Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse dead wood prepared for the Swiss GHGI 2018 (1990-2016)

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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, the C decomposition model Yasso07 was used for deriving estimates of C stock and CSC in dead wood, 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 has been developed further as documented in section 2.4. Since the previous submission, no methodological changes occurred. Meteorological data for 2016 was available to estimate the change in C pools from 2015 to 2016.

In section 3, the results obtained for the Swiss GHGI 2018 (1990-2016) are presented and discussed. As reported in section 3.1, the total CSC in soil, litter and dead wood from 2015 to 2016 was a gain of 0.003 ±0.004 (1SE) Mg C ha^{-1}a^{-1} or 3 364 ±4 189 Mg C a^{-1} (based on 1 155 547 ha of productive forest for the period NFI3-4 (2011-2015) with dominant effects of the dead wood (gain of 0.040 ±0.003 Mg C ha^{-1}a^{-1}) and the litter pool (losses of -0.038 ±0.002 Mg C ha^{-1}a^{-1}). Mineral forest soils were responsible for minor gains of 0.001 ±0.0001 Mg C ha^{-1}a $^{-1}$. The double standard error (2SE) of the estimates for CSC originating from uncertainty in C inputs and in model parameters was ca. 28.6% for dead wood ca. 105.3% for litter, and ca. 24.5% for mineral soil. The Uncertainty for total CSC was estimated as ca. 42.7%. In comparison, Finland reports an uncertainty (2SE) of 31.5% for the net CSC 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 dead wood, litter and soil on forest lands in Switzerland and which are expected to increase the quality of 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 2006a):

- Soil organic carbon
- Litter
- Dead wood

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

- **Soil**: organic C in mineral soil up to a depth of ca. 100 cm
- **Litter**: non-woody material including foliage, bark, fine roots < ca. 5 mm; corresponds to LFH (Litter - Fermenting - Humified) layer, i.e. excludes fine woody material <7 cm
- **Dead wood (CWD)**: stemwood of standing dead trees ≥12 cm, lying dead stemwood and branchwood ≥7 cm and dead coarse roots > ca. 5 mm;
- **All**: the sum of the above listed pools

Dead organic matter **(DOM)**: Term is used as defined in IPCC(2006a), i.e., dead wood and litter.

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

- State analyses (*Zustandsauswertungen*):

- NFI1: field data collected 1983-1985; assumed to be representative of the year 1985
- NFI2: field data collected 1993-1995; assumed to be representative of the year 1995
- NFI3: field data collected 2004-2006; assumed to be representative of the year 2005
- NFI4: field data collected 2009-2017: the NFI4 is a continuous survey during which annually one-ninth of all NFI plots are visited; plots visited within each annual cycle provide a nationally representative sample

- Change analyses (*Veränderungsauswertungen*)

- NFI1-2: assumed to be representative of the period 1986 to 1995; the change is estimated based on all common plots
- NFI2-3: assumed to be representative of the period 1996 to 2005; the change is estimated based on all common plots
- NFI3-4 (2011-2015): assumed to be representative of the period 2006 to 2016; the change is estimated based on the common plots that are included in the 5-year window 2011-2015 of the NFI4

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 $ha^{-1}a^{-1}$) = 1000 Kg $ha^{-1}a^{-1}$
- Gigagram per hectare and year (Gg $ha^{-1}a^{-1}$) = 1000 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, 2011) was used for deriving estimates of CSC in dead wood (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 dead wood. For the GHGI-Submission 2018 (1990-2016), the same methodology was applied as for the GHGI submission 2017 (Didion and Thürig 2016) as several improvements are planned for the GHGI submission 2019 (section 3.3). Meteorological data for 2016 was available to estimate the change in C pools from 2015 to 2016. The primary purpose of this report is to present and discuss the estimates of C stocks and CSC published in the GHG-inventory submission of April 2018 (section 3). Additional information on the methodology, including validity of the Yasso07 model for conditions in Switzerland is provided in section 2.

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 providing and explaining data sources, assumptions and methodologies that were used including 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. Consistent with decisions 6/CMP.9 and 24/CP19, the methodology was ensured to be consistent with the 2006 IPCC Guidelines for National Greenhouse Gas Inventories

(IPCC 2006b) and also with the “Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol” (IPCC 2014).

