Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse deadwood prepared for the Swiss GHGI 2015 (1990-2013)

13. November 2014

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Commissioned by the Federal Office for the Environment FOEN

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Summary

Switzerland prepares annually a greenhouse gas inventory for reporting under the climate convention UNFCCC and the Kyoto Protocol (KP). The Land Use, Land-Use Change and Forestry (LULUCF) sector of the Swiss inventory includes, inter alia, data for the forest sector, encompassing amongst others C stocks and C stock changes (CSC) in above- and belowground dead biomass and in the soil. Starting with the Swiss greenhouse gas inventory (GHGI) 2013 covering the period 1990-2011 (FOEN 2013), the C decomposition model Yasso07 was used for deriving estimates of C stock and CSC in deadwood, incl. stems, branches and roots, non-woody litter and in soils on productive forest lands.

In an effort to improve Switzerland's GHG accounting with regard to the criteria for transparency, consistency, comparability, completeness and accuracy (TCCCA; section 1.1), the method for estimating C stocks and CSC in above- and belowground dead biomass and in the soil was further developed as documented in section 2.3. The improvements increased the accuracy of the estimates of C stocks and CSC since the previous submission.

In section 3, the results obtained for the Swiss GHGI 2015 (1990-2013) are presented and discussed with reference to the impact of the improvements regarding the deadwood and litter inputs on the time series of C stocks and CSC. As reported in section 3.1, the total CSC in soil, litter and deadwood from 2012 to 2013 produced a small sink of -0.018 ±0.007 Mg C ha^{-1} or -20 292 ±7 751 Mg C (based on 1 157 624 ha of productive forest between NFIs 3 and 4b). The standard error of the estimates for CSC originating from uncertainty in C inputs and in model parameters was ca. 10% for the individual pools and ca. 38% for total CSC. In comparison, Finland reports a uncertainties of 46.8% (North) and 26.2% (South) for the net CSC in 2012 in dead wood, litter and soil organic matter.

Section 3.3 presents ongoing and planned projects to further improve the estimates of C stocks and CSC in deadwood, litter and soil on forest lands in Switzerland and which are expected to increase the transparency, consistency, comparability, completeness and accuracy of the reported data for the Swiss GHGI.

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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 previous NIRs: wood of dead trees >12 cm, lying dead wood >7 cm and dead coarse roots); also abbreviated as CWD throughout the report
- Total as the sum of the above listed pools

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

National Forest Inventory of Switzerland (NFI; *Schweizerisches Landesforstinventar*, LFI; www.lfi.ch):

- 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
- NFI4b: assumed to be representative of the year 2013

- 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
- NFI34b: assumed to be representative of the period 2006 to 2013

Units of carbon measurements:

- Carbon stocks:

- Kilogram (Kg)
- Megagram (Mg) = 1 metric ton = 10^3 Kg

- Carbon stock changes:

- Kilogram per hectare and year (Kg $ha^{-1}a^{-1}$) = 0.1 g $m^{-2}a^{-1}$
- Megagram per hectare and year (Mg $ha^{-1}a^{-1}$)

1 Introduction

The United Nations Framework Convention on Climate Change (UNFCCC) and the Kyoto-Protocol are international treaties to reduce greenhouse gas (GHG) emissions. As a signature state, Switzerland is required to maintain a comprehensive GHG inventory, including emissions and removals of CO_2-eq. from Land Use, Land-Use Change and Forestry (LULUCF). In the first commitment period (2008-2012), Switzerland elected to account for Forest Management under Article 3.4. of the Kyoto Protocol; in the second commitment period, the accounting of forest management under the Kyoto Protocol is mandatory for all parties. Thus, C stock changes (CSC) in above- and belowground living and dead biomass and in the soil have to be reported in Switzerland's Greenhouse Gas Inventory (GHGI). Starting with the Swiss GHGI 2013 (1990-2011; FOEN 2013), the C decomposition model Yasso07 (Tuomi et al. 2009, Tuomi et al. 2011) was used for deriving estimates of CSC in deadwood (incl. stems, branches and roots), non-woody litter and in soils on productive forest lands (Didion et al. 2012).

Together with the first publication of the results obtained with Yasso07 in the Swiss GHGI 2013, Switzerland committed to further improve the model implementation and the accuracy of the estimates of temporal changes in soil, litter and deadwood. For the GHGI-Submission 2015 (1990-2013), several improvements were made to the estimation of deadwood and litter production. These estimates are derived from the observed change between two consecutive NFIs. The purpose of this report is to a) give details of the improved methods (section 2.3) and b) to present and discuss the estimates of C stocks and CSC published in the GHG-inventory submission of April 2015 (section 3).

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):

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 section 2 on Methods.

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 which are independent of temporal changes in the underlying forest area. See section 2 on Methods.

Comparability is achieved by applying the Yasso07 model in a consistent manner with several other KP parties using the model, including Austria, Finland and Norway. See section 2 on Methods and section 3.1 for results and 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 for methods and 3 for results and discussion.

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 for methods and 3 for results and discussion.

2 Methods

The Yasso07 model and its implementation for estimating C stock changes on lands with productive forests in Switzerland was described in detail in Didion et al. (2012). The model was validated for conditions in Switzerland by Didion et al. (2014) who found that Yasso07 reproduced observed C losses in deadwood and litter very accurately. In the following, a) the most important aspects of the model and the implementation are summarized, and b) the methodological changes are presented in detail.

2.1 Yasso07

Yasso07 (Tuomi et al. 2009, Tuomi et al. 2011) is a model of C cycling in mineral soil, litter and deadwood. The model was 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 requires information on C inputs from dead organic matter components (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). Decomposition of the different components of C inputs is modeled based on their chemical composition, size of woody parts and climate (Tuomi et al. 2009, Tuomi et al. 2011). Decomposition rates of C that is either insoluble (N), soluble in ethanol (E), in water (W) or in acid (A), and flow rates of C between these four compartments, to a more stable humus compartment (H) and out of the soil (Fig. 1, Tuomi et al. 2011) were derived from a global data set (Tuomi et al. 2009, Tuomi et al. 2011). Parameters defining C decomposition rates and C cycling between carbon compartments (Fig. 1) are obtained probabilistically using Markov Chain Monte Carlo sampling and are fitted based on data from litterbag studies (Tuomi et al. 2009) and woody litter decomposition experiments (Tuomi et al. 2011). The approach allows calculating the maximum a posteriori point estimate and confidence sets for the model parameter vector which consists of a unique combination of 24 correlated parameters

The Yasso07 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 Yasso07 Fortran source code was compiled for the Windows7 operating system. The statistical software R (R Core Team 2013) version 3.0.2 (64 bit) was used for administrating the Yasso07 simulations.

