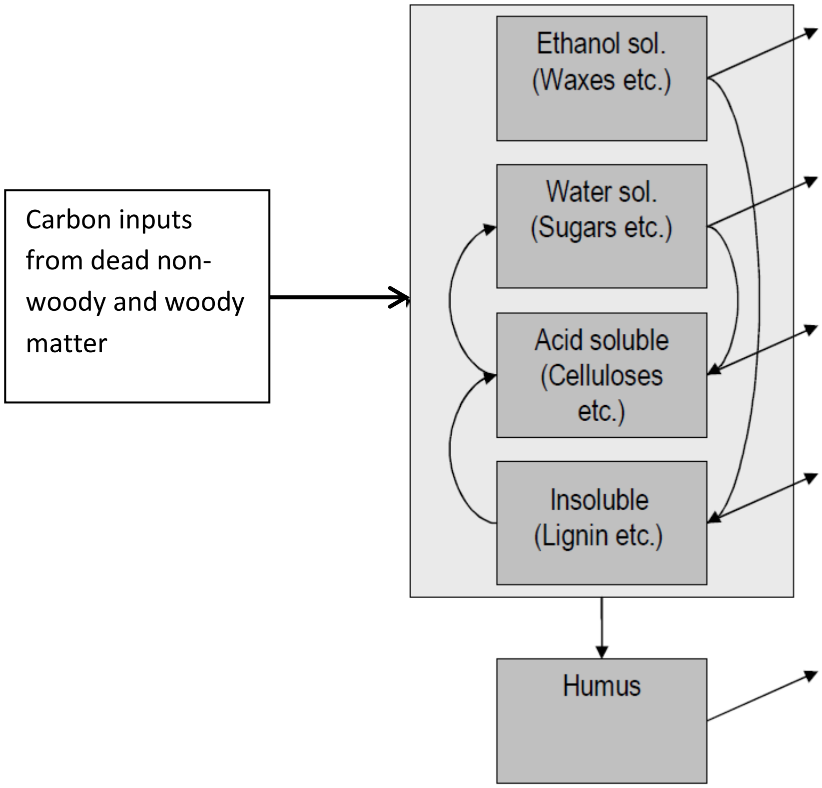

Figure 1. Flow chart of Yasso07 soil carbon model. The boxes represent soil carbon compartments, the arrows carbon flows; only those carbon flows are shown that deviate significantly from zero (adapted from Liski et al. 2009).

For Y07 simulations, initial C stocks are estimated in a *spin-up* procedure (cf. Liski et al. 2009) based on long-term mean annual climate and C inputs. This is to ensures that the model is in equilibrium with prevalent conditions prior to simulating scenarios of changes in C inputs and / or climate. At an annual time step Y07 estimates the combined C stored in deadwood, litter and soil.

The Y07 release 1.0.1 was used in this report. More information and the source code are available on http://code.google.com/p/yasso07ui/. The Y07 Fortran source code was compiled for the Windows7 operating system. The statistical software R (R Core Team 2012) version 2.15.1 (32 bit) was used for administrating the Y07 simulations.

2.1.1 Yasso07 parameter

Y07 relies on parameters defining C decomposition rates and C cycling between carbon compartments (Fig. 1). The parameter values for Y07 are derived by fitting the model to an extensive set of measured data related to cycling of organic carbon in soil (Liski et al. 2009). At the time of this report, two published parameter sets exist: Tuomi et al. (2009) and Tuomi et al. (2011b). Both parameter sets have been validated for conditions in Switzerland (cf. Didion and Frey. in prep; Weggler et al. 2012) based on measured decomposition of fine roots and foliage (Heim and Frey 2004, Frey 2011). Using the parameter set published in Tuomi et al. (2009), henceforth P09, Weggler et al. (2012) were able to reproduce measured decomposition with Y07 very accurately. The results of this study to validate Y07 parameters for conditions in Switzerland were presented and approved in an audit with experts (Soil carbon estimates for climate conference 2011, 4. October 2011, WSL, Birmensdorf ZH, Switzerland). The parameter set P09 was thus selected for all further simulations with Yasso07 and all results presented in this report were obtained using this data set.

The uncertainty of the parameter values is derived through Markov Chain Monte Carlo (MCMC) methods (Liski et al. 2009, Tuomi et al. 2009). Due to technical reasons, the uncertainties for the parameters in the P09 set cannot be estimated (M. Tuomi, pers. com. 25.05.2012) and can thus not be considered in the Y07 simulations of C stocks in this report. The uncertainty in the modeled mean C stocks for 4'726 NFI sites deriving from model parameter uncertainty was estimated as ca. 4 to 5 % with the parameter set from Tuomi et al. (2011b). This presents a reasonable range also for the P09 parameter set (M. Tuomi, pers. com. 30.07.2012) that was used in this report.

2.2 Carbon stock simulations with Yasso07

Based on data on non-woody and woody C inputs derived from measured data and observed climate, which were obtained for each NFI site (see section 2.3), Y07 was used to derive a time series of annual C stocks of litter, dead wood and soil at each sampling site. At each NFI sampling site Y07 was applied as follows:

1. In the initial spin-up phase, C stocks in equilibrium with mean climate 1961 to 1990 and constant, aggregated C inputs (see section 2.3.1) were estimated based on the assumption that current C stocks in the soil have accumulated over centuries (cf. Gimmi et al. in press).
2. In order to cancel out the steady-state conditions after the spin-up phase (cf. Peltoniemi et al. 2007b), the spin-up simulation was followed by simulating 25 years with regionally aggregated, constant C input data but annual climate data for the period 1961 to 1985 (see section 2.3.2).
3. a) *Greenhouse Gas Inventory* (GHGI): For the period after 1986 (i.e., start of the period NFI 1 to 2), site-specific carbon inputs from the 4 NFIs and annual, site-specific climate data until 2011 were used to obtain the time series of annual C stocks. Annual changes in C stocks were then calculated for use in the Swiss GHGI.

   b) *Forest Management Reference Level* (FMRL): For deriving the time series of changes in C stocks until 2020 for determining the FMRL measured C inputs were used only until 2005 (i.e., end of period NFI 2 to 3). In 2006, the simulations were continued with projected C inputs that are representative of the management scenario that was used to construct the FMRL (see section 2.3.1). After 2011, observed climate data were continued with projected data based on the A2 scenario of the IPCC AR3 (see section 2.3.2).

   c) *Forest development scenarios* (FDS): In addition to the management scenario of the FMRL, simulations were carried out as described above for the FMRL but continuing in 2006 until 2050 with projected C inputs for four forest management scenarios and in 2012 with three climate change scenarios (see section 2.3). This resulted in a total of 12 scenarios, including the FMRL management scenario.

2.3 Data

To estimate C stocks Y07 requires data on C inputs and climate. Carbon inputs were derived from measured data in four NFIs since 1985 until 2011 (www.lfi.ch) and from projections of possible future forest development with the MAnagement Scenario SImulation MOdel (MASSIMO; Kaufmann 2000) until 2050. Since the NFIs were carried out at irregular time intervals (i.e., 8 to 11 years for NFIs 1 to 3 and 3 to 7 years between NFI 3 and 4a) and MASSIMO operates on a decadal time step, carbon inputs could only be obtained at these 10-year intervals.

Annual climate data since 1961 were obtained from the Federal Office of Meteorology and Climatology MeteoSwiss (www.meteoschweiz.admin.ch). Climate data for three climate change scenarios to simulate different future forest development scenarios were derived from anomalies provided by the Land Use Dynamics Research Group at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL).

Data on C inputs and on climate were obtained for each NFI sampling site. The sampling sites are located across Switzerland and the NFI data are representative of the forest across Switzerland and for subregions. The NFI distinguishes between 5 production regions (Jura, Plateau, Pre-Alps, Alps and Southern Alps) that are divided into 3 elevation classes (≤601 m, 601-1200 m and >1200 m).

2.3.1 Carbon inputs

Estimates of C inputs for the simulations with Y07 were obtained for three categories of dead organic matter (DOM):

1) Coarse-woody material (standing and lying deadwood ≥7 cm diameter and coarse roots);
2) Fine-woody material (small branches and twigs <7 cm diameter and bark); and
3) Non-woody material (foliage, fruits and fine roots < ca. 5 mm).

The accumulating mass in these categories was derived through allometric relationships to the volume of living standing and removed (harvest and mortality) trees (cf. Thürig et al. 2005b and section 2.2 in Weggler et al 2012). The volume of living and removed trees was obtained from NFI data (NFI 1 through 4a) and data from projections with MASSIMO (Kaufmann 2000). Etzold et al. (2011) verified the accuracy of the C input estimates with independent data from long-term forest ecosystem research sites. The C content of the mass of the accumulated material was assumed to be 50 % (IPCC 2003).

The estimates of C inputs between two consecutive NFIs were obtained for each NFI site that was assessed as accessible forest but not shrub forest (*gemeinsam zugänglicher Wald ohne Gebüschwald*) between two consecutive NFIs.

- GHGI: in all four NFIs for the GHGI simulations (1'548 sites[1]; Tab. 1); henceforth GHGIsites) and
- FMRL and FDS: in NFIs 1 to 3 (4'726 sites[1]; Tab. 1); henceforth FMRLsites).

This was in accordance with the definition of productive and unproductive forest ("Forest Land remaining Forest Land" under UNFCCC and "Forest Management" under KP) used in the Swiss

[1] The difference in the number of available sites for the GHGI (1'548), and the FMRL and FDS (4'726), respectively is due to the fact that the NFI 4 is not fully completed yet. The GHGIsites represent thus a subset of the FMRLsites (Tab. 1). The division into two data sets was implemented to maximize the accuracy in the FMRL and FDS simulations.

greenhouse gas reporting (Thürig et al. 2005a; FOEN 2012). To obtain a consistent time series for each NFI site, only sites that met this definition were included in the Y07 simulations (see section 2.2).

The results of this procedure were 10-year-interval data of carbon in three DOM categories for each NFI sampling site. To be able to capture the change between two consecutive NFIs we extracted the carbon inputs in a difference analysis (V*eränderungsauswertung*) and, thus, obtained measured data that are representative of the time periods between two consecutive NFIs, i.e.:

- NFI 1 to NFI 2: 1986 – 1995
- NFI 2 to NFI 3: 1996 – 2005
- NFI 3 to NFI 4a: 2006 – 2011

For the Y07 simulation at the GHGIsites, the measured data from all three periods were used. Measured data from the periods NFI 1 to 2 and NFI 2 to 3 were combined with projected data from MASSIMO for the simulation at FMRLsites. In a similar fashion to the measured decadal NFI data, the decadal data from the MASSIMO projections for the period 2006 to 2050 were processed in a difference analysis to capture the change in C inputs between two consecutive time steps.

Table 1. Number of NFI sampling sites per subregion that were available for the Yasso07 simulation: GHGIsites (FMRLsites are given in brackets).

	Jura	**Plateau**	**Pre-Alps**	**Alps**	**Southern-Alps**	**Switzerland**
<601 m	103 (307)	229 (715)	34 (94)	47 (114)	54 (164)	467 (1'394)
600 – 1200 m	173 (495)	118 (355)	204 (619)	186 (616)	80 (269)	761 (2'354)
>1200 m	18 (67)	3 (6)	60 (181)	204 (618)	35 (106)	320 (978)
Total	294 (869)	350 (1'076)	298 (894)	437 (1'348)	169 (539)	1'548 (4'726)

Since Y07 operates on an annual time step but the temporal resolution of the measured NFI and the projected data from MASSIMO were greater than 1 year, the derived data on carbon inputs were converted to annual values (Tab. 2 and 3). For the interval period between two consecutive NFIs and two time steps in MASSIMO, a constant C input for Y07 was thus assumed. The observed data differed between the simulations for the GHGI (Tab. 2) and the simulations for the FMRL and FDS (Tab. 3) due to the different number of available NFI sites, i.e., 1'548 GHGIsites and 4'726 FMRLsites.

No historical data on C inputs existed that could be used to obtain the steady-state estimate through the Y07 spin-up procedure. Data that are representative of the period NFI 1 to 2 were thus used. Based on the assumption that over historical times there was a steady input of woody and non-woody material, the NFI site data were averaged using a moving window that included all sites within 20 km.

Table 2. Yasso07 Input Data for GHGIsites (n=1'548): Mean carbon content in three DOM categories of non-woody, fine- and coarse-woody material for different simulation periods and for the spin-up procedure as used to drive the Yasso07 simulations for the Swiss GHGI.

Simulation period	**NFI data**	**Non-woody** [Mg C ha^{-1}a^{-1}]	**Fine-woody** [Mg C ha^{-1}a^{-1}]	**Coarse-woody** [Mg C ha^{-1}a^{-1}]	**Total** [Mg C ha^{-1}a^{-1}]
Spin-up and 1961-1985	**NFI12avg (moving window)**	2.91	0.50	0.62	4.03
1986-1995	**NFI12**	2.96	0.51	0.65	4.04
1996-2005	**NFI23**	3.25	0.56	0.90	4.57
2006-2011	**NFI34a**	3.12	0.50	0.42	3.84

Table 3. Yasso07 Input Data for FMRLsites (n=4'726): Mean carbon content in three DOM categories for different simulation periods and for the spin-up procedure as used to drive the Yasso07 simulations for determining Switzerland's FMRL (1961-2020; grey highlighting) and for the other forest development scenarios (1961-2050). Until 2005 the data were derived from measured sources (i.e., NFIs 1 to 3). Starting in 2006 data were derived from projections with MASSIMO for four management scenarios (see Table 6 for details).

Simulation period	**Non-woody** [Mg C ha^{-1}a^{-1}]				**Fine-woody** [Mg C ha^{-1}a^{-1}]				**Coarse-woody** [Mg C ha^{-1}a^{-1}]			
	Management scenario											
	400	*411*	*425*	*485*	*400*	*411*	*425*	*485*	*400*	*411*	*425*	*485*
Spin-up and 1961-1985 (NFI12avg)	2.91				0.49				0.62			
1986-1995 (NFI12)	2.93				0.50				0.62			
1996-2005 (NFI23)	3.20				0.55				0.87			
2006-2015	3.20	3.17	3.17	3.21	0.50	0.50	0.50	0.51	0.94	1.01	1.02	0.88
2016-2025	3.31	3.18	3.17	3.40	0.51	0.49	0.48	0.53	0.94	1.05	1.09	0.84
2026-2035	3.42	3.18	3.12	3.63	0.52	0.48	0.47	0.55	0.94	1.01	1.07	0.88
2036-2045	3.55	3.19	3.08	3.85	0.53	0.48	0.46	0.58	0.98	1.03	1.06	0.95
2046-2050	3.66	3.21	3.03	4.04	0.54	0.48	0.46	0.60	1.02	1.04	1.10	1.02

Carbon inputs depend on site conditions such as dominant tree species as well as on removal and / or mortality due to disturbance. Carbon inputs can thus vary considerably between sites and regions and also over time (Tab. 4).

Table 4. Mean total carbon input for Yasso07 simulations in 15 NFI subregions based on 1'548 GHGIsites. Values for FMRLsites (n=4'726) are given in brackets; data the period NF1 3 to 4a were based on projected forest development with MASSIMO.

Production region	Elevation class	NFI 1-2 [Mg C ha^{-1}]	NFI 2-3 [Mg C ha^{-1}]	NFI 3-4a [Mg C ha^{-1}]
Jura	<601 m	3.94 (3.67)	4.60 (4.42)	3.76 (4.04)
	601-1200 m	3.66 (3.77)	3.98 (4.20)	3.87 (4.61)
	>1200 m	3.65 (3.17)	2.67 (3.12)	2.71 (3.70)
Plateau	<601 m	4.21 (4.25)	4.85 (4.91)	4.01 (4.35)
	601-1200 m	4.87 (4.60)	5.92 (5.36)	4.55 (5.00)
	>1200 m	4.11 (3.85)	4.87 (4.61)	4.36 (4.59)
Pre-Alps	<601 m	5.63 (5.09)	5.47 (5.27)	5.00 (5.31)
	601-1200 m	4.49 (4.56)	5.92 (5.75)	4.21 (5.23)
	>1200 m	4.30 (4.22)	4.69 (4.77)	4.16 (5.07)
Alps	<601 m	4.11 (3.32)	4.37 (3.67)	3.75 (3.85)
	601-1200 m	3.75 (3.91)	4.22 (4.24)	3.68 (4.46)
	>1200 m	4.56 (4.42)	4.78 (4.68)	4.33 (5.30)
Southern-Alps	<601 m	2.67 (2.61)	2.91 (3.02)	2.99 (3.65)
	601-1200 m	3.03 (2.95)	3.51 (3.45)	3.85 (4.54)
	>1200 m	4.14 (3.95)	5.05 (4.69)	5.42 (6.34)

The mass of carbon was partitioned separately for each pool and plant functional type into the four chemical compartments required by Y07 (Tab. 5).

Table 5. Fractions of chemical compartments used to partition carbon inputs; based on measured data from Switzerland for non-woody material (Heim and Frey 2004, Frey 2011) and Yasso07 default values for woody material derived from global data sets (Liski et al. 2009): A= acid soluble; W=water sol.; E=Ethanol sol.; N=insoluble.