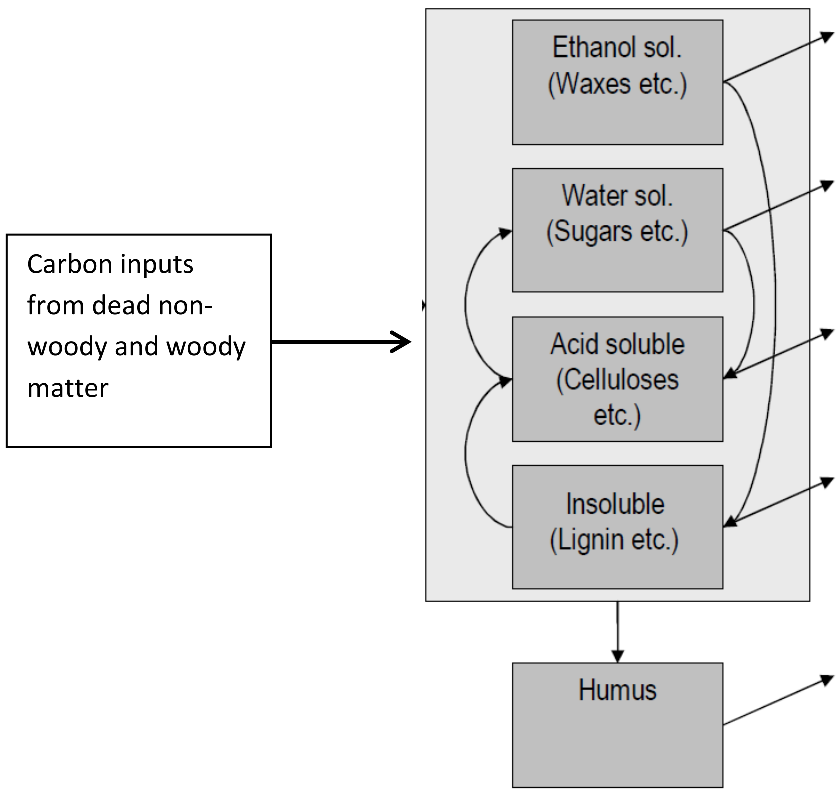

Figure 1. Flow chart of Yasso07 soil carbon model. The boxes represent soil carbon compartments, the arrows carbon flows; only those carbon flows are shown that deviate significantly from zero (adapted from Liski et al. 2009).

2.2 Model implementation for estimating C stock changes in Switzerland

Yasso07 was run on each plot of the Swiss national forest inventory (NFI) that was assessed as accessible forest but not shrub forest (*gemeinsam zugänglicher Wald ohne Gebüschwald*) and as productive forest (Combination Category 12, cf. Tab. 7-6 in FOEN 2014) throughout the four NFIs (Tab. 1), i.e., forests that were considered forest remaining forest. To drive the Yasso07 simulation, a model parameter set was selected and plot-specific annual inputs for a) non-woody and woody C derived from measured data and for b) observed climate were used as follows:

a. Initial C stocks are estimated in a spin-up procedure (cf. Liski et al. 2009) based on mean climate 1961 to 1990 (Tab. 2) and constant, aggregated C inputs from the first NFI (NFI12avg; Tab. 3) assuming that current C stocks in the soil have accumulated over centuries (cf. Gimmi et al. 2013).
b. In order to cancel out the steady-state conditions after the spin-up phase (cf. Peltoniemi et al. 2007), the spin-up simulation is followed by simulating 25 years with regionally aggregated, constant C input data (NFI12avg; Tab. 3) but with annual climate data for the period 1961 to 1985.
c. For the period after 1986 (i.e., start of the period NFI 1 to 2; Tab. 3), plot-specific carbon inputs from the four NFIs and annual, plot-specific climate data until 2013 are used to obtain the time series of annual C stocks. The time series of C inputs since 1986 is derived by backwards-averaging inputs over three years, i.e., the input of the current year was calculated as the mean over the inputs of the current year and the two preceding years. The reason for this three-year averaging is to account for interannual variability (cf. chapter 7.3.4.2 in FOEN 2014).

Table 1. Number of NFI sampling plots per subregion that were available for the Yasso07 simulation. Only plots were included that were classified as accessible forest but not shrub forest. These areas represent the “productive forest CC12”, as it is defined in the Swiss Greenhouse gas inventory (cf. Tab. 7-6 in FOEN 2014).

Elevation class	**Production Region**					**Switzerland**
	Jura	**Plateau**	**Pre-Alps**	**Alps**	**Southern-Alps**	
<601 m	129	346	18	17	40	550
600 – 1200 m	306	253	330	241	116	1246
>1200 m	46	4	145	488	128	811
Total	481	603	493	746	284	2607

To obtain an estimate of uncertainty related to model parameters and litter as well as deadwood inputs, a Monte-Carlo approach was used based on independent simulations of randomly sampled parameter vectors and deadwood and litter samples.

2.2.1 Model parameters

The model parameters identified by Didion et al. (2014) were used to drive the simulations. With this parameter set presented in Rantakari et al. (2012), Yasso07 reproduced observed C losses in decomposing deadwood and litter with a high degree of accuracy (Didion et al. 2014). Uncertainty in model parameter values was included in the simulations by random sampling from the distribution of possible parameter vectors (Tab. A-1).

2.2.2 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 plot, data for mean monthly absolute temperature [°C] and for monthly precipitation sum [mm] since 1961 were extracted from the respective gridded data (Tab. 2 for long-term national means). Annual mean temperature and precipitation sum were calculated as the mean and sum, respectively, of the monthly data. Annual temperature amplitudes were calculated as

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

Since plot-specific climate data from a national observation network are used, the effect of a climatic disturbance affecting temperature or precipitation is reflected in the respective measured data. Thus, changes in climatic conditions are explicitly accounted for in the simulations with Yasso07 because decomposition rates will be affected accordingly.

Table 2. Long-term (1961-1990) mean annual temperature and precipitation sum calculated from the plot-specific data within each region (source: MeteoSwiss 2012a, b).

a) Temperature

		Production region					**Switzerland** [°C]
Elevation class		**Jura** [°C]	**Plateau** [°C]	**Pre-Alps** [°C]	**Alps** [°C]	**Southern Alps** [°C]	
<601 m	*Min*	5.9	6.5	5.1	3.4	4.4	3.4
	Mean	8.2	8.3	7.8	7.5	9.5	8.4
	Max	10.0	10.4	9.4	9.9	11.7	11.7
601-1200 m	*Min*	4.3	5.4	0.6	-1.0	0.4	-1.0
	Mean	7.0	7.7	6.0	5.0	7.3	6.5
	Max	9.5	10.0	9.7	9.6	11.7	11.7
>1200 m	*Min*	4.2	4.4	0.6	-5.0	-2.4	-5.0
	Mean	5.9	6.1	4.4	2.4	4.4	3.3
	Max	8.6	8.4	8.3	9.3	11.0	11.0
Total	*Min*	4.2	4.4	0.6	-5.0	-2.4	-5.0
	Mean	7.2	8.0	5.5	3.2	6.2	5.6
	Max	10.0	10.4	9.7	9.9	11.7	11.7

b) Precipitation sum

Elevation class		**Jura** [mm]	**Plateau** [mm]	**Pre-Alps** [mm]	**Alps** [mm]	**Southern Alps** [mm]	**Switzerland** [mm]
<601 m	*Min*	814	804	1062	687	1361	684
	Mean	1066	1080	1375	1207	1757	1154
	Max	1467	1603	1785	2044	2265	2382
601-1200 m	*Min*	871	890	1061	580	861	580
	Mean	1324	1236	1593	1275	1805	1421
	Max	1862	1838	2273	2324	2322	2538
>1200 m	*Min*	1210	1378	1241	602	861	602
	Mean	1650	1794	1780	1240	1718	1442
	Max	2046	1936	2390	2454	2365	2639
Total	*Min*	813	804	1045	576	861	576
	Mean	1303	1151	1652	1249	1755	1380
	Max	2046	1967	2395	2456	2370	2640

2.2.3 C inputs

Estimates of C inputs (Tab. 3) for the simulations with Yasso07 were obtained separately for coniferous and broadleaved tree species for:

- Coarse-woody material from trees >7 cm in diameter separately for roots, branches and stem; and
- Non-woody material separately for foliage (incl. fruits) and fine roots < ca. 5 mm.

The annually accumulating mass in these DOM components (Tab. 3) was derived through allometric relationships to the volume of living standing and removed (harvest and mortality) trees (cf. Thürig et al. 2005). The volume of living and removed trees was obtained from NFI data (NFI 1 through 4b). Etzold et al. (2011) verified the accuracy of the estimates with independent data from long-term forest ecosystem research sites. The conversion to C was based on measured carbon densities (Dobbertin and Jüngling 2009).

The uncertainty related to the estimation of deadwood and litter inputs was estimated to account for uncertainties in

- applying allometric functions (biomass expansion factors, turnover rates; Wutzler and Mund 2007);
- carbon concentration (Dobbertin and Jüngling 2009); and
- measurement errors in the NFI data.

Based on the mean inputs at each NFI site and estimates of uncertainty, a distribution of possible inputs was created and a combined uncertainty was derived (Tab. A-2).

The estimates of C inputs were obtained separately for each NFI plot to account for local conditions including the prevalent forest management type and background mortality. These disturbances can result in changes in the number and volume of trees on an inventory plot and, thus, to the production of coarse-woody and non-woody material. These effects are explicitly accounted for in the estimation of C inputs for the five DOM components: Estimates of fine root and foliage production vary with a change in tree number and volume. Estimates of coarse-woody production is directly related to the rate of tree mortality due to a disturbance and in the amount of residues that remain after a disturbance. If climatic disturbances such as storms cause the mortality of trees or tree components such as branches and result in an increase in the amount of deadwood, NFI measurements will show this increase. Since the input of C (i.e., the volume of deadwood which is produced in one year) to the model is derived from NFI deadwood measurement, changes in the measured data affect the C inputs to the model accordingly. The result is a temporary (i.e. in the year of the disturbance and possibly also in subsequent years) increase in the amount of fresh C that enters the model and contributes to the annual C balance of the deadwood pool.

Table 3. C inputs for all NFI plots simulated with Yasso07 (n=2 607): Mean and standard deviation of carbon content [Kg C $ha^{-1}a^{-1}$] in five dead organic matter (DOM) components for coniferous and broadleaved tree species for different simulation periods and for the spin-up procedure.

a) conifers

Simulation period	NFI data	DOM component					Total
		Fine roots	Foliage	Coarse-woody (>7 cm diameter)			
				Roots	Branches	Stems	
Spin-up and 1961-1985	NFI12avg (moving window)	745 ±269	1110 ±507	294 ±165	62 ±43	54 ±38	2264 ±826
1986-1995	NFI12	749 ±653	1115 ±1155	285 ±653	60 ±180	53 ±159	2263 ±2174
1996-2005	NFI23	799 ±702	1168 ±1226	347 ±815	89 ±239	79 ±210	2482 ±2417
2006-2013	NFI34b	751 ±683	1093 ±1197	346 ±1078	98 ±376	87 ±333	2375 ±2744

b) broadleaves

Simulation period	NFI data	DOM component					Total
		Fine roots	Foliage	Coarse-woody (>7 cm diameter)			
				Roots	Branches	Stems	
Spin-up and 1961-1985	NFI12avg (moving window)	280 ±166	667 ±407	97 ±84	33 ±27	11 ±11	1089 ±655
1986-1995	NFI12	281 ±371	666 ±866	100 ±316	36 ±171	12 ±55	1095 ±1466
1996-2005	NFI23	319 ±416	749 ±964	103 ±336	48 ±187	13 ±47	1233 ±1619
2006-2013	NFI34b	321 ±398	752 ±922	121 ±469	61 ±334	18 ±89	1273 ±1735

C inputs for each pool were portioned into the four chemical compartments (AWEN, cf. section 2.1) used by Yasso07 following experimentally derived fractions (Tab. 4) as discussed in Didion et al. (2014).

Table 4. Initial fractions for the simulation of foliage and fine root litter and of deadwood separated into the four chemical compartments in Yasso07, i.e., C that is either insoluble (N), soluble in ethanol (E), in water (W) or in acid (A).

Litter type	Tree species	A	W	E	N
Foliage	**Conifers**	0.4065	0.2935	0.065	0.235
	Broadleaves	0.4815	0.1315	0.055	0.33
Fine roots	**Conifers**	0.449	0.28	0.025	0.245
	Broadleaves	0.433	0.1595	0.015	0.39
Deadwood	**Conifers**	0.675	0.0175	0.0025	0.305
	Broadleaves	0.715	0.015	0	0.27

2.3 Methodological improvements

Following the aim to continuously improve the methodology, the derivation of the data on the deadwood and litter production was revised to account for the change in the NFI sampling scheme from an interval-based to a continuous, annual inventory (cf. www.lfi.ch).

The production of deadwood is estimated based on the observed change between two consecutive NFIs and annual estimates are derived based on the time between the two NFIs. The annual data then served as inputs for the simulations with Yasso07 (section 2.2.2). Before the switch to a continuous NFI starting in 2009, the time interval between two consecutive NFIs was between 9 and 11 years on all sites (Brändli 2010). The timespan between observations during the NFI3 and the continuous NFI4 ranges from a minimum of 3 years for sites visited in the first year of the NFI4, i.e. 2009 to a maximum of 12 years for sites that will be inventoried in the final year 2017. Thus, the application of a general estimator for the timespan between two consecutive NFIs became unsuitable. It resulted in an underestimation in the annual estimates since the interval was much shorter than previously. To obtain more accurate annual estimates on deadwood and litter production on each NFI plot, the length of the period between two consecutive observations was derived for each individual NFI plot from the NFI database. This resulted in more accurate estimates of the inputs for Yasso07 and particularly affected the estimates for the period between NFI3 and NFI4b.