Pool	Coniferous tree species				Broad-leaved tree species			
	A	W	E	N	A	W	E	N
Non-woody	0.43	0.29	0.05	0.24	0.46	0.15	0.04	0.36
Fine-woody	0.47	0.02	0.08	0.43	0.47	0.02	0.08	0.43
Coarse-woody	0.67	0.02	0.00	0.31	0.72	0.02	0.00	0.28

The effect of four forest management alternatives (Tab. 6) on forest development was simulated with the forest management model MASSIMO. This included the *business as usual* (BAU) scenario, which represents Switzerland's Forest Management Reference Level (henceforth FMRL scenario). For a given management scenario, the simulated forest development was used to derive the C inputs that drive the simulations with Y07.

Table 6. Forest management scenarios simulated with MASSIMO that provided the data to derive carbon inputs for the Yasso07 simulations. Scenario 425 represents the business as usual scenario, which was used to construct the FMRL (grey highlighting).

ID management scenario	Name management scenario	Definition
400	Sustained harvest	Constant total removal (cut and mortality) of ca. 9.1 Mio. m^3y^{-1} assuming 14% mortality rate (based on NFI 1 to 2 data); scenario delivers ca. 6.7 Mio. m^3y^{-1} merchantable wood (88% of stemwood over bark)
411	Sustained living biomass	Maintaining constant biomass volume corresponding to ca. 460 Mg CO_2ha^{-1}
425 (FMRL)	Business as usual; Increased harvest intensity	Increasing harvested volume relative to scenario 400: 2006-2015: +15% 2016-2055: +30%
485	Decreased harvest intensity	Decreasing harvested volume relative to scenario 400: 2006-2015: -10% 2016-2055: -20%

2.3.2 *Climate*

Climate data required by Y07 are mean annual temperature, annual temperature amplitude and annual precipitation sum. These data were derived for each NFI sampling site for observed climate until 2011 and projected future climate for the FMRL scenario and the forest development scenarios.

2.3.2.1 Observed climate

Data for observed climate were obtained from spatially gridded data prepared by the Federal Office of Meteorology and Climatology MeteoSwiss. Based on measured data from its network of weather stations, MeteoSwiss interpolates a country-wide data set with a spatial resolution of 2.2 km with monthly data since 1961 (MeteoSwiss 2012a, b).

For the location of each NFI sampling site, data for mean monthly absolute temperature [°C] and for monthly precipitation sum [mm] since 1961 were extracted from the respective gridded data. Annual mean temperature and precipitation sum were calculated as the mean and sum, respectively, of the monthly data (cf. Fig. 2 for nationwide data). Annual temperature amplitudes were calculated as

$$Tamp_y = 0.5 \times (max.monthly\ temperature_y - min.monthly\ temperature_y)$$

The suitability of the gridded data from MeteoSwiss was evaluated using data prepared by the Land Use Dynamics Research Group at the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL). The data from WSL are available at a spatial resolution of 100 m but only until the year 2006. At the NFI site level, the annual values of the three climate attributes differed very little over the period 1961 to 2006. Since the finer spatial resolution (i.e., 100 m versus 2.2km) did not result in significantly different values at the NFI site level, the data from MeteoSwiss at the coarser resolution of 2.2 km were considered sufficiently accurate for the purpose at hand.

Based on these data, the long-term annual means for temperature, temperature amplitude and precipitation sum were calculated at each NFI sampling site for the period 1961 to 1990 (Tab. 7 with stratified data). These were used in the spin-up procedure (see section 2.2).

Table 7. Climate data used; mean, minimum and maximum values for the long-term (1961-1990) annual means for a) temperature and b) precipitation of sites within 15 subregions of the NFI. The data are shown for the FMRLsites (n=4'726). The difference between FMRLsites and GHGIsites (n=1'548) was on average <0.01 °C for temperature and 0.7% for precipitation.

a) Temperature

		Production region					Switzerland [°C]
Elevation class		Jura [°C]	Plateau [°C]	Pre-Alps [°C]	Alps [°C]	Southern Alps [°C]	
<601 m	*Min*	5.7	6.5	4.2	-0.4	2.8	-0.4
	Mean	8.2	8.2	7.2	6.7	8.8	8.1
	Max	9.7	10.4	9.7	9.8	11.7	11.7
601-1200 m	*Min*	4.3	6.1	0.6	-1.6	0.4	-1.6
	Mean	6.8	7.7	5.7	4.4	5.8	6.0
	Max	9.3	9.3	9.2	9.3	11.2	11.2
>1200 m	*Min*	4.4	5.3	0.8	-2.7	-0.9	-2.7
	Mean	5.7	5.9	4.2	2.0	3.9	2.9
	Max	7.1	6.8	6.8	8.2	8.4	8.4
Total	*Min*	4.3	5.3	0.6	-2.7	-0.9	-2.7
	Mean	7.2	8.0	5.6	3.5	6.4	6.0
	Max	9.7	10.4	9.7	9.8	11.7	11.7

b) Precipitation

		Production region					Switzerland [mm]
Elevation class		Jura [mm]	Plateau [mm]	Pre-Alps [mm]	Alps [mm]	Southern Alps [mm]	
<601 m	*Min*	850	863	1139	727	1444	727
	Mean	1090	1098	1398	1140	1820	1206
	Max	1508	1579	2034	1978	2187	2187
601-1200 m	*Min*	902	919	1141	676	1002	676
	Mean	1359	1225	1636	1301	1743	1439
	Max	1854	1698	2215	2194	2247	2247
>1200 m	*Min*	1330	1695	1313	694	1222	694
	Mean	1681	1792	1799	1206	1683	1401
	Max	1900	1895	2272	2221	2034	2272
Total	*Min*	850	863	1139	676	1002	676
	Mean	1284	1147	1642	1239	1755	1361
	Max	1900	1895	2272	2221	2247	2272

2.3.2.2 Projected future climate

Data for climate change scenarios that are consistent with the spatial resolution of the observed data were not available. To obtain data for possible future temperature and precipitation for each NFI sampling site, alternative sources were explored. The recently published scenarios for Switzerland (CH2011 2011) were not suitable as they are available at a coarse spatial resolution of 20 km^2 only. From WSL, downscaled data based on the global Hadley Center Model projections (Mitchell et al. 2004) of the IPCC AR3 (IPCC 2000) were available. The WSL data presented the only available data at a spatial resolution that was fine enough to distinguish between individual NFI sites and between the high topographic variability in the Alps.

From the WSL data, monthly anomalies for temperature and precipitation for each NFI sampling site were obtained. The anomalies for the period 2012-2050 were added to the long-term monthly mean temperature and precipitation sum of the observed data from the period 1976-2005. Annual temperature, annual temperature amplitude and annual precipitation sum were calculated as described above for the observed climate. Based on this procedure data were obtained that are representative of the climate change scenarios A1, A2 and B2 of the IPCC AR 3 (IPCC 2000; cf. Fig. 2 for nationwide data). To minimize interannual fluctuations in the projected climate data, a 10-year moving mean was calculated (i.e., data at time *t* were calculated as the mean of the annual values from time *t-9* to time *t*).

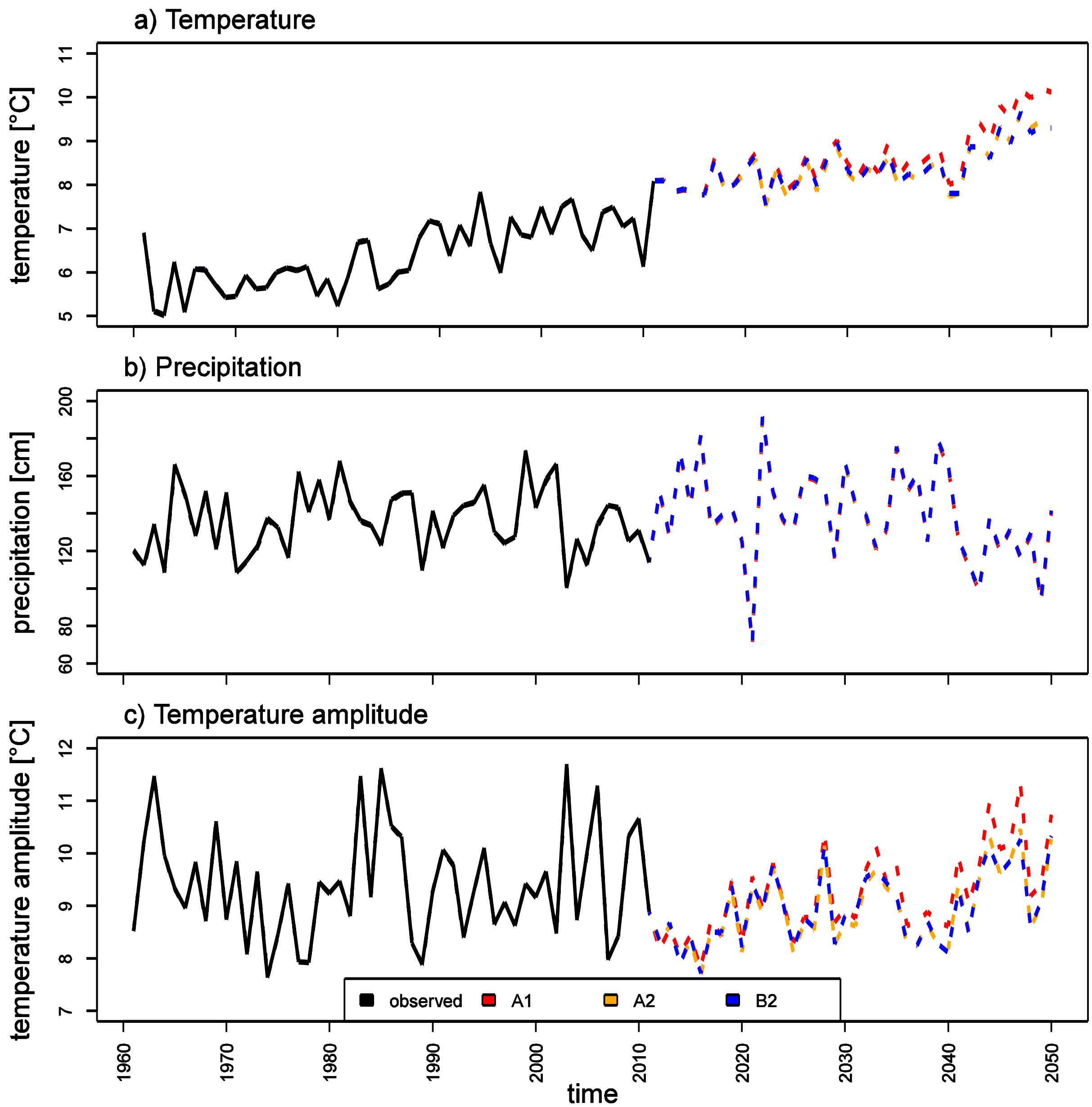

Figure 2. Mean annual temperature and precipitation sum over all GHGIsites (1961-2011; n=1'548; solid lines) and FMRLsites (1961-2050; n=4'726; dashed lines). Data after 2011 represent the climate change scenarios A1, A2 and B2 of the IPCC AR 3 (IPCC 2000). For the period with observed climate data (1961-2011), the shown means differed only minimally between GHGIsites and FMRLsites.

2.4 Analysis

Yasso07 produces annual estimates of carbon available in the four chemical compartments (A, W, E and N) and in the humus compartment (H) separately for the categories of the C input, i.e., non-woody and coarse- and fine-woody material. Using this information, annual estimates of carbon stored in the soil, the litter–fermented humus (LFH) layer and in deadwood were calculated (see Appendix I for a detailed description and verification of this approach). For consistency with previous submissions of Switzerland's NIR (cf. chapter 7.3.4.8 in FOEN 2012), C stocks and C stock changes were estimated for a) the LFH layer pool rather than the litter pool (sensu IPCC 2003) and b) the deadwood pool based on coarse-woody inputs only.

Based on these annual carbon stock estimates at a NFI sampling site, averaged values over three years were calculated as recommended in IPCC (2003). Thus, the stock at time *t* was calculated as the mean of the annual stocks from time *t-2* to time *t*. The change in the C stock was calculated based on the resulting annual, averaged data. For reporting in Switzerland's GHGI and for determining the FMRL, these data were used (Appendix II and III). In addition, the change was calculated based on the original, annual stocks to evaluate the effect of the averaging. If not otherwise noted, the C stock and C stock change data presented in the results and discussion are based on the original, annual results.

To obtain the final data for the GHGI, an additional step was required. The averaged annual C stocks in deadwood were scaled based on NFI data for greater accuracy. This was possible only at the level of the 15 subregions (see Appendix IV for details). The changes in deadwood C stocks were re-calculated based on the scaled stock data. This step became necessary to produce a time series of the deadwood C stock as requested for the data submission for reporting in the GHGI and for determining the FMRL (Meeting on deliverables, 10.09.2012). For comparability between pools, the results (section 3) present the unscaled deadwood C stocks.

2.5 Verification

Estimates of C stocks and C stock changes obtained from Y07 were verified using independent data. The results for the total C stock from simulations with Yasso07 (i.e., C in soil, litter and deadwood, cf. section 2.1) were compared with reported stocks by Weggler et al. (2012), who found that simulated stocks underestimated measured stocks. Based on the separation of the total C stocks into deadwood, LFH layer and soil pools (Appendix I), a more differentiated verification was possible. Pool sizes were compared against published data for soil C stocks (Hagedorn et al. 2010), for C stored in the LFH layer (Moeri 2007) and in deadwood (www.lfi.ch).

Particularly important is the verification of the stock changes that were calculated for reporting in Switzerland's NIR and for determining the Swiss FMRL. Since relevant data is scarce, a verification of changes, especially on an annual resolution is in most cases not possible. Thus, data at greater than annual intervals or ancillary data have to be used. The most relevant data that are referred to in the discussion are:

- Soil carbon: Swiss Soil Monitoring Network (NABO; www.nabo.admin.ch) including data from 28 sites in forests that are sampled since 1985 at 5-year intervals.
- LFH layer carbon: Results of the Y07 parameter validation (cf. Didion and Frey. in prep; Weggler et al. 2012) based on measured data from a Swiss litter bag experiment (Heim and Frey 2004, Frey 2011).
- Deadwood carbon: Forest health inventory (Sanasilva; www.wsl.ch/dienstleistungen/inventare/sanasilva/index_EN) which reports the annual relative basal area of deadwood measured at 48 sites since 1985.

2.6 Uncertainty

Each input data set (climate, NFI, MASSIMO) and the Y07 model parameters are associated with uncertainty. The uncertainty for the climate data (measurement error, spatial interpolation) could not be quantified and no other relevant data were available. The NFI reports uncertainty for the measured data and the NFI sampling procedure is designed to minimize sampling error (Brassel and Lischke 2001). The C inputs for the Y07 simulations that were used in this study were derived from measured NFI data and from MASSIMO simulation results. The derivation of the data (allometric relationships etc.) presents a source of uncertainty that is difficult to estimate; Monni et al. 2007 provide an estimate of 30%. Parameter uncertainty of the Y07 was estimated as ca. 4 to 5 % with the parameter set from Tuomi et al. (2011b). For the parameter set used in this study uncertainty could not be estimated due to technical reasons; 4-5% is a plausible estimate (see section 2.1.1). At the level of an individual NFI sampling site, the cumulative uncertainty could thus not be estimated. For stratified data (subregion, nationally), the variability between sites is reported. The variability between sites is large due to differences in forest type, climate (cf. also Don et al. 2007), harvesting and mortality. It is higher than the uncertainty deriving from the data and the model.

3 Results

Results are shown for data prepared for a) GHG Inventory reporting, b) determining FMRL (i.e., management scenario 425 and climate scenario A2) and c) other forest development scenarios. Reported are results for C stocks and C stock changes in three pools: soil, LFH layer and deadwood (excluding C inputs from fine-woody material for consistency with the data submitted for GHGI reporting and determining FMRL, cf. section 2.4). Deadwood C stocks C stock changes prepared for the GHGI and for the determining the FMRL are reported for unscaled data (cf. section 2.4) to provide results that are comparable between pools. The difference between unscaled and scaled deadwood C stocks and C stock changes is illustrated and discussed in Appendix IV. For completeness and if not otherwise noted, the total stocks include C stored in fine-woody material, which contributes ca. 1 to 2% to the total stock (as compared to 78-80% for soil C, 9-11% for deadwood C and 7-9% for LFH layer C)

By default annual rather than averaged annual data (cf. section 2.4) are given. C stocks and C stock changes are presented as carbon per unit area to minimize errors introduced by changes in the forest area. This is to allow for better comparability since the total forest area changed over time. The averaged data that were prepared for GHGI reporting are in Appendix II and for determining FMRL in Appendix III.

3.1 C stocks and C stock changes

To illustrate the relationship between C inputs and C stocks, Figure 3 shows the total C input (i.e., sum of inputs from non-woody and woody material as reported in Tab. 2), the total C (i.e., sum of deadwood, LFH layer and soil) and the soil C stocks for the GHGI data. The soil C pool is nearly constant over time, whereas the total C stock responds immediately to changes in C inputs, which indicates a high correlation between the above-ground deadwood and litter (incl. LFH layer) pools (cf. Fig. 4) with C inputs. Carbon inputs increased significantly from the period between NFIs 1 and 2 to the period between NFIs 2 and 3, which was due to large-scale windthrow events including Vivian (1990) and Lothar (1999). Following the NFI 3 carbon inputs decreased again to the level of the period between NFIs 1 and 2 (Fig. 3, Tab. 2).