As a consequence of the continuous sampling, additional data become available annually. Compared to the GHGI 2014, information from additional 1 059 NFI plots was available for the GHGI 2015 corresponding to an increase from 1 548 to 2 607 plots. Due to the additional data, the accuracy of the estimates increased and the sampling error decreased.

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 five C input components (cf. Tab. 3). Using this information, annual estimates of carbon stored in the soil (sum of C in the H compartment from all components), the litter-fermented humus (LFH) layer (i.e., sum C in the AWEN compartments of fine roots and foliage) and in deadwood (CWD; i.e., sum C in the AWEN compartments of stem, branches and roots) were calculated (cf. Appendix I in Didion et al. 2012, Didion et al. 2014). For consistency with previous submissions of Switzerland's NIR (chapter 7.3.4.8 in FOEN 2014), 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 CWD pool based on coarse-woody inputs only.

Annual estimates of carbon stocks in the soil, LFH and CWD pools for each NFI plot were derived from Yasso07 simulations for the period 1989 to 2013. Averaged annual estimates of C stocks were derived from annual estimates by averaging over three years, i.e. the mean over the current year and the two preceding years (cf. chapter 7.3.4.8 in FOEN 2014). For both resulting time series, the annual change in carbon stock between consecutive years was calculated. Thus, for each pool a total of four time series was obtained giving the mean and the uncertainty estimate (standard error (SE) derived from 100 replicate simulations (i.e., 10 parameter vectors and 10 deadwood and litter samples) for:

1) *annual carbon stock change based on annual stocks*: SO_{csc}, LFH_{csc}, CWD_{csc} and the sum (ALL_{csc}); contained in result tables[1] 1 [Mg C $ha^{-1}a^{-1}$] and 2 [Mg C a^{-1}].
2) *annual carbon stock change based on averaged annual stocks*: $SO_{avg, csc}$, $LFH_{avg, csc}$, $CWD_{avg, csc}$ and the sum ($ALL_{avg, csc}$); result tables 3 [Mg C $ha^{-1}a^{-1}$] and 4 [Mg C a^{-1}].
3) *annual carbon stocks*: LFH, CWD; result tables 5 [Mg C ha^{-1}] and 6 [Mg C].
4) *averaged annual carbon stocks*: LFH_{avg}, CWD_{avg}; result tables 7 [Mg C ha^{-1}] and 8 [Mg C].

Estimates of absolute stocks [Mg C] and total stock change [Mg C a^{-1}] stratified for five production regions and three elevation classes (≤600 m, 601-1200 m, >1200 m) were obtained based on the respective area of forest land remaining forest land calculated for commonly accessible forest of NFIs 3 and 4b (Tab. A-3; note that for the final preparation of the Swiss GHGI activity data from aerial photographs of the Swiss land use statistics (AREA) are used; cf. chapter 7.2.2.1 in FOEN 2014)

3 Results and Discussion

The complete set (cf. section 2.4) of C stock and CSC that were prepared for the Swiss GHGI 2015 (1990-2013) can be found in Appendix II. In the following, the results for CSC and stocks are presented and additional data that are relevant for verification are documented. If not noted otherwise, the stock and CSC data are based on the 3-year-averaged annual results.

[1] see Appendix II for details and nomenclature.

3.1 Carbon stock change

For the mean total CSC 2012-2013 in soil, LFH and deadwood, a small sink effect of ca. -0.018 ±0.007 Mg C ha^{-1} was estimated ($ALL_{csc,avg}$ in Fig. 2, Tab. 5). This corresponded to a national sink effect of -20 292 ±7 751 Mg C based on 1 157 624 ha of productive forest as derived for the period between NFIs 3 and 4b (Tab. A-3).The dynamics in deadwood and LFH dominated total CSC (Fig. 2).

Deadwood formed a persistent sink since NFI2, which was due to two reasons:

- In 1999 (i.e. between NFI2 and 3), the storm Lothar caused large scale mortality across Swiss forests. Although the majority of the felled trees were removed, the deadwood volume increased significantly. As particularly the larger sized felled trees decay slowly (Didion et al. 2014), the storm resulted in a sustained C sink. The additional deadwood pool which resulted from the storm will slowly release the stored C over the coming decades.
- The trend of decreasing harvest rates starting after NFI3 resulted in more volume of deadwood remaining in the forest compared to the years before. This lead to an increase in the C stock in deadwood.

While LFH alternated between source and sink between the different NFIs, soil acted continuously as a comparably moderate sink. The standard error resulting from uncertainty in C inputs and in model parameters was ca. 10% for the individual pools. This is comparable to reported uncertainties (e.g., Keller et al. 2006, Schöning et al. 2006, Luyssaert et al. 2010). The uncertainty in total combined CSC was estimated as ca. 38%. In comparison, for the net CSC in 2011 in dead wood, litter and soil organic matter Finland reports an uncertainty of 46.8% in South Finland, 26.2% in North Finland and 24.1% for the whole country (double standard error; cf. chapter 7.2.4.2 in Statistics Finland 2014). Whether CSC resulted in a source or sink effect varied between pools and regions (Tabs. 5 and A-6 to A-9 and A-14 to A-17 for a complete time series of areal [Mg C $ha^{-1}a^{-1}$] and absolute CSC [Mg C a^{-1}]).