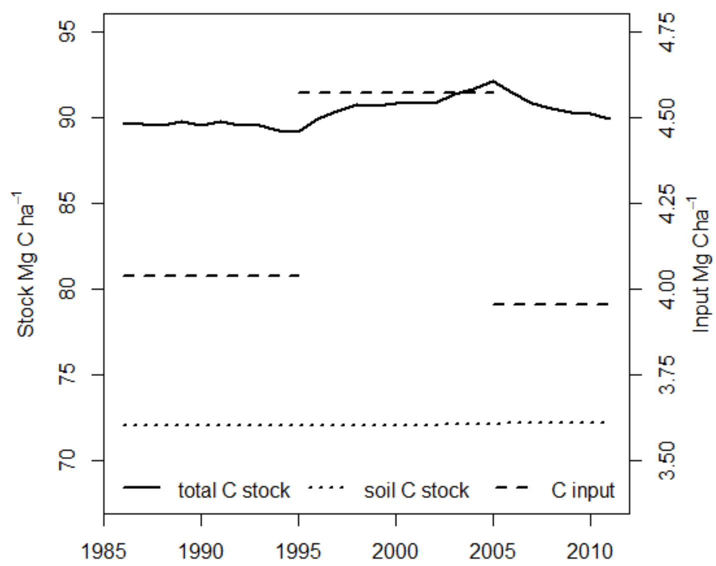

Figure 3. Annual mean total carbon inputs for Yasso07 simulations based on measured data from 4 NFIs and annual mean total and soil carbon stocks based on data for the GHGI reporting (GHGIsites, n=1'548).

The nationwide C stocks in deadwood and LFH layer are only ca. 10 to 15% of size of the soil pool but, relative to the mean values, the variability in the deadwood and LFH layer stocks is higher than in the soil pool (Fig. 4). The variability in the LFH layer pool and, particularly, in the deadwood pool is correlated to the amount of C inputs (cf. Fig. 3) as indicated by the increase in variability from ca. 1985 to ca. 2005 and the subsequent decrease (Fig. 4a, c and e).

According to the FMRL scenario (i.e., management scenario representing Switzerland's FMRL), only a moderate increase in deadwood pool size can be expected in the near future while the LFH layer pool and, particularly, the soil pool remain nearly constant (Fig. 4b, d and f). The FMRL scenario, which was implemented in 2010, overestimated particularly the coarse-woody C inputs after the NFI 3, i.e., 1.02 Mg C $ha^{-1}a^{-1}$ rather than 0.42 Mg C $ha^{-1}a^{-1}$ (cf. Tab. 2 and 3). The effect is apparent in the development of the pool sizes from 2006 to 2011 between the measurement-based NIR pool estimates and simulation-based FMRL pool projections (Fig. 4).

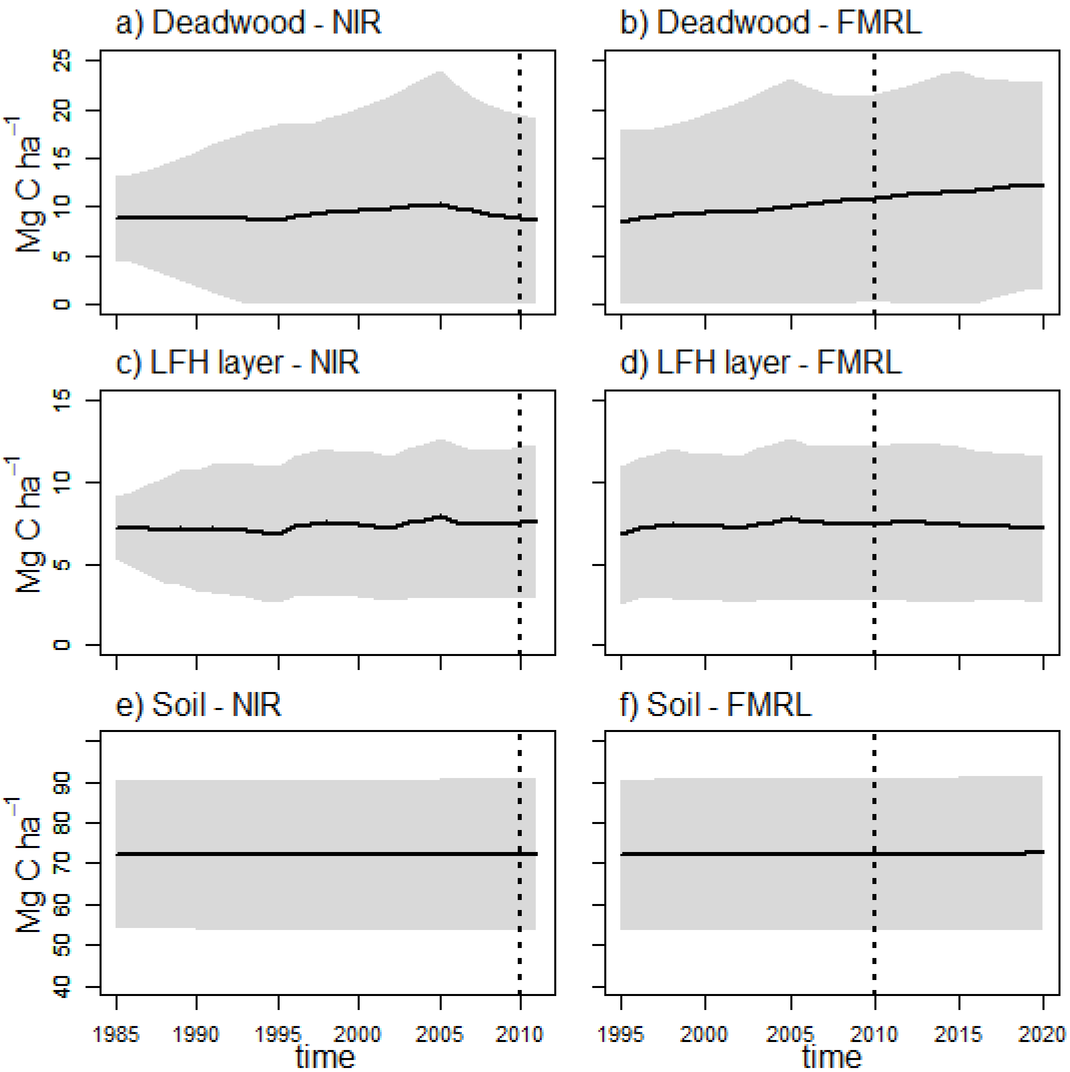

Figure 4. Mean carbon stocks (solid black line) ± 1 standard deviation (shaded area) for 3 pools for GHGI (a, c, e) and FMRL data (b, d, f). GHGI data are shown for the period 1985 to 2011, FMRL data for the period 1995 to 2020; for comparison, the dashed vertical lines indicate the year 2010.

Site-specific variation in C inputs and site conditions drive the variability in C pools. Mean pool sizes and their variability vary strongly between the 15 NFI subregions (Fig. 5). With the exception of the deadwood pool there is generally an increase in pool size with elevation class (cf. the respective totals for Switzerland in Fig. 5).

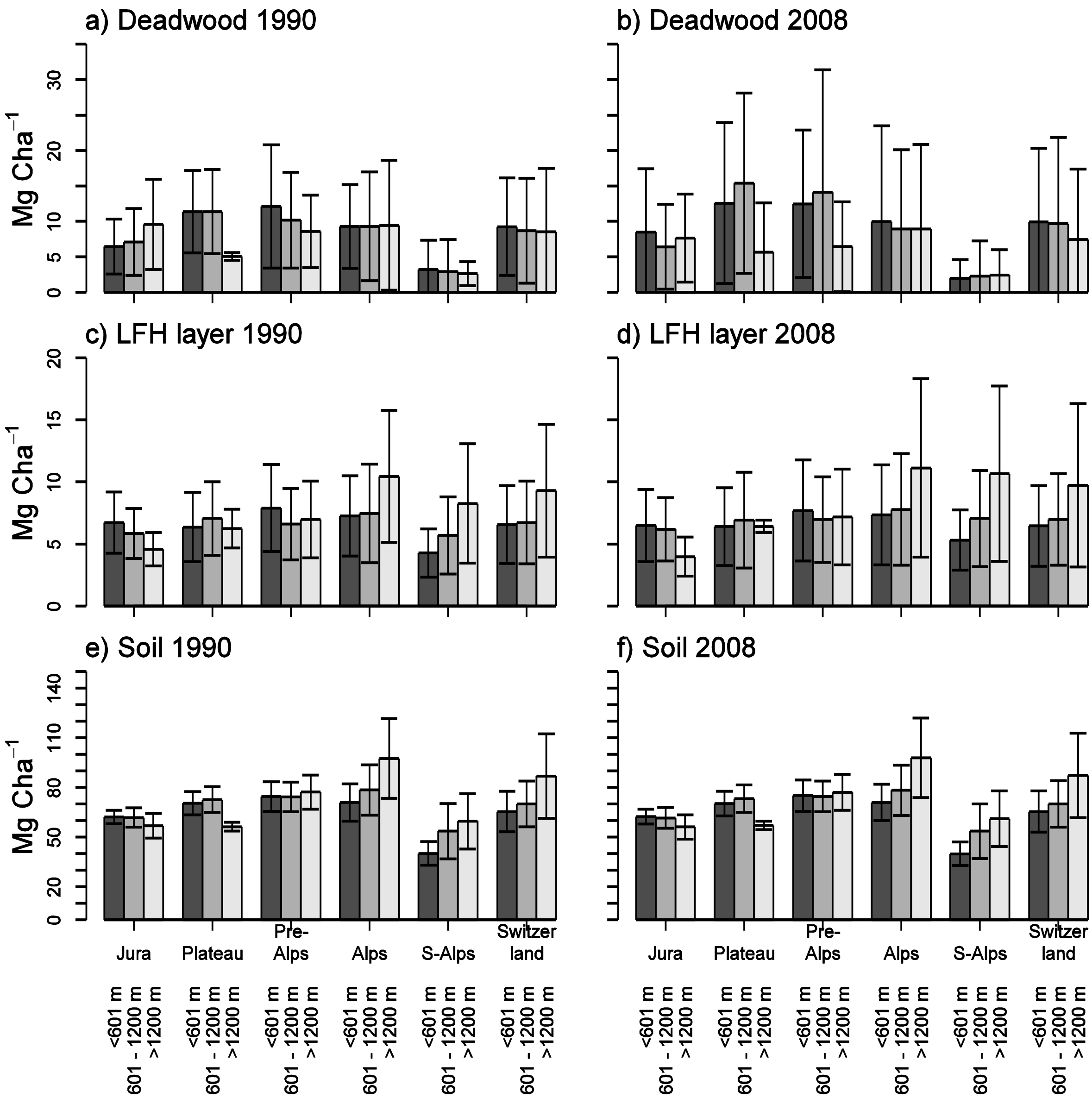

Figure 5. Mean C stock estimates with Yasso07 for GHGIsites in 1990 and 2008 in 15 NFI subregions (three elevation classes in 5 production regions. Whiskers indicate mean ± 1 standard deviation

The differences in the variability of C stocks in different pools affect the resulting stock changes (Fig. 6). C stock changes and their temporal variability are highest (up to ca. 400 Kg C $ha^{-1}a^{-1}$) in the deadwood and LFH layer pools (Fig. 6c and d). Until 2005 deadwood was typically a carbon sink and became a source following the decrease in carbon inputs from coarse-woody material (cf. Tab. 2). The temporal dynamic in the total combined flux (Fig. 6f) results from the dynamics in the deadwood and LFH layer pools. In comparison, the C stock changes in the soil pool are smaller and less variable over time (Fig. 6e) with maxima of ca. 30 Kg C $ha^{-1}a^{-1}$. With the exception of C stock changes in the LFH layer, which is has a statistically significant negative correlation with precipitation, stock changes (Fig. 6 c-f) and climate variables (Fig. 6 a and b) are only weakly correlated.

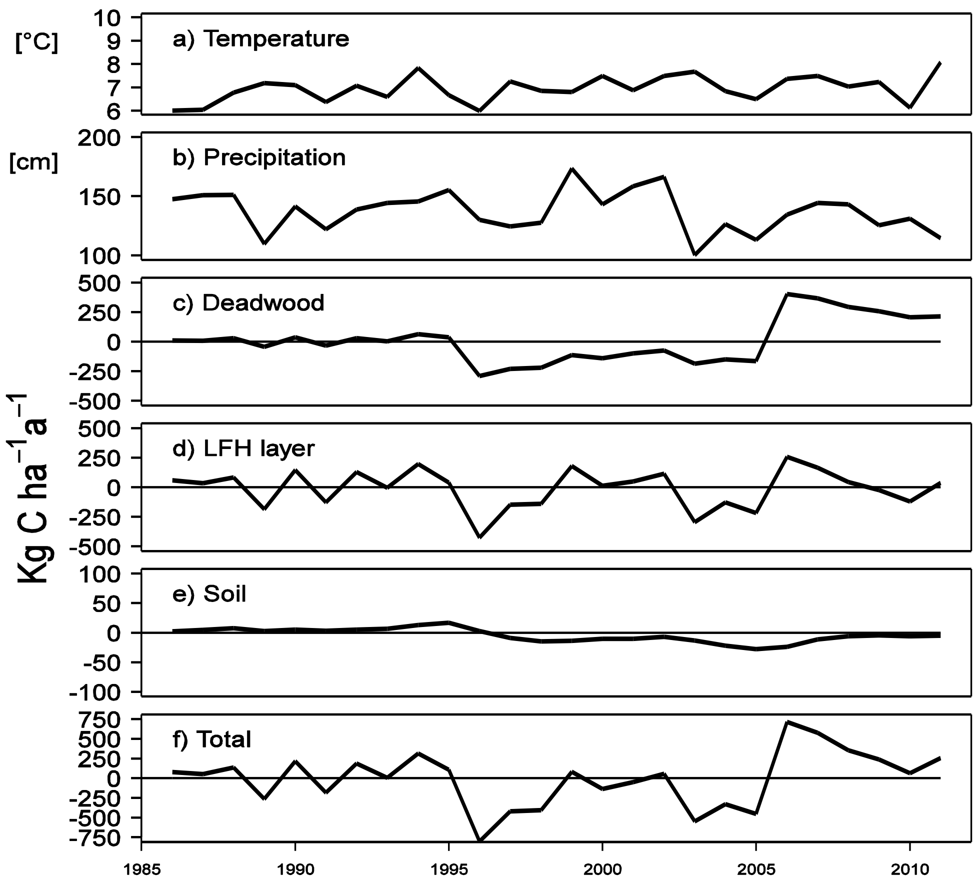

Figure 6. Climate and C stock change 1986-2011; Annual means of a) temperature, b) precipitation sum, c) deadwood, d) LFH layer, e) soil and f) total C stock change estimated with Yasso07 for the GHGIsites. Negative values indicate a carbon sink, positive values a carbon source.

Similarly to the C stocks (Fig. 5), the C stock changes differ strongly between NFI subregions (Fig. 7 for total C stock change). For the period 1990 to 2011 C stock changes are small compared to the change from 2010 to 2011 (Fig. 7). Between 1990 and 2011 the change in pool sizes varies between source and sink effects (Fig. 7a). The C stock changes from 2010 to 2011 range up to ca. 600 Kg C $ha^{-1}a^{-1}$ and, with the exception of the Southern-Alps, act consistently as a C source (Fig. 7b). C stock changes in the colline subregions (≤600 m a.s.l.) are only approximately a third of those in the montane (601 m to 1200 m) and subalpine (>1200 m) subregions (Fig. 7). The total C stock in soil and dead organic material in Swiss forest decreased from 2010 to 2011 by 0.243 Mg C $ha^{-1}a^{-1}$ (Fig. 6d) or 0.284 Tg C a^{-1} (based on a forest area of 1'165'345 ha observed for the period LFI 3 to 4a). This small source effect is based on the annual data and differs from the sink effect obtained for the averaged values of 0.029 Mg C $ha^{-1}a^{-1}$ or 0.034 Tg C a^{-1} that were prepared for GHGI reporting (cf. section 2.4 and Appendix II).

There is an order of magnitude difference in the mean total C stock changes for the period 1990 to 2011 that were estimated for the GHGI (-18.58 Kg C $ha^{-1}a^{-1}$) and the FMRL (-146.69 Kg C $ha^{-1}a^{-1}$). This is mainly due to the differences in the change in the deadwood pool size (Tab. 8). The between-site variability indicated by the standard deviation is especially high for the C stock change in deadwood estimated for the GHGI data, which is an order of magnitude higher than for the corresponding FMRL data. This affects the pattern for total stocks while there is only a minimal difference in the case of the LFH layer and soil pools (Tab. 8).