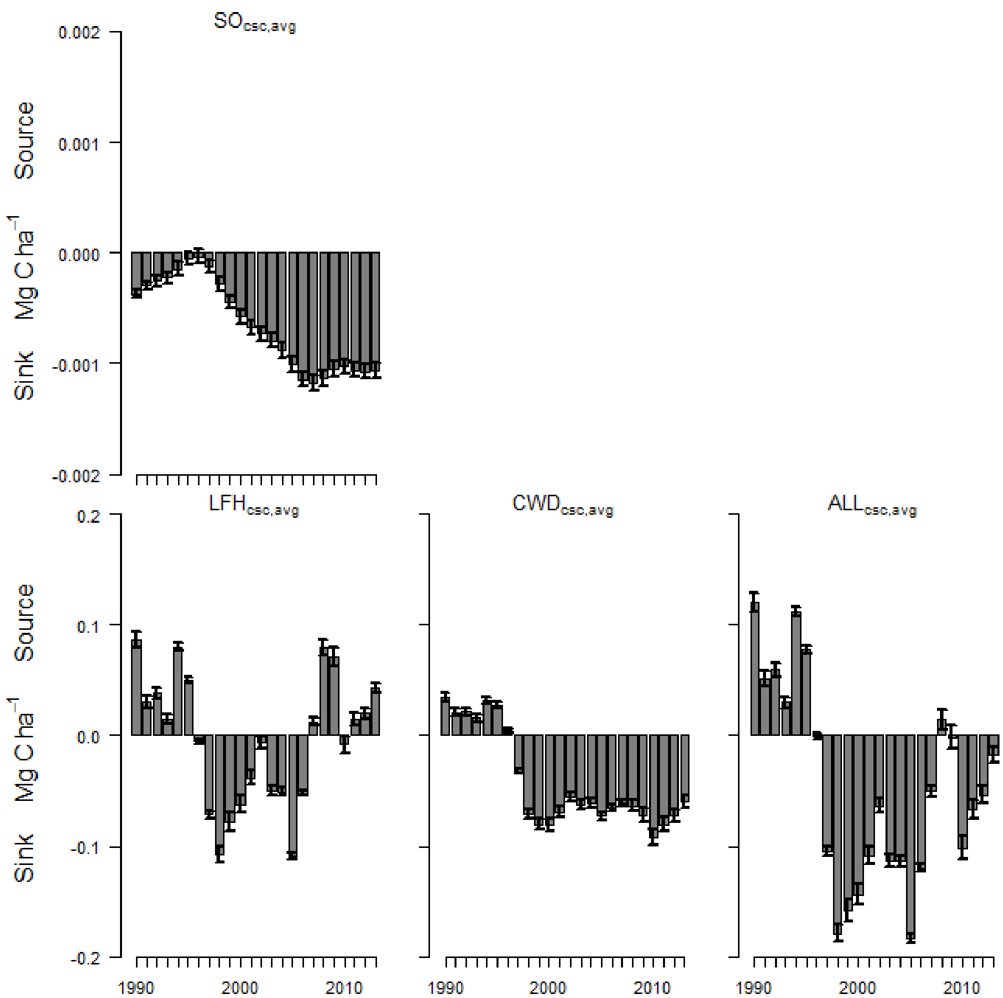

Figure 2. National mean carbon stock change (CSC) based on 3-year averaged annual carbon stocks for 3 pools soil (SO), litter (LFH), dead wood (CWD) and their sum (ALL). Note the difference of the y-axis scale between $SO_{csc,avg}$ and $LFH_{csc,avg}$, $CWD_{csc,avg}$ and $ALL_{csc,avg}$, respectively. Negative values indicate a sink of C, positive values a carbon source. The error bars indicate the standard error.

Table 5. Mean Carbon stock change ± standard error [Mg C ha^{-1}] between 2012 and 2013 stratified into 3 elevation classes and 5 NFI-production regions. Negative values indicate a sink of C, positive values a carbon source.

Elevation class	**Production region**					**Switzerland**
	Jura	**Plateau**	**Pre-Alps**	**Alps**	**Southern Alps**	
<601 m	-0.032 ±0.028	-0.020 ±0.018	-0.400 ±0.092	-0.243 ±0.066	-0.070 ±0.029	-0.046 ±0.014
601-1200 m	-0.112 ±0.014	-0.068 ±0.026	0.059 ±0.021	-0.023 ±0.021	-0.066 ±0.022	-0.036 ±0.009
>1200 m	0.104 ±0.023	-0.068 ±0.026	0.055 ±0.026	0.062 ±0.018	-0.142 ±0.032	0.031 ±0.013
Total	-0.070 ±0.012	-0.040 ±0.015	0.041 ±0.016	0.027 ±0.014	-0.101 ±0.018	-0.018 ±0.007

For comparing the effect on CSC estimates of the improved method applied in the GHGI 2015 (see section 2.3) with the method used in the GHG 2014 (Didion et al. 2013, FOEN 2014), C stocks and CSC were recalculated for the complete time series since 1990. The difference in methods had a negligible impact on the estimates of CSC in the LFH and soil C pools. The largest effect of the improved method occurred in the deadwood pool since 2006, i.e. the start of the period NFI34b: For the GHG 2014, the application of a general estimator for the length of the period between two consecutive NFIs produced incorrect estimates. Thus the methodological improvements affected particularly the C stocks and CSC of the CWD pool after 2006. The period since 2006 was previously estimated as a source, whereas now it is a small sink (Fig. 2). The national estimate for mean CWD CSC 2011-2012 reported in the previous GHGI was a source of 0.220 ±0.005 Mg C ha^{-1} (Didion et al. 2013) compared to a sink of -0.072 ±0.006 Mg C ha^{-1} calculated for the same period based on the improved methodology.

3.2 Carbon stocks

Due to the improvements in the methods (cf. section 2.3), the accuracy of the simulated trend in CWD stocks since 2006 increased significantly compared to the results in GHGI 2014 (FOEN 2014) where there was only moderate agreement between simulated stocks since 2006 and observed data from the NFI (Tab. 6).

In the Swiss NFI, estimates of coarse deadwood C stocks based on measured tree volume are available since the NFI3. The simulated national mean deadwood C stock overestimates the national stock derived from the NFI by ca. 30% (Tab. 6). This is not surprising since NFI data are associated with uncertainty (cf. Didion et al. 2014), especially regarding the measurement of the decay class, which is important for applying the correct wood density. Also, the model cannot account for information that is available for the calculation of the C stocks of individual trees in the NFI, e.g., volume reduction due to damage, or diameter and length of a piece of deadwood. Nevertheless, the simulated stocks are plausible since they agree well with NFI estimates of national mean deadwood C stocks that are based on the observed full volume of deadwood pieces (i.e., not accounting for observed damage), i.e., 7.16 (±0.26) Mg C ha^{-1} at NFI3 and 7.75 (±0.26) Mg C ha^{-1} at NFI4b.

The observed change in CWD C stocks in Switzerland between NFI3 and 4b was reproduced accurately by the model (Tab. 6). Considering the lower number of available plots within a region (cf. Tab. 1), the simulated change in the production regions also agreed well with observations. With the exception of the Southern-Alps, the model reproduced the trends in individual production regions (Tab. 6). In the Southern-Alps the application of Yasso07 is difficult due to the highly variable precipitation pattern in this region with extended periods of drought interrupted by heavy rainfall events (cf. Didion et al. 2011).

Table 6. Mean and standard error of carbon stored in deadwood (CWD) based on observations in NFIs 3 and 4b and simulated deadwood carbon stock with Yasso07; the simulated stock was calculated as the mean of the annual stocks in years 2004-2006 for NFI 3 and 2011-2013 for NFI 4b.