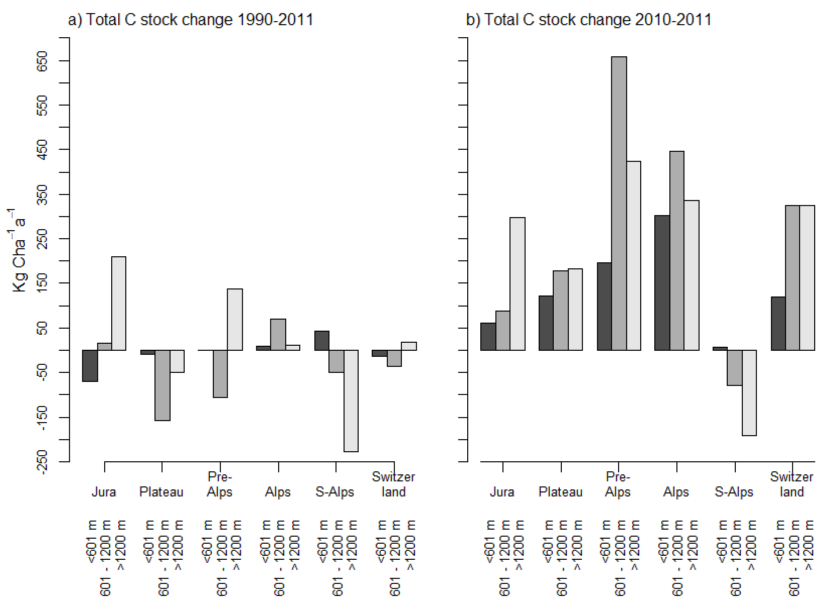

Figure 7. Mean total C stock changes in 15 NFI subregions (3 elevation classes in 5 production regions) and nationwide totals for three elevation classes for GHGIsites. Total C stock changes were calculated as the sum of the changes in deadwood, LFH layer and soil. No standard deviations are shown due to their size, i.e., several times larger than the mean. Negative values indicate a carbon sink, positive values a carbon source.

The variability expressed by the standard deviation in the C stock changes between GHGIsites is generally more than one magnitude higher than the mean (Tab. 8), which is a result of the a small mean that fluctuates around zero changing from small sources to a small sinks and the revers.

Table 8. Nationwide means and standard deviations for C stock changes in 3 pools and the total change over the period 1990 to 2011 for GHGI (measurement-based) and FMRL (simulation-based since 2006) data. Standard deviations are given in brackets.

	Deadwood [Kg C ha^{-1}a^{-1}]	**LFH layer** [Kg C ha^{-1}a^{-1}]	**Soil** [Kg C ha^{-1}a^{-1}]	**Total** [Kg C ha^{-1}a^{-1}]
NIR	8.39 (±473.45)	-20.05 (±137.67)	-6.6 (±130.11)	-18.58 (±525.31)
FMRL	-117.62 (±502.8)	-22.9 (±148.12)	-5.44 (±131.14)	-146.69 (±590.93)

Changes in C stock over time intervals that are relevant for reporting under the Kyoto Protocol are presented in Table 9. For comparison Table 9 includes C stock changes calculated from annual stocks and from stocks that were averaged over three years (cf. section 2.4). The estimates based on the FMRL data indicate a sink effect in all 3 pools for the first commitment period 2008 to 2012 with a total mean sink of ca. 53 Kg C $ha^{-1}a^{-1}$ (averaged data, incl. scaled deadwood C stock cf. Appendix III) to ca. 167 Kg C $ha^{-1}a^{-1}$ (averaged data; Tab. 9) and ca. 186 Kg C $ha^{-1}a^{-1}$ (annual data; Tab. 9). In contrast, the measurement-based GHGI data that are available until 2011 result in a carbon source from 2008 to 2011 of on average ca. 21 Kg C $ha^{-1}a^{-1}$ (averaged data, incl. scaled deadwood C stock) to ca. 185 Kg C $ha^{-1}a^{-1}$ (annual data) and ca. 264 Kg C $ha^{-1}a^{-1}$ (averaged data). In the second commitment period, for both intervals that are under discussion (i.e., 2013-2017 and 2013-2020) the LFH layer pool becomes a source of carbon in the FMRL scenario. In the FMRL scenario the deadwood and soil pools compensate this source effect resulting in a total sink effect of ca. 67 Kg C $ha^{-1}a^{-1}$ (annual data) to ca. 86 Kg C $ha^{-1}a^{-1}$ (averaged data) for the period 2013 to 2017 and ca. 62 Kg C $ha^{-1}a^{-1}$ (annual data) to ca. 79 Kg C $ha^{-1}a^{-1}$ (averaged data) for the period 2013 to 2020, respectively (Tab. 9). Annual and averaged data give similar estimates that differ by <10% with the exception of the LFH layer (and consequently for the sum of pools).

Table 9. C stock changes for KP commitment periods (1st CP and two periods under discussion for 2nd CP) for FMRLsites in dead wood (unscaled), LFH layer and soil and total. Negative values indicate a carbon sink, positive values a carbon source. The 'avg' suffix indicates the flux calculated from stocks that were averaged using a moving window of three years. Standard deviations are given in brackets.

	Deadwood [Kg C $ha^{-1}a^{-1}$]	**LFH layer** [Kg C $ha^{-1}a^{-1}$]	**Soil** [Kg C $ha^{-1}a^{-1}$]	**Total** [Kg C $ha^{-1}a^{-1}$]
2008 - 2012	-164.19 (±1365.43)	-10.73 (±168.67)	-17.19 (±146.15)	-186.30 (±1513.11)
2008 – 2012 avg	-171.52 (±1499.99)	8.94 (±239.47)	-16.67 (±143.37)	-166.64 (±1666.91)
2013 - 2017	-124.76 (±837.05)	55.85 (±302.27)	-16.54 (±158.46)	-67.14 (±876.04)
2013 – 2017 avg	-123.13 (±786.13)	41.55 (±178.68)	-17.82 (±159.09)	-86.10 (±811.74)
2013 - 2020	-118.81 (±964.56)	53.77 (±268.95)	-14.42 (±152.87)	-61.88 (±1041.45)
2013 – 2020 avg	-124.66 (±845.25)	45.40 (±247.29)	-15.70 (±153.67)	-79.28 (±897.05)

Figure 8 shows possible dynamics in C stocks until 2050. Carbon stock estimates for management scenario with less intense harvesting (i.e., mgmt. 400 and 485; Tab. 6) diverge one year after the implementation of the management change (2006) from the scenarios with increased harvesting intensity (i.e., mgmt. 411 and the BAU scenario 425; Tab. 6). Until 2050 the general pattern is similar for the harvest-intensive management scenarios 411 and 425 on the one hand, and for the more moderate scenarios 400 and 485 on the other hand (Fig. 8). The pool size for the two harvest-intensive management scenario peaks in ca. 2025 at ca. 93 to 94 Kg C ha^{-1}. A continuous increase in pool size to ca. 94 to 96 Kg C ha^{-1} in 2050 is projected for the two moderate scenarios. The effect of a changing climate is comparatively small with no difference between the A2 and B2 climate scenarios. The difference in the development of C stocks between the A2 and B2 scenarios on the one hand, and the A1 scenario on the other hand, becomes first apparent in ca. 2040 (Fig. 8).

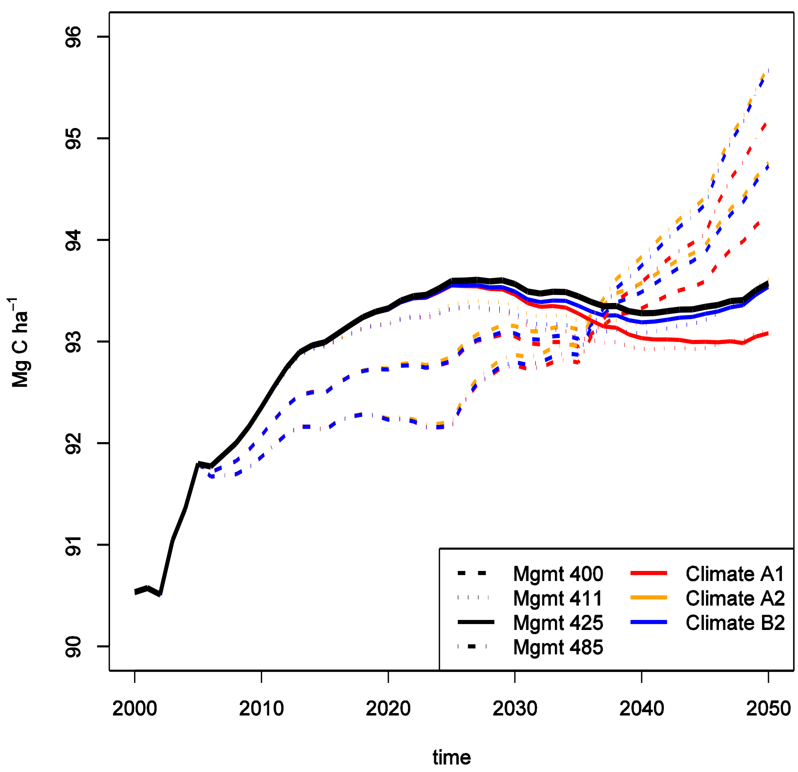

Figure 8. Total carbon stocks for 12 forest development scenarios (4 management scenarios (Mgmt; cf. Tab. 6) and 3 climate change scenarios (cf. Fig. 2). The BAU scenario used for determining the forest management reference level FMRL (Mgmt 425, Climate A2) is shown as fat, solid black line.

3.2 Verification

The carbon stocks of the deadwood, LFH layer and soil pools derived from the default Yasso07 results (cf. Appendix I) were verified using independent data. Relevant measured data on C stock changes were not available. Estimated C stock changes with Y07 are presented in Figures 6 and 7 and in Tables 8 and 9.

Weggler et al. (2012) found that simulated stocks underestimated measured stocks. This is true also for the revised estimates presented in this report. The pattern differs between the deadwood, LFH layer and soil pools (Tab. 10 to 13). The Y07 estimates presented here are based on the GHGI data and were formatted according to the available observed data and respective metrics were calculated (see Table captions for details).

Hagedorn et al. (2010) reported mean carbon stocks in the mineral soil in 5 NFI production regions and in Switzerland. The re-calculated stocks derived from observations at 213 NFI sites and corresponding estimates from Y07 are shown in Table 10. While the pattern in the central production regions, Swiss Plateau, Pre-Alps and Alps, are similar, estimations and observations differ strongly in the Jura and Southern-Alps. The increase in pool size with elevation of 1.9 Mg C ha^{-1}100 m^{-1} that was calculated for the Y07 estimates (Fig. 9) compares well with the 2.3 Mg C ha^{-1}100 m^{-1} reported by Hagedorn et al. (2010).

Table 10. Minimum and maximum of the mean soil pool size for five NFI production regions and for Switzerland calculated for the GHGI data for the period 1961 to 2011 and mean measured soil pool size (cf. Fig. 2 in Hagedorn et al. 2010). Standard deviations are given in brackets.

Production region	**Mean estimated soil pool size (Mg C ha^{-1})**		**Mean observed soil pool size [1] (Mg C ha^{-1})**
	Min (1961-2011)	*Max (1961-2011)*	
Jura	61.44 (±5.47)	61.59 (±5.48)	138.06 (±69.86)
Plateau	70.91 (±7.49)	71.12 (±7.95)	81.32 (±32.85)
Pre Alps	74.76 (±9.28)	75.08 (±9.77)	130.12 (±58.99)
Alps	86.36 (±22.12)	86.61 (±22.40)	124.15 (±66.86)
Southern-Alps	50.33 (±16.12)	50.83 (±16.38)	218.97 (±124.40)
Switzerland	71.96 (±18.26)	72.20 (±18.52)	133.95 (±82.16)

[1] Mean mineral soil pool size to 1 m depth based on observations at 213 NFI sites (Soil database, Soil Science Unit)

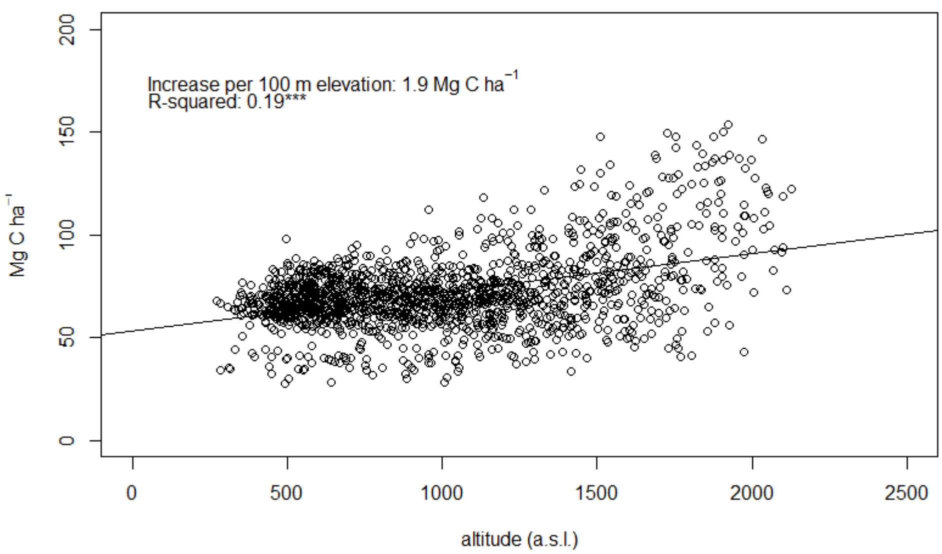

Figure 9. Soil pool size at 1'548 NIRsites with altitude.

Moeri (2007) provides a comprehensive analysis of carbon stored in the LFH layer. The estimated pool sizes from Y07 are ca. 50 to 75% lower than reported values dependent on the region (Tab. 11). With the exception of the Southern-Alps, the pattern between production regions were reproduced by Y07.

Table 11. Minimum and maximum of mean LFH layer pool size for five NFI production region and for Switzerland calculated for the GHGIsites for the period 1961 to 2011 and mean measured LFH layer pool size based on 870 observations (Tab.5.5 in Moeri 2007). Standard errors are given in brackets

Production region	**Mean estimated LFH layer pool size (Mg C ha^{-1})**		**Mean observed LFH layer pool size (Mg C ha^{-1})**
	Min	*Max*	
Jura	5.82 (2.47)	6.76 (0.71)	11.07 (1.78)
Plateau	6.32 (3.24)	7.22 (0.68)	11.60 (0.79)
Pre Alps	6.63 (3.45)	7.62 (4.00)	20.53 (1.68)
Alps	8.56 (2.53)	9.63 (6.40)	37.20 (3.07)
Southern-Alps	5.48 (3.85)	7.24 (4.77)	26.01 (4.85)
Switzerland	6.85 (0.11)	7.85 (0.12)	20.93 (1.01)

The amount of carbon stored in deadwood was analysed for the observed deadwood volume in the NFI 3 (www.lfi.ch; Tab. 12). Pool sizes of carbon modeled with Y07 generally overestimated reported values except in the Southern-Alps (Tab. 13).

Table 12. Mean carbon in deadwood based on measured data on volume of deadwood >12 cm in diameter calculated for NFI 3 sites that were assessed as accessible forest but not scrub forest for NFI 2 and 3. Relative standard errors (%) are given in brackets.

	Jura	**Plateau**	**Pre-Alps**	**Alps**	**Southern-Alps**	**Switzerland**
	Mg/ha	**Mg/ha**	**Mg/ha**	**Mg/ha**	**Mg/ha**	**Mg/ha**
<601 m	5.10 (±12)	4.10 (±9)	5.29 (±29)	5.17 (±28)	8.81 (±18)	4.82 (±6)
600 – 1200 m	5.96 (±9)	5.47 (±10)	7.17 (±9)	7.35 (±8)	4.94 (±12)	6.33 (±4)
>1200 m	4.43 (±22)	12.64 (±51)	11.8 (±9)	7.44 (±6)	5.79 (±12)	7.85 (±5)
Total	5.56 (±7)	4.76 (±7)	8.72 (±6)	7.36 (±5)	5.89 (±8)	6.59 (±3)

Table 13. Mean carbon in deadwood based on estimates with Yasso07 for GHGIsites. Carbon stocks were calculated as the mean of the years 2004 to 2006 to match the period of the NFI 3 measurement campaign. Relative standard errors (%) are given in brackets.

	Jura	**Plateau**	**Pre-Alps**	**Alps**	**Southern-Alps**	**Switzerland**
	Mg/ha	**Mg/ha**	**Mg/ha**	**Mg/ha**	**Mg/ha**	**Mg/ha**
<601 m	8.94 (±1)	13.31 (±1)	12.99 (±1)	10.47 (±1)	2.18 (±2)	10.75 (±1)
600 – 1200 m	6.76 (±1)	16.14 (±1)	15.35 (±2)	9.54 (±1)	2.14 (±1)	10.71 (±1)
>1200 m	8.43 (±2)	6.50 (±3)	6.83 (±1)	9.39 (±1)	2.06 (±4)	8.03 (±)
Total	7.63 (±1)	14.20 (±1)	13.37 (±2)	9.57 (±1)	2.13 (±1)	10.17 (±3)

3.3 International comparison

The UNFCCC publishes annually a summary of national inventory reports submitted by the signature states. For forest land remaining forest land, Table 5.2a of the Synthesis and Assessment Report on the Greenhouse Gas Inventories submitted in 2012 (UNFCCC 2012) presents data on reported net carbon change from 2009 to 2010 in mineral soil and in dead organic matter. Table 14 compares the relevant data that were calculated with Yasso07 for Switzerland with the data for European countries that have either similar forests (Austria and Liechtenstein) as Switzerland and / or apply Yasso7 (Austria, Finland and Norway).