Region	NFI 3		NFI 4b		Change	
	Mg C ha^{-1}				%	
	NFI	Yasso07	NFI	Yasso07	NFI	Yasso07
Jura	4.49 ±0.38	6.60 ±0.08	5.28 ±0.46	7.36 ±0.08	17.6	11.5
Central Plateau	4.81 ±0.47	10.82 ±0.10	4.51 ±0.35	11.63 ±0.11	-6.2	7.5
Pre-Alps	8.28 ±0.66	10.64 ±0.12	8.93 ±0.69	10.97 ±0.12	7.76	3.1
Alps	7.18 ±0.44	7.39 ±0.06	7.46 ±0.39	7.57 ±0.08	3.9	2.5
Southern-Alps	4.85 ±0.50	2.33 ±0.05	5.64 ±0.49	2.86 ±0.08	16.3	22.8
Switzerland	6.16 ±0.23	8.10 ±0.04	6.54 ±0.22	8.60 ±0.05	6.2	6.2

For verification of the LFH C stocks, the simulated data were compared with observed data from Moeri (2007). The simulated national mean LFH C stock was ca. 70% of the observed stock (Tab. 7). This difference is not surprising since the simulated values do not include non-woody litter inputs from the herb and shrub layers. Carbon inputs from litter produced by ground vegetation can account for almost all carbon inputs in recently harvested stands and between 10 to 50% in middle-aged and old stands (cf. de Wit et al. 2006). Based on experimental data from Muukkonen and Mäkipää (2006), the C inputs from herb- and shrub vegetation in Finnish forests was estimated to be in the range of 500 to 660 Kg C ha^{-1} a^{-1}. This would contribute additional 15-25% to the currently used non-woody C inputs used for the Swiss GHGI (Tab. 3). Thus, the simulated value for the national mean LFH C stock can be considered as a reliable and plausible estimate, which was also indicated by the overlapping ranges of the standard deviations (Tab. 7). An estimate of the contribution of the herb and shrub layer to carbon inputs on NFI plots may become available with the project 'The carbon cycle of LWF-sites in Switzerland' (P. Waldner, WSL) for the GHGI 2016.

Table 7. Carbon stock in the litter pool based on observed (sum of L, F and H horizons from Tab. 5.3 in Moeri 2007) and simulated LFH carbon stock with Yasso07; the simulated stock was calculated as the long-term mean over the period 1989-2013. Standard deviation in brackets.

Region	**Moeri 2007**	**Yasso07**
	Mg C ha^{-1}	
Jura	9.71 (±15.1)	9.28 (±0.31)
Central Plateau	9.5 (±13.3)	9.79 (±0.31)
Pre-Alps	17.3 (±28.4)	11.13 (±0.39)
Alps	33.4 (±43.3)	12.46 (±0.41)
Southern-Alps	22.3 (±29.9)	9.61 (±0.54)
Switzerland	18.1 (±30.0)	10.69 (±0.18)

The variability in LFH C stocks between regions is greater in the measured data from Moeri (2007) than in the simulated data (Tab. 7). There are several explanations for this, including a) statistics (e.g., on harvest) that are used to derive inputs for the Yasso07 simulation are not available on the basis of NFI plots but are spatially aggregated, and b) the measured data are based on a limited number of observations and thus the uncertainty of the means is higher as indicated by the large standard deviations in table 7.

The data in tables 6 and 7 indicate that the estimated LFH and deadwood C stocks agree well with observations and are plausible, certainly at the national level. Since observed C decomposition was reproduced highly satisfactory with Yasso07 (Didion et al. 2014), confidence can be placed in the reported stocks and stock changes in the LFH and CWD pools.

Due to the incomplete knowledge of the origin of the high soil carbon stocks in Switzerland (Nussbaum et al. 2012, 2014), they cannot be reproduced by models yet. Hence, only changes in soil C stocks derived from the Yasso07 are reported in the GHG 2015. Although soil C stocks cannot be reproduced, it can be assumed that the changes obtained from the simulated stocks were realistic since a) the pyrogenic carbon which is found particularly in the soils of the Southern Alps is very stable (Eckmeier et al. 2010), b) the simulated CSC including standard error is less than the variability resulting from repeated SOC measurements (e.g., Keller et al. 2006), and c) observed environmental gradients are reproduced by the model, including the increase in soil C stocks with elevation. The increase in soil C per 100 m increase in elevation was 1.04 Mg C ha^{-1}. This was less than the 2.3 Mg C ha^{-1} reported by Hagedorn (2010). However, the correlation of the Yasso07 estimates with elevation was stronger, i.e. $r = 0.35$ ($p = 0$) than in the analysis by Hagedorn (2010), i.e. $r = 0.12$ (p value not reported).

3.3 Further development

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

- Investigating the validity of the forthcoming new version of Yasso07 for application in Switzerland. The new model version and a new parameter set that are currently developed at the Finnish Environment Institute and Tampere University of Technology (http://www.syke.fi/en-US/Research__Development/Research_and_development_projects/Projects/Soil_carbon_model_Yasso/News) are expected to result in improvements to the Swiss Yasso07 implementation.
- Examining the suitability of Yasso07 for estimating CSC on lands converted to forests, based on the experience from Finland and Norway, where Yasso07 is already applied on afforested lands. This would improve the consistency in methods in the Swiss GHGI.
- Improving the derivation of C inputs from litter and deadwood, including a) interpolating between two consecutive NFIs and b) accounting for the contribution of fine-woody litter <7 cm and of litter from the herb- and shrub layer; the latter in collaboration with S. Etzold, WSL. These activities will improve the accuracy of the Yasso07 estimates and result in an increase in completeness.
- Revision of densities of deadwood in various stages of decomposition based on new data from two projects: “Deadwood pools and drivers in Swiss and European forests” by S. Herman., WSL and “Kernfäule” (heart rot) by J. Wunder, WSL.
- Quantifying the effect of uncertainty associated with the spatially interpolated temperature and precipitation data on CSC estimates. MeteoSwiss is currently developing ensembles of the gridded climate data that will allow to address this source of uncertainty in the simulations with Yasso07. The ensembles are expected to become available in 2016.

It is also anticipated that the previously completed European task force on forest soil modeling with Yasso07 (LULUCF MRV project: "Analysis of and proposals for enhancing Monitoring, Reporting and Verification (MRV) of land use, land use change and forestry (LULUCF) in the EU"; http://forest.jrc.ec.europa.eu/activities/lulucf/) will provide new insights and stimulate further improvements of the Yasso07 application. The project demonstrated strengths and weaknesses of Yasso07 for estimating the C balance of deadwood, litter and soil in forests along a wide environmental gradient. Contributors to the task force came from Austria, Estonia, Finland, France, Romania, Spain and Switzerland representing a large variety of forest types. Implications and further research needs are currently evaluated and will be discussed in a workshop at WSL on 15 December 2014; a manuscript is in preparation.