Table 14. International comparison: Carbon stock change 2009 to 2010 in dead organic matter and in mineral soil on forest land remaining forest land as reported for European countries (Tab. 5.2a in UNFCCC 2012) and as estimated with Yasso07 for Switzerland. For the estimate for Switzerland the change in dead organic matter was based on the sum of changes in deadwood and LFH layer; the standard deviation is given in brackets. Negative values indicate a sink and positive values a source.

Country	Net CSC in soil [Mg C $ha^{-1}a^{-1}$]	Net CSC in dead organic matter [Mg C $ha^{-1}a^{-1}$]
Austria	0.19	-0.06
EU15	-0.05	-0.03
Finland	-0.09	Not given
Liechtenstein	-0.01	0.00
Norway	-0.12	-0.08
Switzerland, averaged[1]	-0.006 (±0.128)	-0.01 (±1.194)
Switzerland, annual[2]	-0.006 (±0.124)	-0.007 (±0.111)

[1]Estimates of C stock change corresponding to the data for reporting to the GHGI, i.e., based on C stocks that were averaged over three years incl. scaled deadwood stocks (cf. section 2.4 and Appendix IV).
[2]Estimates of C stock change calculated based on not averaged, annual C stocks.

4 Discussion

The report addressed two aspects: a) the implementation of the Yasso07 model to estimate C stocks in Switzerland and to present and discuss these estimates; and b) the presentation of C stock changes for reporting in Switzerland's Greenhouse Gas Inventory and for determining Switzerland's FMRL. Given the comprehensive data sets on inputs that are required by Y07, the National Forest Inventory and gridded climate data that matches the spatial resolution of the NFI, the model could be implemented to obtain consistent and complete estimates of annual change in carbon pool sizes since 1961 and for the forest area.

4.1 Verification

First it should be noted, that the approach for deriving separate estimates for C stocks in deadwood, LFH layer and soil from the default Yasso07 output presents only an approximation that is based on the source of C inputs (i.e., non-woody and woody material) and the five carbon compartments in Y07 (cf. section 2.4 and Appendix I).

The results presented here corresponded to the findings by Weggler at al. (2012) that Y07 underestimates the combined C stock of soil, litter and deadwood. Based on the approach to separate the combined Y07 data into individual pools, the main reason for the underestimation can be attributed to the soil pool (Tab. 10). Yasso07 estimates C stocks solely on data on C inputs and climate. However, in reality pool sizes can in addition consist of C derived from other sources. This is the case in the Southern-Alps, where pyrogenic C adds significantly to current pool sizes (Preston and Schmidt 2006, Zanelli et al. 2006, Eckmeier et al. 2010, Singh et al. 2011, Thum et al. 2011). This explains, to a large extent, the particularly large underestimation by Y07 of stocks in the Southern-Alps, and may also be responsible for the underestimation in other regions. The presence of Iron- and Aluminum-oxides are also responsible for above-average soil C stocks in other regions (Zanelli et al. 2006, Heim et al. 2009, Hagedorn et al. 2010).

Soil C may be stabilized by sorption (Eckmeier et al. 2010) and result in smaller loss of carbon from the soil than is estimated by Y07. The decomposition rate of C in the more stable H compartment of Y07 is currently under investigation. A revision of the decomposition rate for soil C may improve the accuracy of the modeled pool size. Since the estimated change in C stock of soil C with Y07 were to a large degree independent of the pool size (data not shown), their estimates were rather robust. Soil C stock changes were comparatively small (2009 to 2010 ca. 0.006 Mg C $ha^{-1}a^{-1}$) and well in line with values reported by other countries (Tab. 14) or in research (0.2 Mg C $ha^{-1}a^{-1}$ in Europe; Luyssaert et al. 2010). The data from the Swiss Soil Monitoring Network (NABO) corroborate the finding of minimal change in the soil C stocks (cf. also chapter 7.3.6 in FOEN 2012).

The verification of the LFH layer pool size also indicated an underestimation by Y07 (Tab. 11) in comparison to data by Moeri (2007). There are several reasons explaining this underestimation. The LFH pool in Y07 is comprised of C inputs of non-woody material derived from trees. In reality, the shrub and herb layer contribute to the LFH layer pool (de Wit et al. 2006, Liski et al. 2006) and fine-woody material may not be clearly separated from non-woody material and thus also add to the LFH layer pool. The effect is difficult to quantify but further investigations are warranted to improve the accuracy of the Y07 estimates. It is encouraging that with the exception of the Southern-Alps, observed pattern were reproduced (Tab. 11).

Carbon stock changes in the LFH layer pool were higher and more erratic than changes in the deadwood and soil pools (Fig. 6). This is expected since non-woody material decomposes faster than deadwood (Tuomi et al. 2011a), and there is a higher interannual variability in the production of foliage (Etzold et al. 2011). We can be confident however, that estimated carbon stock changes are accurate since Y07 reproduced very closely measured decomposition rate from a litterbag experiment (Weggler et al. 2012). These experiments showed the annual loss of C simulated over 5 years by Y07 compared with the annually measured loss of C in a Swiss litter bag experiment (Heim and Frey 2004, Frey 2011).

For both, the soil and LFH layer C pools it is known that these can be highly variable in time and space, and that observed C stock changes may well be within the natural variability (Schöning et al. 2006, Peltoniemi et al. 2007a). The estimated C stock changes in the soil and LFH layer with Yasso07 were within the minimal detectable change reported by Schöning et al (2006), i.e., 0.3 Kg OC m^{-2} in the litter (incl. LFH layer) layer and 3.6 kg OC m^{-2} in the solum > 0.12 m depth.

In contrast to the soil and LFH layer pools, Y07 overestimated the size of the deadwood C pool, except for the Southern-Alps (Tab. 12 and 13). The C decomposition in this pool depends on the size of the deadwood in the model (Tuomi et al. 2011a) and in reality (Kahl 2008, Rock et al. 2008). The mean diameter of the deadwood material may have been incorrectly estimated leading to the deviation between modeled and observed deadwood stock. It is expected that the accuracy of the deadwood pool size estimate can be improved by defining the deadwood inputs more accurately. This may include a revision of the fractionation of the deadwood C input into the four chemical compartments used in Y07 (section 2.3.1) based on regional data from, e.g., Lombardi et al. (in press).

Although data are scarce to verify deadwood stock changes, we are confident that the Y07 estimates of C stocks and C stock changes in deadwood carbon present an improvement in accuracy and consistency over the estimates used in previous Swiss GHGI submissions. The dependency on ancillary data on stock of deadwood (i.e., basal area derived from Sanasilva network) was reduced. The deadwood stock and the stock of carbon in deadwood are correlated, however a change in the deadwood stock may not result in a corresponding change in the stock of carbon in deadwood since the latter depends on the decomposition stage of the deadwood.

For all three pools, C stocks were significantly underestimated for the Southern-Alps. Besides the elevated soil pool sizes that cannot be represented in the model, a limitation may be the highly variable climate in this region with high annual precipitation of uneven distribution including heavy rainfall events interrupted by extended periods of drought in spring and summer.

4.2 Uncertainties

Since models are only a simplified representation of the real world, their projections are uncertain by definition. In addition to model uncertainty, several other factors contribute to the uncertainty of the model results. These include measurement errors for climate data and of data that were used to derive carbon inputs, as well as errors in methods such as in the spatial interpolation of the climate data (cf. MeteoSwiss 2012a, b) and on assumptions for estimating carbon inputs from observed variables (cf. section 2.6).

A source of uncertainty is the derivation of conditions that prevailed before observational data were available. The simulated temporal dynamics depend on the data that are used to derive initial conditions for the simulations. We attempted to reduce the bias that is introduced by the input data (cf. Peltoniemi et al. 2007b). First, we simulated 25 years based on observed climate and aggregated C inputs and then continued the simulation with observed C input data at individual NFI sampling sites (see section 2.2). However, the proxy data for C inputs that need to be used before observed data can be employed, may not represent reality. Thus simulated C stocks at the time of the NFI 1 may not correspond to real stocks. We relied on expert opinion and published data (e.g., Gimmi et al. in press) for selecting the most accurate proxy data for carbon inputs before measurement-based data were available with the NFI 1.

Due to technical reasons the model uncertainty could not be estimated and could thus not be included in the uncertainty estimates for the data presented in this report. Since uncertainties could partly not be quantified (e.g., uncertainty of spatial climate interpolation), we adopted a conservative approach and presented the standard deviations calculated for between-site variability. Since the changes in stocks fluctuate around zero, the standard deviation from between-site variability were one order of a magnitude larger than expected uncertainties from data sources and model, i.e., ca. 4-5% model uncertainty and ca. 30% for derived C input data (cf. section 2.6).

4.3 International comparison

For comparability, we implemented Y07 whenever possible in such a way as is done by other UNFCCC signature states that use the model for their GHGI, including Austria, Finland and Norway. In particular the exchange with colleagues in Finland was helpful in this regard. The colleagues from Austria (R. Jandl, Federal Research and Training Centre for Forests (BFW), Natural Hazards and Landscape; pers. com. 09.08.2012) and Finland (A. Lehtonen, Finnish Forest Research Institute Metla; pers.com) reported that stock estimates obtained with Yasso07 corresponded well to observations. The deviation of estimated stocks with Y07 in Switzerland may be due to regional characteristics that did not always allow using the same approaches.

Finland has NFI data available since 1921 allowing for a more accurate representation of historical C stocks. Finish forests are dominated by boreal conditions and are thus less diverse than Swiss forests. Due to highly variable topography and climate in Switzerland, a simplification of the Y07 simulations into subregions – Finland uses two subregions - is not suitable. However, the simulation per individual NFI sampling site in Switzerland introduces a higher variability in the C stock and C stock change estimates. Despite these limitations for the application in Switzerland, the estimates that we obtained with Y07 are in the range of other countries (cf. section 3.3).

Similar to Switzerland, Norway is considering an approach to separate the default Yasso07 output into soil, litter and deadwood pools (L. Dalsgaard, Norwegian Forest and Landscape Institute; pers. com. 25.05.2012). A closer collaboration with Norway may be fruitful since conditions are more similar, including regions of comparatively high precipitation that may affect the Y07 estimations.

4.4 Forest management reference level and projections until 2050

Modeled pool sizes with Y07 started to differ between GHGIsites and FMRLsites in 2006 (cf. Fig. 4) when the measurement-based C inputs on the FMRLsites were replaced by simulation-based data. Although the FMRLsites were simulated based on observed climate until 2011 like the GHGIsites, the deviation increased from 2006, except for soil; the soil carbon pool is more stable and little sensitive to short term changes. The implications of this deviation may need to be considered since it affects time intervals that are relevant for the Kyoto Protocol.

The projections until 2050 that were based on forest development scenarios showed a possible range of trajectories for future carbon pool sizes (cf. Fig. 8). If the real harvesting intensity between 2006 and 2011 is considered, management scenarios 400 and 485 may be more representative of dynamics in the near future. A change in climate had a comparatively small effect. This was to be expected since even the two contrasting scenarios A1 and B2 did not differ strongly by 2050 (Fig. 2), which is in line with current expectations for Switzerland (cf. CH2011 2011). It is important to note that these data do not indicate occurrences of extreme weather events such as storms and droughts, which may cause mortality and affect the carbon balance of the deadwood, litter and soil pools.

4.5 Items for consideration and further development

In previous GHG Inventories, Switzerland reported time series of annual C stocks in deadwood but not in soil and in the LFH layer (i.e., Table 7-9 in FOEN 2011 and 2012). Regarding the TCCCA criteria, it may be an item of consideration to also report time series of annual C stocks in soil and in the LFH layer. Possible approaches could be to

- not report annual stocks derived with Y07 but to use SOC data from, e.g., Nussbaum et al. (2012) and data for the LFH layer from Moeri (2007). However, these data cannot be associated to a particular point in time as they were sampled, or are based on samples over several years;
- assume a year for which the above data are representative and calculate annual values using carbon stock changes estimated by Yasso07 (or any other method);
- report stocks estimates from Yasso07 (if they can be improved sufficiently) and use above data for verification.

Research to improve Yasso07 is ongoing at WSL and elsewhere. Improvements to the application in Switzerland that are expected for the NIR 2014 include:

- A more accurate representation of the decomposition of non-woody pool and coarse-woody C inputs. This will be achieved by disaggregating non-woody C inputs into foliage and fine roots, and by a better estimation of the dimensions of deadwood.
- A revision of the partitioning of C inputs into the chemical compartments of Yasso07 based on decay classes.
- An investigation to use Yasso07 on monthly time-steps to more accurately represent the effect of the high variability in precipitation, particularly in the Southern-Alps.
- An application of forthcoming new parameters for Yasso07. This will also improve the estimation of model uncertainty.

For a more accurate uncertainty estimation, additional steps are planned, incl. an evaluation based on the data from the NABO sites. To improve the credibility of modeled C stocks and C stock changes, a comparison between Yasso07 and a further carbon budget model such as RothC (Coleman and Jenkinson 1999) may be considered.

It is further expected to develop Yasso07 further in collaboration with colleagues from Norway and Finland. Also, at the Agroscope Reckenholz-Tänikon Research Station (ART) a Yasso07 to croplands in Switzerland is currently investigated. A collaboration with the colleagues at ART would be beneficial for the application of the model in Switzerland. Valuable data on the contribution of pyrogenic C and sorption to C stocks in Switzerland can be expected from the NRP project "Sustainable use of Soil as a Resource" by F. Hagedorn, WSL.

Improvements are also on the way that will allow for a more accurate estimation of C inputs for the Y07 simulations. Among others, MASSIMO is further developed to derive annual values for forest variables from NFI data.

5 Conclusions

Following the intention of Switzerland to improve the estimation of temporal changes in soil carbon pools in future GHG Inventories (FOEN2012), time series of annual C stock changes in the soil, LFF layer and litter, respectively, and deadwood pools were derived with the Yasso07 model. The Swiss National Forest Inventory and the Federal Office of Meteorology and Climatology MeteoSwiss provide accurate data that are required by Yasso07. The estimates of temporal C stock changes in three pools proved to be robust and accurate despite current underestimation of pool sizes. The large uncertainties and high variability in the C stock changes in soil, litter and deadwood are well known (Schöning et al. 2006, Luyssaert et al. 2010) and the Yasso07 estimates were within reported error margins. Nevertheless, there is considerable room for improvement for the application of Yasso07 in Swiss forests.

Despite current limitations, the application of Yasso07 implies improvements in transparency, consistency and comparability. The model source code is openly available, it is widely used in research and by signature states of the UNFCCC and the Kyoto protocol for their National Inventory reporting. Improvements to the model will further increase its accuracy.

Acknowledgements

We are grateful to Nele Rogiers and Andreas Schellenberger at FOEN for valuable discussions and comments on this report. Jari Liski, Mikko Tuomi, Finnish Environment Institute and Aleksi Lehtonen, Finnish Forest Research Institute provided support with the implementation of Yasso07. We also appreciate the support of Massimiliano Zappa and Felix Fundel, Mountain Hydrology and Mass Movements, WSL with the conversion of the climate data. We thank Andri Baltensweiler, Forest Resources and Forest Management, WSL for his help to extract climate data from the spatial grid for NFI sampling site locations.

6 References

Brassel, P., and H. Lischke, editors. 2001. Swiss National Forest Inventory, Methods and models of the second assessment. Swiss Federal Research Institute WSL, Birmensdorf.

CH2011. 2011. Swiss Climate Change Scenarios CH2011. C2SM, MeteoSwiss, ETH, NCCR Climate, and OcCC, Zurich, Switzerland. Available at www.ch2011.ch

Coleman, K., and D. Jenkinson. 1999. RothC-26.3. A Model for the Turnover of Carbon in Soils. Model Description and Windows Users Guide. IACR Rothamsted, Harpenden.

de Wit, H. A., T. Palosuo, G. Hylen, and J. Liski. 2006. A carbon budget of forest biomass and soils in southeast Norway calculated using a widely applicable method. Forest Ecology and Management 225:15-26.

Didion, M., and B. Frey. in prep. Analysing the validity of the Yasso07 soil carbon model for application in Switzerland. Manuscript in preparation.

Don, A., J. Schumacher, M. Scherer-Lorenzen, T. Scholten, and E.-D. Schulze. 2007. Spatial and vertical variation of soil carbon at two grassland sites — Implications for measuring soil carbon stocks. Geoderma 141:272-282.

Eckmeier, E., M. Egli, M. W. I. Schmidt, N. Schlumpf, M. Nötzli, N. Minikus-Stary, and F. Hagedorn. 2010. Preservation of fire-derived carbon compounds and sorptive stabilisation promote the accumulation of organic matter in black soils of the Southern Alps. Geoderma 159:147-155.

Etzold, S., M. Dobbertin, P. Waldner, A. Thimonier, and M. Schmitt. 2011. Interim Report: The carbon cycle of LWF-sites in Switzerland. Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf.