Several opportunities for collaboration and further development of Yasso07 are arising from national and international projects, including

- National Research Programme project "Sustainable use of Soil as a Resource" by F. Hagedorn, WSL;
- “Kernfäule” (heart rot) by J. Wunder, WSL;
- “Carbon sources and sinks in agricultural soils” at the Agroscope Reckenholz-Tänikon Research Station (ART);
- “Bayesian methods and the dynamics of soil processes of forests” by M. Järvenpää, J. Liski, A. Akujärvi, M. Kaasalainen at Tampere University of Technology and Finnish Environment Institute; and
- ongoing research and collaboration between Finnish Environment Institute, Finnish Forest Research Institute, Norwegian Forest and Landscape Institute and WSL.

4 Conclusions

The methodology for estimating carbon stocks and carbon stock changes in deadwood, litter and soil for the Swiss GHGI has been further improved since Switzerland’s latest GHGI (FOEN 2014). Carbon stocks in deadwood and litter (LFH layer in the Swiss inventory) can now be estimated accurately within the limits of missing information on the contribution of the herb- and shrub layer. The carbon decomposition in deadwood and litter has been shown to be accurate (cf. Didion et al. 2014) and, thus, a high degree of confidence can be placed in the accuracy of the reported carbon stock changes in all pools.

The comprehensive analysis of uncertainties, which included uncertainty in the deadwood and litter inputs and in the model parameters, presented a further advancement. The uncertainties and variability in the C stock changes in soil, litter and deadwood were within reported error margins (e.g., Luyssaert et al. 2010).

Current limitations such as lack of data and source of the high soil C stocks are under investigation in ongoing and planned research projects.

Acknowledgements

We are grateful to Nele Rogiers and Andreas Schellenberger at FOEN for valuable discussions and comments on this report. We also appreciate the support of Massimiliano Zappa and Käthi Liechti, Mountain Hydrology and Mass Movements, WSL with the conversion of the climate data. The contributions and support of the NFI team at WSL is acknowledged.

5 References

Brändli, U.-B., editor. 2010. Schweizerisches Landesforstinventar: Ergebnisse der dritten Erhebung 2004-2006. [Results of the third Swiss National Forest Inventory 2004-2006] Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf (ZH) and Federal Office for the Environment (FOEN), Bern.

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., B. Frey, N. Rogiers, and E. Thürig. 2014. Validating tree litter decomposition in the Yasso07 carbon model. Ecological Modelling **291**:58-68.

Didion, M., E. Kaufmann, and E. Thürig. 2012. Estimation of carbon stocks and fluxes in soil, LFH layer and deadwood in Swiss forests with Yasso07. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/climatereporting.

Didion, M., E. Kaufmann, and E. Thürig. 2013. Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse deadwood prepared for the Swiss GHGI 1990-2012. Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/climatereporting.

Didion, M., A. Kupferschmid, A. Wolf, and H. Bugmann. 2011. Ungulate herbivory modifies the effects of climate change on mountain forests. Climatic Change **109**:647-669.

Dobbertin, M., and E. Jüngling. 2009. Totholzverwitterung und C-Gehalt. [Wood density and carbon content with changing degree of dead wood decay: First results]. Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf. avl. online at www.bafu.admin.ch/climatereporting.

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.

FOEN (Federal Office for the Environment). 2013. Switzerland's Greenhouse Gas Inventory 1990–2011. National Inventory Report 2013 including reporting elements under the Kyoto Protocol Submission of 15 April 2013 under the United Nations Framework

Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. avl. online at www.bafu.admin.ch/climatereporting.

FOEN (Federal Office for the Environment). 2014. Switzerland's Greenhouse Gas Inventory 1990–2012. National Inventory Report 2014 including reporting elements under the Kyoto Protocol Submission of 15 April 2013 under the United Nations Framework Convention on Climate Change and under the Kyoto Protocol. Federal Office for the Environment, Bern. avl. online at www.bafu.admin.ch/climatereporting.

Gimmi, U., B. Poulter, A. Wolf, H. Portner, P. Weber, and M. Bürgi. 2013. Soil carbon pools in Swiss forests show legacy effects from historic forest litter raking. Landscape Ecology **28**:835-846.

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.

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.

Keller, A., A. Desaules, P. Schwab, P. Weisskopf, S. Scheid, and H.-R. Oberholzer. 2006. Monitoring Soil Quality in the long-term: Examples from the Swiss National Soil Monitoring Network. Mitteilungen der Österreichischen Bodenkundlichen Gesellschaft **73**:5-12.

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

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, Zurich.

MeteoSwiss (Federal Office of Meteorology and Climatology). 2012b. Documentation of MeteoSwiss Grid-Data Products Monthly and Yearly Precipitation: RhiresM and RhiresY. Federal Office of Meteorology and Climatology MeteoSwiss, Zurich.

Moeri, A. C. 2007. Kohlenstoffvorräte in Schweizer Waldböden unter besonderer Berücksichtigung der organischen Auflage. Universität Zürich, Zürich. avl. online at www.bafu.admin.ch/climatereporting.

Muukkonen, P., and R. Mäkipää. 2006. Empirical biomass models of understorey vegetation in boreal forests according to stand and site attributes. Boreal Environment Research **11**:355-369.

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.

Nussbaum, M., A. Papritz, A. Baltensweiler, and L. Walthert. 2014. Estimating soil organic carbon stocks of Swiss forest soils by robust external-drift kriging. Geosci. Model Dev. Discuss. **6**:7077-7116.

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. 2007. Models in country scale carbon accounting of forest soils. Silva Fennica **41**:575–602.

R Core Team. 2013. R: a language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria.

Rantakari, M., A. Lehtonen, T. Linkosalo, M. Tuomi, P. Tamminen, J. Heikkinen, J. Liski, R. Mäkipää, H. Ilvesniemi, and R. Sievänen. 2012. The Yasso07 soil carbon model – Testing against repeated soil carbon inventory. Forest Ecology and Management **286**:137-147.

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.

Statistics Finland. 2014. Greenhouse gas emissions in Finland 1990-2012. National Inventory Report under the UNFCCC and the Kyoto Protocol. Statistics Finland, Helsinki.

Thürig, E., T. Palosuo, J. Bucher, and E. Kaufmann. 2005. 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. 2011. Wood decomposition model for boreal forests. Ecological Modelling **222**:709-718.

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.

Appendix I: Additional data

Table A-1. Maximum a posteriori (MAP) estimators and standard errors for the parameter set developed by Rantakari et al. (2012), which was validated for simulating deadwood and litter decomposition in Swiss forests (Didion et al. 2014).