Fischlin, A., B. Buchter, L. Matile, K. Ammon, E. Hepperle, J. Leifeld, and J. Fuhrer. 2003. Bestandesaufnahme zum Thema Senken in der Schweiz. Verfasst im Auftrag des BUWAL. Systems Ecology Report No. 29. Institut für Terrestrische Ökologie, Eidgenössische Technische Hochschule Zürich (ETHZ), Zürich, Schweiz. Available at www.sysecol2.ethz.ch/Articles_Reports/Fi81.pdf

FOEN (Federal Office for the Environment). 2011. Switzerland's Greenhouse Gas Inventory 1990–2009. National Inventory Report 2011 including reporting elements under the Kyoto Protocol. Submission of 15 April 2011 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. Available at www.climatereporting.ch

FOEN (Federal Office for the Environment). 2012. Switzerland's Greenhouse Gas Inventory 1990–2010. National Inventory Report 2012 including reporting elements under the Kyoto Protocol. Submission of 13 April 2012 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. Available at www.climatereporting.ch

Frey, B. 2011. Langfristige Streuabbauexperimente auf LWF-Flächen - Daten zur Validierung von Bodenkohlenstoffmodellierungen im Schweizer Wald, final report. Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf. Available at www.climatereporting.ch

Gimmi, U., B. Poulter, A. Wolf, H. Portner, P. Weber, and M. Bürgi. in press. Soil carbon pools in Swiss forests show legacy effects from historic forest litter raking. Landscape Ecology.

Hagedorn, F., A. Moeri, L. Walthert, and S. Zimmermann. 2010. Kohlenstoff in Schweizer Waldböden - bei Klimaerwärmung eine potenzielle CO2-Quelle | Soil organic carbon in Swiss forest soils - a potential CO2 source in a warming climate. Schweizerische Zeitschrift fur Forstwesen 161:530-535.

Heim, A., and B. Frey. 2004. Early stage litter decomposition rates for Swiss forests. Biogeochemistry 70:299-313.

Heim, A., L. Wehrli, W. Eugster, and M. W. I. Schmidt. 2009. Effects of sampling design on the probability to detect soil carbon stock changes at the Swiss CarboEurope site Lägeren. Geoderma 149:347-354.

IPCC. 2000. Special Report on Emissions Scenarios. IPCC. Cambridge University Press, Cambridge, UK.

IPCC. 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry IPCC/IGES [Penman, J., Gytarsky, M., Hiraishi, T., Krug, T., Kruger, D., Pipatti, R., Buendia, L., Miwa, K., Ngara, T., Tanabe, K. and Wagner, F. eds.)]. Intergovernmental Panel on Climate Change (IPCC), Hayama, Japan.

IPCC. 2007. Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change [Solomon, S., D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor and H.L. Miller (eds.)]. IPCC. Cambridge University Press, Cambridge, UK and New York, NY, USA.

Johnson, K., F. N. Scatena, and Y. Pan. 2010. Short- and long-term responses of total soil organic carbon to harvesting in a northern hardwood forest. Forest Ecology and Management 259:1262-1267.

Kahl, T. 2008. Kohlenstofftransport aus dem Totholz in den Boden. Albert-Ludwigs-Universität, Freiburg i. Brsg. Available at www.freidok.uni-freiburg.de/volltexte/5522/

Kaufmann, E. 2000. Estimation of standing timber, growth and cut. Pages 162–196 *in* P. Brassel and H. Lischke, editors. Swiss National Forest Inventory: Methods and Models of the Second Assessment. Swiss Federal Research Institute WSL, Birmensdorf.

Liski, J., A. Lehtonen, T. Palosuo, M. Peltoniemi, T. Eggers, P. Muukkonen, and R. Mäkipää. 2006. Carbon accumulation in Finland's forests 1922–2004 – an estimate obtained by combination of forest inventory data with modelling of biomass, litter and soil. Ann. For. Sci. 63:687-697.

Liski, J., T. Palosuo, M. Peltoniemi, and R. Sievänen. 2005. Carbon and decomposition model Yasso for forest soils. Ecological Modelling 189:168-182.

Liski, J., M. Tuomi, and J. Rasinmäki. 2009. Yasso07 user-interface manual. Finnish Environment Institute, Helsinki.

Lombardi, F., P. Cherubini, R. Tognetti, C. Cocozza, B. Lasserre, and M. Marchetti. in press. Investigating biochemical processes to assess deadwood decay of beech and silver fir in Mediterranean mountain forests. Forest Ecology and Management.

Luyssaert, S., P. Ciais, S. L. Piao, E. D. Schulze, M. Jung, S. Zaehle, M. J. Schelhaas, M. Reichstein, G. Churkina, D. Papale, G. Abril, C. Beer, J. Grace, D. Loustau, G. Matteucci, F. Magnani, G. J. Nabuurs, H. Verbeeck, M. Sulkava, G. R. Van Der Werf, I. A. Janssens, and members of the Carboeurope-Ip Synthesis Team. 2010. The European carbon balance. Part 3: forests. Global Change Biology 16:1429-1450.

MeteoSwiss (Federal Office of Meteorology and Climatology). 2012a. Documentation of MeteoSwiss Grid-Data Products Mean Monthly and Yearly Mean Temperature (1961-1990): TnormM6190 and TnormY6190. Federal Office of Meteorology and Climatology MeteoSwiss. Available at www.meteoschweiz.ch

MeteoSwiss (Federal Office of Meteorology and Climatology). 2012b. Documention of MeteoSwiss Grid-Data Products Monthly and Yearly Precipitation: RhiresM and RhiresY. Federal Office of Meteorology and Climatology MeteoSwiss. Available at www.meteoschweiz.ch

Mitchell, T. D., T. R. Carter, P. D. Jones, M. Hulme, and M. New. 2004. A comprehensive set of climate scenarios for Europe and the globe. Tyndall Centre Working Paper 55. Available at www.tyndall.ac.uk/sites/default/files/wp55.pdf

Moeri, A. C. 2007. Kohlenstoffvorräte in Schweizer Waldböden unter besonderer Berücksichtigung der organischen Auflage. Universität Zürich, Zürich. Available at www.climatereporting.ch

Monni, S., M. Peltoniemi, T. Palosuo, A. Lehtonen, R. Mäkipää, and I. Savolainen. 2007. Uncertainty of forest carbon stock changes – implications to the total uncertainty of GHG inventory of Finland. Climatic Change 81:391-413.

Nussbaum, M., A. Papritz, A. Baltensweiler, and L. Walthert. 2012. Organic Carbon Stocks of Swiss Forest Soils. Final Report. Institute of Terrestrial Ecosystems, ETH Zürich and Swiss Federal Institute for Forest, Snow and Landscape Research (WSL), Zürich and Birmensdorf. http://dx.doi.org/10.3929/ethz-a-007555133

Peltoniemi, M., J. Heikkinen, and R. Mäkipää. 2007a. Stratification of regional sampling by model-predicted changes of carbon stocks in forested mineral soils. Silva Fennica 41:527-539.

Peltoniemi, M., E. Thürig, S. Ogle, T. Palosuo, M. Schrumpf, T. Wutzler, K. Butterbach-Bahl, O. Chertov, A. Komarov, A. Mikhailov, A. Gärdenäs, C. Perry, J. Liski, P. Smith, and R. Mäkipää. 2007b. Models in country scale carbon accounting of forest soils. Silva Fennica 41:575–602.

Preston, C. M., and M. W. I. Schmidt. 2006. Black (pyrogenic) carbon: a synthesis of current knowledge and uncertainties with special consideration of boreal regions. Biogeosciences 3:397-420.

R Core Team. 2012. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. Available at www.r-project.org/

Rock, J., F.-W. Badeck, and M. E. Harmon. 2008. Estimating decomposition rate constants for European tree species from literature sources. European Journal of Forest Research 127:301-313.

Schöning, I., K. U. Totsche, and I. Kögel-Knabner. 2006. Small scale spatial variability of organic carbon stocks in litter and solum of a forested Luvisol. Geoderma 136:631-642.

Singh, N., S. Abiven, M. S. Torn, and M. W. I. Schmidt. 2011. Fire-derived organic carbon turnover in soils on a centennial scale. Biogeosciences Discuss. 8:12179-12195.

Thum, T., P. Räisänen, S. Sevanto, M. Tuomi, C. Reick, T. Vesala, T. Raddatz, T. Aalto, H. Järvinen, N. Altimir, K. Pilegaard, Z. Nagy, S. Rambal, and J. Liski. 2011. Soil carbon model alternatives for ECHAM5/JSBACH climate model: Evaluation and impacts on global carbon cycle estimates. J. Geophys. Res. 116, G02028.

Thürig, E., E. Kaufmann, S. Schmid, and H. Bugmann. 2005a. Treibhausgas Inventar: Waldkennzahlen und jährlicher Klimaeinfluss. Internal report for the Federal Office for the Environment. Available at www.climatereporting.ch

Thürig, E., T. Palosuo, J. Bucher, and E. Kaufmann. 2005b. The impact of windthrow on carbon sequestration in Switzerland: a model-based assessment. Forest Ecology and Management 210:337-350.

Tuomi, M., R. Laiho, A. Repo, and J. Liski. 2011a. Wood decomposition model for boreal forests. Ecological Modelling 222:709-718.

Tuomi, M., J. Rasinmäki, A. Repo, P. Vanhala, and J. Liski. 2011b. Soil carbon model Yasso07 graphical user interface. Environmental Modelling & Software 26:1358-1362.

Tuomi, M., T. Thum, H. Järvinen, S. Fronzek, B. Berg, M. Harmon, J. A. Trofymow, S. Sevanto, and J. Liski. 2009. Leaf litter decomposition—Estimates of global variability based on Yasso07 model. Ecological Modelling 220:3362-3371.

UNFCCC. 2012. Synthesis and Assessment Report on the Greenhopuse Gas Inventories submitted in 2012. UNFCCC Secretariat, Geneva.

Weggler, K., K. Steinmann, E. Kaufmann, and E. Thürig. 2012. Modeling soil carbon stock including dead wood and L, F, H-horizon using the models Massimo and Yasso07. Swiss Federal Institute for Forest Snow and Landscape Research (WSL). Available at www.climatereporting.ch

Zanelli, R., M. Egli, A. Mirabella, M. Abdelmoula, M. Plötze, and M. Nötzli. 2006. `Black' soils in the southern Alps: clay mineral formation and transformation, X-ray amorphous Al phases and Fe forms. Clays and Clay Minerals 54:703-720.

Appendix I: Deriving estimates for deadwood, litter and soil carbon pools from default Yasso07 outputs

By default, Yasso07 (Y07; Tuomi et al. 2009, Tuomi et al. 2011b) does not provide separate estimates of carbon pool sizes for deadwood, litter and soil. Separate estimates for these pools are required for reporting under the UNFCCC and KP in the national inventory report (IPCC 2003). In order to be able to report estimates for each pool, the structure of Y07 was examined for deriving separate estimates (Didion and Frey. in prep). Deadwood, litter and soil pools could be correlated with modeled data based on the category of carbon input, i.e., non-woody and woody material, and the five carbon compartments in Yasso07, i.e. four chemical partitions (insoluble (N), soluble in ethanol (E), in water (W) or in acid (A) and humus (H).

For this approach Didion and Frey (in prep) assumed that carbon in the Y07 H compartment represents carbon in an advanced decomposition stage and builds a stabile pool (cf. also Tuomi et al. 2011b). Carbon that is still cycling through the four chemical fractions in Y07, was separated into deadwood and litter (incl. LFH layer) pools based on the category of the carbon input:

- Deadwood: Carbon inputs from coarse-woody material ≥ 7 cm in diameter as measured in a NFI.
- Litter: Carbon inputs from fine-woody material < 7 cm in diameter as estimated based on NFI observations and from non-woody material, including foliage and fine roots, as estimated based on NFI observations. Considering only carbon inputs from non-woody material, the litter pool can be further separated to represent the LFH layer pool.

This approach is robust and reproduced published and measured relative proportions of the three pools (Tables A-1 and A-2; Didion and Frey. in prep). Since Y07 models stocks are based solely on readily available NFI and climate data, a deviation from measured stocks is expected (cf. section 4). The decrease in the relative proportion of soil carbon pool size to LFH layer pool size that was postulated by Moeri 2007 is more apparent in the Yass07 data than in the data reported by Moeri 2007 (Tab. A-2).

Table A-1. Percent fraction of the soil carbon stock of the combined carbon stock in soil, litter and deadwood. Data are based on research in similar forests (Camps Arbestain et al. 2007, Taverna et al. 2007, Takahashi et al. 2010) and on Yasso07 estimates for Switzerland. Yasso07 data are based on data from 1986 to 2011.

	Proportion of soil carbon stock [%]			
	Camps Arbestain et al. 2007	**Takahashi et al. 2010**	**Taverna et al. 2007[1]**	**Yasso07**
Minimum	73	70	88	65
maximum	84	94	88	93

[1]Taverna et al. 2007 presented only a mean value.

Table A-2. Relative proportion of soil carbon stock size to LFH layer carbon pool size reported by Moeri (2007; chapter 5.10.1) and calculated based on Yasso07 estimates for 4 elevation classes in Switzerland. Yasso07 data are based on stock estimates for the years 1992 to 1994 to be comparable to the data published by Moeri 2007 for the year 1993.

Elevation class [m a.s.l.]	**Moeri et al 2007**	**Yasso07**
<800	17	18
800 – 1200	13	17
1200 – 1600	15	16
>1600	10	13

References

Camps Arbestain, M., R. Pardo-Lorenzo, A. Gonzalez-Arias, S. Virgel, M. Anza, and F. Macias. 2007. Effect of Parent Material and Pedogenic Processes on the Distribution, Form and Dynamics of Organic Carbon in Forest Ecosystems in NW Spain. A Biogeochemical Approach. Pages 117-153 in S. I. Muńoz, editor. Ecology research progress. Nova Science Publishers, New York.

Didion, M., and B. Frey. in prep. Analysing the validity of the Yasso07 soil carbon model for application in Switzerland. Manuscript in preparation.

Moeri, A. C. 2007. Kohlenstoffvorräte in Schweizer Waldböden unter besonderer Berücksichtigung der organischen Auflage. Universität Zürich, Zürich. Available at www.climatereporting.ch

Takahashi, M., S. Ishizuka, S. Ugawa, Y. Sakai, H. Sakai, K. Ono, S. Hashimoto, Y. Matsuura, and K. Morisada. 2010. Carbon stock in litter, deadwood and soil in Japan's forest sector and its comparison with carbon stock in agricultural soils. Soil Science & Plant Nutrition 56:19-30.

Taverna, R., P. Hofer, F. Werner, E. Kaufmann, and E. Thürig. 2007. CO2-Effekte der Schweizer Wald- und Holzwirtschaft. Szenarien zukünftiger Beiträge zum Klimaschutz. Umwelt-Wissen Nr. 0739. Federal Office for the Environment, Bern, Switzerland. Available at http://www.bafu.admin.ch/publikationen/publikation/00076/index.html?lang=de

Tuomi, M., R. Laiho, A. Repo, and J. Liski. 2011a. Wood decomposition model for boreal forests. Ecological Modelling 222:709-718.

Tuomi, M., J. Rasinmäki, A. Repo, P. Vanhala, and J. Liski. 2011b. Soil carbon model Yasso07 graphical user interface. Environmental Modelling & Software 26:1358-1362.

Appendix II: Data prepared for Switzerland's GHGI

C stock changes for use in Switzerland's GHGI were calculated from C stocks that were averaged over three years following the recommendation in IPCC (2003). The following tables correspond to the tables that were submitted to FOEN for reporting in Switzerland's GHGI. The submitted data were based on scaled deadwood C stocks (cf. Appendix IV), which were included in the submission.

For the data prepared for Switzerland's GHGI, a separate uncertainty analysis was conducted. The uncertainty in the estimates of annual stock changes derived with the Yasso07 model derives from the following sources:

- spatial climate data interpolation

- C input estimates obtained from the NFI (measurement errors, allometries, etc.)

- decomposition parameters used in the Yasso07 model

- derivation of estimates for the soil, litter and deadwood pools from the pooled Yasso07 result for the total stock.

The uncertainty associated with the climate data and the derivation of estimates for individual pools could not be estimated.

The uncertainty associated with C inputs (deadwood and litterfall) was estimated based on NFI data and expert opinion: The uncertainty of applying biomass functions to obtain deadwood volume (U_{dw}) is similar to the uncertainty typical for BCEF and is estimated to be 30% (e.g. Monni et al. 2007). A conservative estimate of the uncertainty associated with allometries to obtain foliage and fine root estimates for the litter pool (U_{li}) is assumed to be also in the order of 30%.

Parameter uncertainty of the Yasso07 model was estimated based on independent simulations with varying parameter combinations from the MCMC (Markov Chain Monte Carlo) parameter estimates listings of Yasso07 (cf. Tuomi et al. 2011). The results for the annual changes were used to calculate the uncertainty related to model parameters for the period 1990 to 2011. This was calculated for the default output of Yasso07 (i.e., total C stock in soil, litter and deadwood ($Upar_{total}$) and for the individual pools that were derived from the total following the method described in Appendix I ($Upar_{soil}$, $Upar_{litter}$, $Upar_{dw}$). The posterior separation of the Yasso07 results into the 3 pools soil, litter and deadwood is the reason why the uncertainty of the changes in the total stock is not calculated based on the uncertainties in the pools.

The combined uncertainty from C inputs and model parameters was calculated following equation 6.4 in chapter 'Quantifying Uncertainties in Practice' in the report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (IPCC 2000).

Uncertainty of the change in soil carbon:

$$U_{total_{soil}} = \sqrt{U_{dw}^2 + U_{li}^2 + U_{par_{soil}}^{\,2}} = \sqrt{30^2 + 30^2 + 9.45^2} = 43\%$$

Uncertainty of the change in litter:

$$U_{total_{litter}} = \sqrt{U_{li}^2 + U_{par_{litter}}^2} = \sqrt{30^2 + 7.56^2} = 31\%$$

Uncertainty of the change in deadwood:

$$U_{total_{dw}} = \sqrt{U_{dw}^2 + U_{par_{dw}}^2} = \sqrt{30^2 + 2.6^2} = 30\%$$

For comparison, the uncertainty on mortality data from Finnish NFI is assessed to be 30% (Monni et al. 2007).

Uncertainty of the change in the total stock:

$$U_{total} = \sqrt{U_{dw}^2 + U_{li}^2 + U_{par_{total}}^2} = \sqrt{30^2 + 30^2 + 6.32^2} = 43\%$$

For comparison, the uncertainty reported by Finland where the Yasso07 model is also applied was 46.8% for the 2010 emission factor in South Finland, 26.2% in North Finland, and 24.1% for the net change in the whole country (chapter 7.2.4.2 in Statistics Finland 2012).

References

IPCC 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. Available at http://www.ipcc-nggip.iges.or.jp/public/gp/english/

Monni, S., M. Peltoniemi, T. Palosuo, A. Lehtonen, R. Mäkipää, and I. Savolainen. 2007. Uncertainty of forest carbon stock changes – implications to the total uncertainty of GHG inventory of Finland. Climatic Change 81:391-413.

Statistics Finland 2012. Greenhouse gas emissions in Finland 1990-2010. National Inventory Report under the UNFCCC and the Kyoto Protocol. Available at http://tilastokeskus.fi/tup/khkinv/unfccc_nir_2012.pdf

Tuomi, M., R. Laiho, A. Repo, and J. Liski. 2011. Wood decomposition model for boreal forests. Ecological Modelling 222:709-718.

Table A-3. Annual C stock changes in a) deadwood, b) LFH layer, c) soil and d) totals from soil, LFH layer and deadwood per hectare since 1989 for Switzerland's GHGI. Elevation classes 601-1200 and >1200 in production region 2 are combined in the calculations and have the same value reported. Negative values indicate a sink and positive values a source.

a) Deadwood

Prod Reg	Elev. Class [m a.s.l.]	Annual C stock change in deadwood																					
		89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11
		Kg C $ha^{-1}a^{-1}$																					
1	<601	4.9	-10.4	5.6	-2.7	16.8	21.2	-74.2	-160.7	-236.5	-190.5	-167.0	-138.2	-126.4	-134.5	-140.1	-154.3	-295.0	-191.6	-85.1	-109.2	-131.2	-142.5
1	601-1200	26.9	9.6	25.3	15.6	33.1	33.7	-145.1	-159.2	-173.7	-149.8	-146.6	-133.8	-134.2	-148.5	-161.6	-187.0	-365.1	-287.0	-206.8	-226.1	-255.9	-257.5
1	>1200	-53.9	-51.6	-41.8	-39.7	-31.3	-28.4	-396.9	-362.6	-315.5	-292.7	-279.7	-262.6	-254.2	-252.9	-254.9	-265.5	-782.2	-657.7	-509.1	-472.2	-456.6	-423.5
2	<601	2.1	-3.1	1.5	-1.0	6.0	7.7	-225.8	-253.5	-285.2	-280.1	-278.5	-271.1	-273.6	-287.8	-303.8	-323.9	0.3	68.5	128.0	106.2	83.7	69.9
2	601-1200	5.7	-2.6	5.3	0.4	11.6	13.8	-209.7	-282.4	-360.1	-346.9	-341.9	-327.1	-327.1	-342.5	-359.9	-383.6	-97.4	14.2	113.8	86.3	53.0	37.6
2	>1200	5.7	-2.6	5.3	0.4	11.6	13.8	-209.7	-282.4	-360.1	-346.9	-341.9	-327.1	-327.1	-342.5	-359.9	-383.6	-97.4	14.2	113.8	86.3	53.0	37.6
3	<601	-15.3	-15.7	-12.9	-12.6	-8.5	-6.8	-449.8	-454.7	-458.9	-451.6	-449.2	-438.7	-435.9	-443.6	-455.8	-475.6	-241.5	-184.6	-135.7	-146.0	-162.4	-161.3
3	601-1200	1.5	-4.1	0.5	-3.0	7.8	9.4	-264.8	-361.6	-466.7	-456.3	-456.4	-444.6	-441.7	-447.6	-461.7	-481.8	-137.6	63.8	246.9	211.0	172.3	158.7
3	>1200	138.6	120.7	117.6	101.6	108.7	100.9	-733.6	-719.5	-711.6	-678.2	-665.3	-637.5	-620.9	-613.2	-623.2	-647.0	-434.9	-302.2	-177.9	-192.0	-221.0	-200.0
4	<601	-34.0	-34.0	-22.7	-21.8	-13.8	-12.4	-276.4	-291.2	-308.3	-296.5	-293.2	-282.3	-282.3	-294.4	-310.6	-336.1	208.3	274.0	324.5	298.3	267.8	251.4
4	601-1200	91.0	77.9	88.7	78.4	85.8	78.4	-30.0	-90.1	-148.4	-122.2	-108.8	-91.6	-84.4	-97.6	-110.9	-139.0	-200.0	-57.2	89.8	82.0	59.0	54.5
4	>1200	-60.0	-60.9	-45.4	-44.9	-31.2	-31.7	-238.7	-225.9	-210.2	-193.9	-184.3	-173.0	-171.5	-188.5	-206.2	-236.5	-57.1	28.6	117.4	107.1	84.7	73.3
5	<601	-95.9	-89.1	-70.2	-53.0	-30.4	-32.8	-668.2	-521.6	-332.9	-292.3	-257.9	-247.8	-225.3	-265.6	-259.1	-329.2	-158.3	-53.6	133.1	145.6	151.8	114.3
5	601-1200	17.8	11.4	14.5	15.0	21.6	11.6	-324.8	-281.0	-215.8	-194.5	-172.7	-160.0	-146.7	-161.3	-161.4	-195.6	-85.1	-187.4	-250.4	-238.9	-231.7	-236.5
5	>1200	259.2	233.2	223.7	211.7	206.4	182.1	-50.6	-98.2	-132.8	-122.7	-111.3	-107.6	-101.1	-121.1	-126.9	-170.6	142.0	-8.9	-76.8	28.5	116.9	190.8
Switzerland		3.2	-6.1	4.8	-0.2	14.1	15.3	-208.2	-257.8	-307.5	-286.6	-277.9	-261.7	-258.8	-272.3	-287.7	-312.7	-155.8	-37.6	75.9	53.4	24.4	12.9

b) LFH layer

Prod Reg	Elev. Class [m a.s.l.]	Annual C stock change in LFH layer																					
		89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11
		Kg C $ha^{-1}a^{-1}$																					
1	<601	-31.0	-133.7	30.1	-45.0	115.7	111.3	-21.3	-147.0	-208.2	38.2	60.6	121.5	71.0	-46.1	-111.8	-207.6	101.6	184.9	241.8	62.4	-36.2	-53.9
1	601-1200	37.2	-61.0	51.4	-17.6	98.4	81.0	-56.5	-151.9	-208.1	-5.2	7.9	62.2	37.6	-35.9	-78.4	-162.2	-0.1	39.1	51.5	-56.3	-148.0	-106.6
1	>1200	116.5	45.1	110.3	51.5	99.2	64.3	89.6	108.8	117.6	131.0	94.2	93.7	62.2	23.8	-6.2	-52.4	-84.8	-115.7	-141.0	-142.2	-169.6	-119.1
2	<601	43.8	-75.3	45.0	-22.3	125.2	120.7	-33.8	-185.3	-250.6	-12.9	51.6	129.7	73.0	-46.6	-123.5	-199.4	44.1	129.4	172.8	46.3	-52.7	-72.8
2	601-1200	-25.9	-118.6	20.9	-48.1	110.5	105.2	-37.4	-173.1	-250.5	-16.5	34.7	128.0	71.6	-40.2	-122.9	-205.2	86.5	218.9	282.3	109.5	-23.3	-37.4
2	>1200	-25.9	-118.6	20.9	-48.1	110.5	105.2	-37.4	-173.1	-250.5	-16.5	34.7	128.0	71.6	-40.2	-122.9	-205.2	86.5	218.9	282.3	109.5	-23.3	-37.4
3	<601	-93.0	-146.7	-30.5	-59.8	90.6	90.9	-4.2	-76.6	-119.5	66.5	82.3	140.1	104.4	3.9	-69.6	-159.7	1.4	83.9	100.3	23.3	-46.0	-14.4
3	601-1200	69.0	-11.5	39.7	-11.3	97.3	78.8	-100.2	-217.4	-305.0	-93.5	-57.9	27.7	25.1	-8.4	-66.7	-131.8	42.4	154.8	188.2	76.4	-13.4	25.8
3	>1200	91.0	23.9	62.8	2.9	94.9	62.7	-70.9	-149.8	-223.3	-63.8	-60.4	15.2	21.4	8.4	-50.4	-118.2	17.3	121.3	150.7	52.0	-42.4	30.8
4	<601	-15.3	-59.3	82.6	28.8	110.3	79.1	-39.7	-127.7	-197.5	-0.3	43.0	110.2	77.1	-40.0	-117.3	-239.7	-65.8	73.9	180.2	103.4	-6.5	-13.4
4	601-1200	30.1	-12.0	89.6	39.1	99.1	60.8	-49.4	-133.5	-194.7	-20.3	36.4	88.8	68.5	-42.3	-109.7	-231.6	-107.7	14.8	112.7	60.7	-42.3	-28.7
4	>1200	-48.7	-81.6	67.2	18.3	123.1	53.2	-76.6	-213.3	-277.0	-61.9	42.1	116.5	94.8	-64.9	-161.7	-329.1	-156.0	23.1	200.1	122.2	-17.0	-49.4
5	<601	51.1	20.5	41.8	51.1	79.9	32.3	-99.5	-182.5	-198.7	-90.6	-17.6	-27.7	16.3	-94.3	-55.1	-206.1	-131.0	-133.1	44.8	74.8	82.6	-2.8
5	601-1200	37.9	10.1	53.0	66.5	109.9	24.0	-134.5	-246.9	-242.3	-104.4	-10.1	-8.5	25.6	-114.4	-91.1	-299.3	-194.0	-178.4	62.5	79.1	64.1	-6.4
5	>1200	-214.8	-175.2	-62.1	-6.3	77.3	-24.7	-252.0	-401.3	-388.2	-174.8	-38.8	-31.2	22.2	-165.7	-132.9	-443.3	-251.4	-208.3	158.7	141.3	98.9	13.9
Switzerland		14.1	-56.1	49.2	-1.0	107.2	76.6	-64.0	-178.8	-238.0	-36.2	17.4	79.9	57.9	-45.3	-104.1	-214.7	-30.4	67.0	154.4	60.7	-34.0	-36.8

c) Soil

Prod Reg	Elev. Class [m a.s.l.]	Annual C stock change in soil																					
		89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11
		Kg C $ha^{-1}a^{-1}$																					
1	<601	-1.3	-4.8	-6.0	-6.2	-3.9	1.4	1.9	-3.8	-14.1	-18.9	-18.5	-16.3	-13.6	-14.6	-19.4	-27.1	-28.8	-20.8	-10.0	-2.1	-0.9	-2.0
1	601-1200	14.0	12.3	13.6	13.7	17.2	21.6	20.6	14.5	5.4	3.0	3.9	6.5	9.1	8.5	5.4	-0.9	-2.9	-0.3	3.1	3.7	-0.8	-5.2
1	>1200	16.7	16.0	18.2	18.8	21.4	22.9	25.0	29.7	35.8	45.0	51.8	58.7	63.3	64.5	63.9	59.8	60.0	59.6	59.3	54.9	48.1	44.5
2	<601	16.1	13.7	14.5	14.2	18.8	25.2	25.0	16.9	4.0	-1.1	-0.5	3.3	6.7	5.3	-0.4	-9.0	-10.9	-4.1	5.7	13.1	14.3	13.2
2	601-1200	-10.2	-13.4	-14.9	-15.2	-12.7	-7.3	-7.1	-14.8	-27.7	-37.0	-39.5	-39.5	-37.6	-38.7	-43.8	-51.4	-54.8	-45.8	-32.0	-19.6	-15.3	-14.6
2	>1200	-10.2	-13.4	-14.9	-15.2	-12.7	-7.3	-7.1	-14.8	-27.7	-37.0	-39.5	-39.5	-37.6	-38.7	-43.8	-51.4	-54.8	-45.8	-32.0	-19.6	-15.3	-14.6
3	<601	-26.5	-31.4	-35.9	-38.2	-37.5	-34.0	-31.7	-33.9	-38.2	-40.8	-38.5	-34.2	-28.6	-25.6	-27.1	-31.7	-34.5	-30.3	-23.9	-18.8	-17.9	-17.3
3	601-1200	14.4	14.4	15.4	15.1	18.6	22.8	19.5	7.7	-9.3	-21.4	-27.7	-31.8	-33.4	-35.5	-39.1	-45.2	-47.6	-40.1	-26.9	-15.0	-9.0	-4.5
3	>1200	6.5	8.3	10.6	11.5	15.3	19.2	17.9	12.2	3.4	-0.3	-1.7	-0.7	1.5	2.9	2.0	-2.0	-2.0	3.8	11.7	16.8	16.5	18.1
4	<601	3.9	1.6	3.0	3.8	6.9	9.9	9.2	4.1	-3.5	-5.8	-3.9	-0.7	2.3	0.9	-3.7	-12.6	-16.9	-13.3	-4.3	3.1	5.2	5.2
4	601-1200	12.3	12.4	15.7	17.8	22.2	25.2	24.1	18.9	11.1	8.5	9.1	11.9	14.5	13.1	8.5	0.4	-4.3	-3.0	2.4	7.4	8.4	9.0
4	>1200	-13.6	-15.7	-16.0	-14.7	-12.8	-10.5	-12.2	-17.9	-25.7	-30.5	-29.2	-26.6	-22.4	-22.4	-25.4	-32.0	-37.9	-37.8	-32.3	-25.6	-22.4	-21.9
5	<601	21.7	21.7	22.7	24.8	28.1	29.2	26.2	19.2	12.9	9.7	10.3	10.8	12.2	9.8	7.6	1.1	-4.7	-9.5	-9.4	-5.2	-1.0	1.5
5	601-1200	15.9	15.4	16.8	19.4	23.8	24.9	20.4	10.7	1.5	-3.5	-3.5	-2.7	-1.2	-3.6	-7.3	-14.6	-23.3	-29.9	-32.2	-28.8	-25.7	-24.4
5	>1200	-47.9	-53.0	-55.8	-55.7	-53.8	-51.4	-57.3	-70.2	-86.0	-96.2	-99.9	-99.6	-99.8	-98.3	-103.3	-104.1	-117.2	-123.7	-132.7	-128.4	-124.6	-121.9
Switzerland		5.1	3.6	4.2	4.8	8.1	12.0	10.7	3.5	-7.0	-12.4	-12.9	-11.4	-9.1	-10.1	-14.0	-20.9	-24.6	-21.1	-14.0	-7.4	-5.6	-5.3