Parameter	MAP (±SE)	Unit	Interpretation
αA	0.517 (±0.0004)	a-1	Decomposition rate of A
αW	3.552 (±0.003)	a-1	Decomposition rate of W
αE	0.346 (±0.0005)	a-1	Decomposition rate of E
αN	0.266 (±0.0002)	a-1	Decomposition rate of N
ρ1	0.0449 (±0.0001)		Relative mass flow, W → A
ρ2	0.0029 (±0.00009)		Relative mass flow, E → A
ρ3	0.978 (±0.00006)		Relative mass flow, N → A
ρ4	0.637 (±0.0001)		Relative mass flow, A → W
ρ5	0.312 (±0.0002)		Relative mass flow, E → W
ρ6	0.0187 (±0.00003)		Relative mass flow, N → W
ρ7	0.0225 (±0.00002)		Relative mass flow, A → E
ρ8	0.0117 (±0.00006)		Relative mass flow, W → E
ρ9	0.001 (±0.00005)		Relative mass flow, N → E
ρ10	0.336 (±0.0002)		Relative mass flow, A → N
ρ11	0.042 (±0.00005)		Relative mass flow, W → N
ρ12	0.0899 (±0.0001)		Relative mass flow, E → N
β1	0.0895 (±0.00009)	10-2 °C-1	Temperature dependence
β2	-0.0023 (±0.000005)	10-4 °C-2	Temperature dependence
γ	-2.94 (±0.001)	m-1	Precipitation dependence
αH	0.24 (±0.001)	10-3 a-1	Humus decomposition rate
ρH	0.15 (±0.0002)	10-2	Mass flow to humus
φ1	-0.539 (±0.0003)	cm-1	First order size dependence
φ2	1.186 (±0.0005)	cm-2	Second order size dependence
r	-0.263 (±0.000002)		Size dependence power

Table A-2. Uncertainty in litter inputs (%).

	Conifers	Broadleaves
Wood density[1]	25.9	23.6
Spatial uncertainty in the NFI[2]	3	3
Litter turnover[3]	17	4
Total[4]	31.1	27.6

[1] Estimated based on data Table 1 in Dobbertin and Jüngling (2009).

[2] Approximated based on the estimation error for tree volume reported for the NFI; cf. chapter 1.4 in Brändli, U.-B., editor. 2010. Schweizerisches Landesforstinventar: Ergebnisse der dritten Erhebung 2004-2006. [Results of the third Swiss National Forest Inventory 2004-2006]. Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf (ZH) and Federal Office for the Environment (FOEN), Bern.

[3] Data from Wutzler, T., and M. Mund. 2007. Modelling mean above and below ground litter production based on yield tables. Silva Fennica 41:559-574.

[4] Calculated following equation 6.4 in chapter 'Quantifying Uncertainties in Practice' in the IPCC (2000) report on Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories (avl. at: www.ipcc-nggip.iges.or.jp/public/gp/english/).

Table A-3. Area of productive forest in Switzerland based on the area of forest land remaining forest land calculated for commonly accessible forest of NFIs 3 and 4b.

Elevation class	Production region										Switzerland	
	Jura		Plateau		Pre-Alps		Alps		Southern Alps			
	ha	± %	ha	± %	ha	± %	ha	± %	ha	± %	ha	± %
<601 m	51944.01	8	131845.7	4	7233.055	25	9999.95	21	19916.59	14	220939.3	4
601-1200 m	124512.4	4	93816.63	5	133776.2	4	98174.97	6	52458.94	8	502739.2	2
>1200 m	23325.2	13	2627.465	41	77225.62	6	257593.2	3	73174.27	6	433945.7	2
Total	199781.7	1	228289.8	1	218234.9	2	365768.1	2	145549.8	2	1157624	1

Appendix II: Data prepared for Switzerland's GHGI 2015 (1990-2013)

Table A-5. List of result tables that were included in the data delivery from 21.05.2014. The associated Excel file presents the relevant data based on averaged annual stocks and stock changes.

Table	Table name	Submitted table	Content
	Annual C stock change [Mg C $ha^{-1}a^{-1}$]	1a	Mean CWD pool stock change
		1b	Mean LFH pool stock change
		1c	Mean Soil pool stock change
		1d	Mean stock change for ALL pools
		1e	Standard error CWD pool stock change
		1f	Standard error LFH pool stock change
		1g	Standard error Soil pool stock change
		1h	Standard error stock change for ALL pools
	Annual absolute C stock change [Mg C a^{-1}]	2a	Mean CWD pool stock change
		2b	Mean LFH pool stock change
		2c	Mean Soil pool stock change
		2d	Mean stock change for ALL pools
		2e	Standard error CWD pool stock change
		2f	Standard error LFH pool stock change
		2g	Standard error Soil pool stock change
		2h	Standard error stock change for ALL pools
A-6	Average annual C stock change [Mg C $ha^{-1}a^{-1}$]	3a	Mean CWD pool stock change
A-7		3b	Mean LFH pool stock change
A-8		3c	Mean Soil pool stock change
A-9		3d	Mean stock change for ALL pools
A-10		3e	Standard error CWD pool stock change
A-11		3f	Standard error LFH pool stock change
A-12		3g	Standard error Soil pool stock change
A-13		3h	Standard error stock change for ALL pools
A-14	Average annual absolute C stock change [Mg C a^{-1}]	4a	Mean CWD pool stock change
A-15		4b	Mean LFH pool stock change
A-16		4c	Mean Soil pool stock change
A-17		4d	Mean stock change for ALL pools
A-18		4e	Standard error CWD pool stock change
A-19		4f	Standard error LFH pool stock change
A-20		4g	Standard error Soil pool stock change
A-21		4h	Standard error stock change for ALL pools
	Annual C stock [Mg C ha^{-1}]	5a	Mean CWD pool stock
		5b	Mean LFH pool stock
		5c	Standard error CWD pool stock
		5d	Standard error LFH pool stock
	Annual absolute C stock [Mg C]	6a	Mean CWD pool stock
		6b	Mean LFH pool stock
		6c	Standard error CWD pool stock
		6d	Standard error LFH pool stock
A-22	Average annual C stock [Mg C ha^{-1}]	7a	Mean CWD pool stock
A-23		7b	Mean LFH pool stock
A-24		7e	Standard error CWD pool stock
A-25		7f	Standard error LFH pool stock
A-26	Average annual absolute C stock [Mg C]	8a	Mean CWD pool stock
A-27		8b	Mean LFH pool stock
A-28		8e	Standard error CWD pool stock
A-29		8f	Standard error LFH pool stock

NOTE:
1) Elevation classes 601-1200m and >1200m in production region 2 were combined in the calculations and have the same value reported.
2) Table values were rounded to 3 decimal places.
3) Tables of absolute CSC and stock contain national estimates based on the area of productive forest between NFIs 3 and 4 of 1,165,344 ha.
4) Negative values for CSC indicate a C sink, positive values a C source.