d) Totals from soil, LFH layer and deadwood

Prod Reg	Elev. Class [m a.s.l.]	Total annual C stock change																					
		89-90	90-91	91-92	92-93	93-94	94-95	95-96	96-97	97-98	98-99	99-00	00-01	01-02	02-03	03-04	04-05	05-06	06-07	07-08	08-09	09-10	10-11
		Kg C $ha^{-1}a^{-1}$																					
1	<601	-27.3	-148.9	29.7	-54.0	128.5	133.9	-93.5	-311.5	-458.7	-171.2	-124.9	-32.9	-69.0	-195.3	-271.4	-389.0	-222.2	-27.5	146.6	-48.9	-168.3	-198.4
1	601-1200	78.0	-39.0	90.3	11.6	148.6	136.3	-181.0	-296.6	-376.4	-152.0	-134.9	-65.1	-87.5	-176.0	-234.7	-350.0	-368.2	-248.3	-152.2	-278.6	-404.7	-369.3
1	>1200	79.3	9.5	86.6	30.5	89.3	58.8	-282.2	-224.2	-162.0	-116.7	-133.7	-110.2	-128.7	-164.6	-197.1	-258.2	-807.0	-713.7	-590.8	-559.6	-578.2	-498.1
2	<601	62.0	-64.7	61.0	-9.1	150.0	153.6	-234.5	-421.9	-531.8	-294.1	-227.5	-138.1	-194.0	-329.1	-427.7	-532.3	33.4	193.9	306.6	165.7	45.3	10.2
2	601-1200	-30.4	-134.6	11.3	-62.9	109.3	111.6	-254.2	-470.3	-638.2	-400.4	-346.8	-238.6	-293.1	-421.3	-526.6	-640.3	-65.6	187.3	364.2	176.2	14.3	-14.4
2	>1200	-30.4	-134.6	11.3	-62.9	109.3	111.6	-254.2	-470.3	-638.2	-400.4	-346.8	-238.6	-293.1	-421.3	-526.6	-640.3	-65.6	187.3	364.2	176.2	14.3	-14.4
3	<601	-134.8	-193.9	-79.3	-110.6	44.5	50.1	-485.7	-565.2	-616.6	-425.9	-405.4	-332.9	-360.1	-465.3	-552.4	-667.0	-274.5	-131.0	-59.4	-141.5	-226.3	-193.0
3	601-1200	84.8	-1.2	55.5	0.8	123.7	110.9	-345.5	-571.3	-781.0	-571.2	-542.1	-448.7	-450.1	-491.6	-567.5	-658.8	-142.9	178.5	408.2	272.3	149.8	180.0
3	>1200	236.1	152.9	191.0	115.9	218.9	182.8	-786.5	-857.1	-931.6	-742.3	-727.4	-622.9	-598.1	-602.0	-671.6	-767.1	-419.6	-177.1	-15.5	-123.2	-247.0	-151.1
4	<601	-45.4	-91.7	62.9	10.8	103.4	76.6	-306.9	-414.8	-509.3	-302.5	-254.1	-172.8	-202.9	-333.5	-431.6	-588.4	125.7	334.7	500.4	404.8	266.5	243.2
4	601-1200	133.4	78.3	194.0	135.4	207.1	164.4	-55.3	-204.8	-332.0	-134.0	-63.3	9.0	-1.4	-126.8	-212.1	-370.2	-312.0	-45.4	204.9	150.1	25.1	34.8
4	>1200	-122.3	-158.3	5.8	-41.3	79.1	11.0	-327.5	-457.1	-512.9	-286.2	-171.4	-83.1	-99.1	-275.7	-393.3	-597.6	-250.9	13.8	285.2	203.7	45.3	1.9
5	<601	-23.2	-47.0	-5.7	22.9	77.6	28.7	-741.5	-684.9	-518.7	-373.2	-265.2	-264.7	-196.8	-350.0	-306.6	-534.2	-294.0	-196.1	168.6	215.2	233.4	113.0
5	601-1200	71.6	36.9	84.3	100.9	155.2	60.6	-438.9	-517.1	-456.6	-302.3	-186.3	-171.2	-122.2	-279.3	-259.7	-509.5	-302.5	-395.7	-220.1	-188.7	-193.3	-267.3
5	>1200	-3.5	5.0	105.8	149.8	229.9	106.0	-359.8	-569.6	-607.1	-393.8	-250.1	-238.4	-178.7	-385.2	-363.1	-718.0	-226.6	-341.0	-50.7	41.4	91.2	82.8
Switzerland		22.4	-58.7	58.2	3.6	129.4	103.9	-261.5	-433.1	-552.4	-335.1	-273.4	-193.1	-210.0	-327.7	-405.8	-548.3	-210.8	8.3	216.4	106.6	-15.2	-29.2

Table A-4. Scaled annual C stocks per hectare in deadwood since 1989 for Switzerland's GHGI. Elevation classes 601-1200 and >1200 in production region 2 are combined in the calculations and have the same value reported.

Prod Reg	Elev. Class [m a.s.l.]	Scaled annual C stock in deadwood																						
		89	90	91	92	93	94	95	96	97	98	99	00	01	02	03	04	05	06	07	08	09	10	11
		Mg C ha^{-1}																						
1	<601	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.6	3.8	4.0	4.2	4.4	4.5	4.7	4.8	4.9	5.1	5.4	5.6	5.7	5.8	5.9	6.1
1	601-1200	4.6	4.5	4.5	4.5	4.5	4.5	4.4	4.6	4.7	4.9	5.1	5.2	5.3	5.5	5.6	5.8	6.0	6.3	6.6	6.8	7.0	7.3	7.6
1	>1200	1.2	1.3	1.4	1.4	1.4	1.5	1.5	1.9	2.3	2.6	2.9	3.1	3.4	3.7	3.9	4.2	4.4	5.2	5.9	6.4	6.9	7.3	7.7
2	<601	1.3	1.3	1.3	1.3	1.3	1.3	1.3	1.5	1.8	2.1	2.4	2.6	2.9	3.2	3.5	3.8	4.1	4.1	4.0	3.9	3.8	3.7	3.6
2	601-1200	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.6	2.9	3.2	3.6	3.9	4.2	4.6	4.9	5.3	5.7	5.8	5.7	5.6	5.5	5.5	5.5
2	>1200	2.4	2.4	2.4	2.4	2.4	2.4	2.4	2.6	2.9	3.2	3.6	3.9	4.2	4.6	4.9	5.3	5.7	5.8	5.7	5.6	5.5	5.5	5.5
3	<601	0.7	0.7	0.7	0.7	0.8	0.8	0.8	1.2	1.7	2.1	2.6	3.0	3.5	3.9	4.4	4.8	5.3	5.5	5.7	5.9	6.0	6.2	6.3
3	601-1200	2.9	2.9	2.9	2.9	2.9	2.9	2.8	3.1	3.5	3.9	4.4	4.8	5.3	5.7	6.2	6.6	7.1	7.3	7.2	7.0	6.7	6.6	6.4
3	>1200	5.8	5.7	5.6	5.5	5.4	5.3	5.2	5.9	6.6	7.3	8.0	8.7	9.3	9.9	10.5	11.2	11.8	12.2	12.5	12.7	12.9	13.1	13.3
4	<601	2.1	2.1	2.1	2.1	2.2	2.2	2.2	2.5	2.8	3.1	3.4	3.7	3.9	4.2	4.5	4.8	5.2	5.0	4.7	4.4	4.1	3.8	3.5
4	601-1200	6.8	6.7	6.7	6.6	6.5	6.4	6.3	6.4	6.4	6.6	6.7	6.8	6.9	7.0	7.1	7.2	7.4	7.6	7.6	7.5	7.4	7.4	7.3
4	>1200	5.1	5.2	5.3	5.3	5.3	5.4	5.4	5.6	5.9	6.1	6.3	6.5	6.6	6.8	7.0	7.2	7.4	7.5	7.5	7.3	7.2	7.2	7.1
5	<601	5.0	5.1	5.2	5.3	5.3	5.4	5.4	6.1	6.6	6.9	7.2	7.5	7.7	8.0	8.2	8.5	8.8	9.0	9.0	8.9	8.7	8.6	8.5
5	601-1200	3.0	3.0	3.0	3.0	3.0	2.9	2.9	3.3	3.5	3.8	3.9	4.1	4.3	4.4	4.6	4.7	4.9	5.0	5.2	5.5	5.7	5.9	6.2
5	>1200	6.0	5.7	5.5	5.2	5.0	4.8	4.6	4.7	4.8	4.9	5.0	5.2	5.3	5.4	5.5	5.6	5.8	5.6	5.7	5.7	5.7	5.6	5.4
Switzerland		3.9	3.9	3.9	3.9	3.9	3.9	3.9	4.1	4.3	4.6	4.9	5.2	5.5	5.7	6.0	6.3	6.6	6.7	6.8	6.7	6.6	6.6	6.6

Appendix III: Data prepared for determining Switzerland's Forest management reference level

C stock changes for determining Switzerland's FMRL were calculated from C stocks that were averaged over three years following the recommendation in IPCC (2003). The following tables correspond to the tables that were submitted to FOEN for reporting purposes. The submitted data were based on scaled deadwood C stocks (cf. Appendix IV), which were included in the submission.

Table A-5. Annual C stock changes in deadwood, LFH layer, soil and totals per hectare since 1989 for determining Switzerland's FMRL. Elevation classes 601-1200 and >1200 in production region 2 are combined in the calculations and have the same value reported. Negative values indicate a sink and positive values a source.

	Annual C stock change Kg C $ha^{-1}a^{-1}$			
	Soil	LFH layer	Deadwood	Total
1989-1990	8	24	11	44
1990-1991	7	-47	1	-39
1991-1992	8	55	11	74
1992-1993	9	5	6	19
1993-1994	12	110	20	142
1994-1995	16	77	20	114
1995-1996	15	-61	-208	-253
1996-1997	8	-175	-257	-424
1997-1998	-2	-234	-307	-542
1998-1999	-7	-37	-286	-330
1999-2000	-7	17	-277	-268
2000-2001	-6	78	-262	-190
2001-2002	-3	57	-259	-206
2002-2003	-5	-48	-273	-325
2003-2004	-9	-104	-288	-401
2004-2005i	-16	-213	-314	-543
2005-2006	-21	-57	-77	-155
2006-2007	-21	7	-61	-75
2007-2008	-19	98	-39	40
2008-2009	-16	45	-43	-15
2009-2010	-16	18	-43	-41
2010-2011	-17	-9	-46	-71
2011-2012	-18	-19	-46	-82
2012 2013	-19	-12	-43	-75
2013-2014	-19	12	-36	-44
2014-2015	-19	38	-27	-8
2015-2016	-17	58	-14	26
2016-2017	-16	59	-5	38
2017-2018	-14	52	2	40
2018-2019	-13	49	3	39
2019-2020	-12	51	5	45

Table A-6. Scaled annual C stocks per hectare in deadwood since 1989 for determining Switzerland's FMRL. Elevation classes 601-1200 and >1200 in production region 2 are combined in the calculations and have the same value reported.

	Scaled annual C stock in deadwood Mg C ha^{-1}
1989	3.9
1990	3.9
1991	3.9
1992	3.9
1993	3.9
1994	3.9
1995	3.9
1996	4.1
1997	4.3
1998	4.6
1999	4.9
2000	5.2
2001	5.5
2002	5.7
2003	6
2004	6.3
2005	6.6
2006	6.7
2007	6.7
2008	6.8
2009	6.8
2010	6.8
2011	6.9
2012	6.9
2013	7
2014	7
2015	7
2016	7.1
2017	7.1
2018	7.1
2019	7.1
2020	7.1

Appendix IV: Scaling Yasso07 estimates of the deadwood carbon stock

In previous National Inventory Reports, Switzerland provided annual estimates of carbon stored in deadwood based on extrapolations of the pool size that was analyzed for the NFI 3. To be able to replace these estimates in the next NIR with more robust data that are consistent with the most accurate available observations from the NFI 3, modeled stocks with Y07 were considered. To account for the overestimation of the pool size by Y07 (cf. sections 3 and 4), modeled values were scaled based on a) measured deadwood volume from the NFIs 2 to 4a, and b) carbon that is stored in deadwood as analysed for the observed deadwood volume in the NFI 3). Estimates from Y07 were scaled as follows:

1. Extract from the NFI database for 15 NFI subregions for sites that were assessed as accessible forest but not scrub forest (i.e., productive forest; Thürig et al. 2005)
   a) observed data on deadwood volume for NFIs 2, 3 and 4a (Tab. A-7), and
   b) calculated data on deadwood carbon stock for the NFI 3 (Tab. A-8).
2. Extrapolate for 15 NFI subregions the deadwood carbon stock for NFIs 2 and 4a (Tab. A-8) based on the deadwood C stock for the NFI 3 and the ratios of deadwood volume between NFI 3 and NFI 2 and NFI 3 and NFI 4a, respectively.
3. Calculate the relative difference between the deadwood C stocks for the 3 NFIs (i.e., Tab. A-8) and the corresponding estimates from Y07 (mean carbon stocks at the times of the NFIs 2, 3 and 4a; Tab. A-9). This resulted in three values (henceforth scalars; Tab. A-10) that were assumed to be representative of the ratio between modeled deadwood C stocks from Y07 and measurement-based deadwood C stocks for the years 1995, 2005 and 2011.
4. Obtain a complete time series of these scalars that can be applied to the total time series of Y07 estimates, i.e., NIR: 1989-2011 and FMRL: 1989-2020, by
   a) linear interpolation between 2 consecutive scalars 1995 and 2005 and 2005 and 2011, respectively, resulting in a time series from 1995 to 2011;
   b) assuming that for 1989 to 1994 the same conditions apply as in 1995;
   c) assuming that in case of the FMRL for 2006 to 2020 the same conditions apply as in 2005 (because for the FMRL observed data are used until 2005 only).
5. The so derived time series of annual scalars for the GHGI and the FMR data were applied to the respective time series of Y07 estimates of deadwood C stocks for the GHGI and the FMRL data to obtain revised estimates for the mean deadwood carbon pool size for the GHGIsites and the FMRLsites.

These steps, including additional detail were documented and accompanied the data delivery on GHGI and FMRL data to FOEN from October 2012. Note that the subregions Plateau 600-1200 m and >1200 m were treated as one due to the low number of NFI sites in subregion Plateau >1200 m.

Table A-7. Mean observed deadwood volume (deadwood >12 cm in diameter) for NFI 2 (1994-1996), NFI3 (2004-2006) based on sites that were assessed as productive forest for NFI 2 and 3 and for NFI4a (2009-2011) based on sites that were assessed as productive forest for NFI 3 and 4a.

		Deadwood volume		
		m^3		
Production region	**Elevation class**	**NFI 2**	**NFI 3**	**NFI 4a**
Jura	<601 m	368098	524912	799070
	600 – 1200 m	868781	1171069	1528049
	>1200 m	76460	227049	168826
Plateau	<601 m	498483	1549018	1372711
	600 – 1200 m	544237	1294935	1486578
	>1200 m	544237	1294935	1486578
Pre-Alps	<601 m	20503	139730	155361
	600 – 1200 m	1082740	2714261	2717719
	>1200 m	1391458	3188172	3613880
Alps	<601 m	56076	131992	131729
	600 – 1200 m	1393810	1619139	1857478
	>1200 m	4177141	5743636	6118704
Southern-Alps	<601 m	272499	443707	481649
	600 – 1200 m	436044	735677	874852
	>1200 m	800178	997149	1121311
Switzerland		11986509	20480449	22427917

Table A-8. Mean carbon in deadwood based on measured data on volume of deadwood >12 cm in diameter for NFI 2 (1994-1996), NFI3 (2004-2006) based on sites that were assessed as productive forest for NFI 2 and 3 and for NFI4a (2009-2011) based on sites that were assessed as productive forest for NFI 3 and 4a. NFI3 data as reported in the NFI 3, NFI 2 and NFI 4a data derived based on deadwood volume (Tab. A-7) and carbon in deadwood for NFI 3.

		C stock in deadwood		
		Kg C ha^{-1}		
Production region	**Elevation class**	**NFI 2**	**NFI 3**	**NFI 4a**
Jura	<601 m	3574	5096	6051
	600 – 1200 m	4425	5964	7562
	>1200 m	1491	4429	7730
Plateau	<601 m	1321	4104	3647
	600 – 1200 m	2379	5660	5452
	>1200 m	2379	5660	5452
Pre-Alps	<601 m	776	5290	6322
	600 – 1200 m	2843	7126	6411
	>1200 m	5150	11800	13328
Alps	<601 m	2195	5166	3542
	600 – 1200 m	6328	7351	7323
	>1200 m	5409	7438	7084
Southern-Alps	<601 m	5411	8811	8478
	600 – 1200 m	2930	4944	6174
	>1200 m	4643	5786	5394
Switzerland		3854	6585	6612

Table A-9. Y07 estimates of deadwood C stocks at the times of the NFIs 2, 3 and 4a.

		C stock in deadwood Kg C ha^{-1}		
Production region	**Elevation class**	**NFI 2**	**NFI 3**	**NFI 4a**
Jura	<601 m	6326	9142	7855
	600 – 1200 m	6882	6849	5968
	>1200 m	10774	8563	6435
Plateau	<601 m	11179	13557	11463
	600 – 1200 m	11023	16232	14039
	>1200 m	11023	16232	14039
Pre-Alps	<601 m	12894	13121	11758
	600 – 1200 m	10092	15790	11836
	>1200 m	7802	6902	5769
Alps	<601 m	9632	10618	9149
	600 – 1200 m	8740	9717	7695
	>1200 m	9785	9496	8047
Southern-Alps	<601 m	3341	2212	1561
	600 – 1200 m	2870	2105	2507
	>1200 m	2134	1993	3045
Switzerland		8691	10357	8615

Table A-10. Scalars at the times of the NFIs 2, 3 and 4a (ratio of NFI-observations and Yasso07 estimate).

Production region	Elevation class	NFI 2	NFI 3	NFI 4a
Jura	<601 m	0.56	0.56	0.77
	600 – 1200 m	0.64	0.87	1.27
	>1200 m	0.14	0.52	1.20
Plateau	<601 m	0.12	0.30	0.32
	600 – 1200 m	0.22	0.35	0.39
	>1200 m	0.22	0.35	0.39
Pre-Alps	<601 m	0.06	0.40	0.54
	600 – 1200 m	0.28	0.45	0.54
	>1200 m	0.66	1.71	2.31
Alps	<601 m	0.23	0.49	0.39
	600 – 1200 m	0.72	0.76	0.95
	>1200 m	0.55	0.78	0.88
Southern-Alps	<601 m	1.62	3.98	5.43
	600 – 1200 m	1.02	2.35	2.46
	>1200 m	2.18	2.90	1.77
Switzerland		0.44	0.64	0.77

References

Thürig, E., E. Kaufmann, S. Schmid, and H. Bugmann. 2005a. Treibhausgas Inventar: Waldkennzahlen und jährlicher Klimaeinfluss. Internal report for the Federal Office for the Environment. Available at www.climatereporting.ch