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 for the base and all subsequent years 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 estimating removals by sinks and emissions by sources based on methodologies and formats agreed by the COP. The C cycling model Yasso07 was applied 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 achieved by calculating annual estimates of removals by sinks and emissions by sources since 1989 for the litter, dead wood and soil pools. Full geographical coverage of the sources and sinks was ensured by relying on data from the Swiss National Forest Inventory. See sections 2 for methods and 3 for results and discussion.

Accuracy is achieved by employing reliable and accurate data and a methodology that is applied by other countries and in research, and which is consistent with the 2006 IPCC Guidelines. All results were verified with independent data and deviations were identified and discussed. This was to ensure that emission and removal estimates are systematically neither over nor under true emissions or removals, and that uncertainties are reduced as far as practicable. 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 first described in detail in Didion et al. (2012) as supporting documentation of the GHGI 2013. In the following, the model is described (section 2.1) and supporting information on the validity of Yasso07 for conditions in Switzerland is provided (section 2.2). Section 2.3 presents in detail the implementation of the model for estimating carbon stocks and carbon stock changes in dead wood and litter (DOM) and in soils of forests in Switzerland. Methodological changes for the current inventory are presented in detail in section 2.4. This section also lists aspects of further development of the model implementation realized in the previous inventories since the GHGI 2013 demonstrating efforts of inventory development.

2.1 Yasso07

Yasso07 (Tuomi et al. 2009, 2011) is a model of C cycling in mineral soil, litter and dead wood. 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 dead wood 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, 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, 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. At the time of this study, three independent parameter sets, i.e., vectors of 24 paramamters have been developed and published (Tuomi et al. 2009, 2011, Rantakari et al. 2012).

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 2016) version 3.3.2 (64 bit) was used for administrating the Yasso07 simulations.

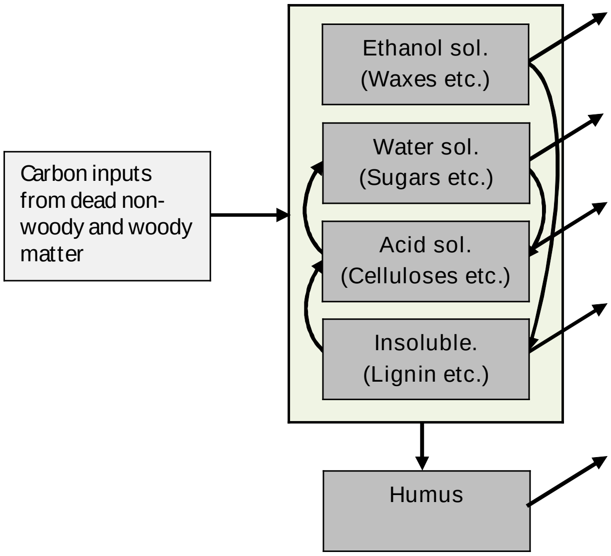

Figure 1. Flow chart of Yasso07 soil carbon model. The boxes represent soil carbon compartments, the arrows carbon flows; only those carbon flows are shown that deviate significantly from zero (adapted from Liski et al. 2009).

2.2 Verifying the suitability of Yasso07 for application in Switzerland

Didion et al. (2014a) examined the validity of the Yasso07 model in Swiss forests based on data on observed decomposition of i) foliage and fine root litter from sites along a climatic and altitudinal gradient and ii) of dead trees from plots of the Swiss National Forest Inventory. The study analyzed, among other, the accuracy of Yasso07 for reproducing observed C decomposition in litter and dead wood in Swiss forests.

The best agreement of Yasso07 results with observed C decomposition was obtained with the parameter presented in Rantakari et al. (2012), which was obtained by restricting the global dataset on dead wood, litter, and soil decomposition set (Tuomi et al. 2009, 2011) to European sites. Didion et al. (2014a) found that no significant differences existed between simulated and observed remaining C in foliage and fine root litter after 10 years and in lying dead trees after 14 to 21 years (Figs. 2 and 3).

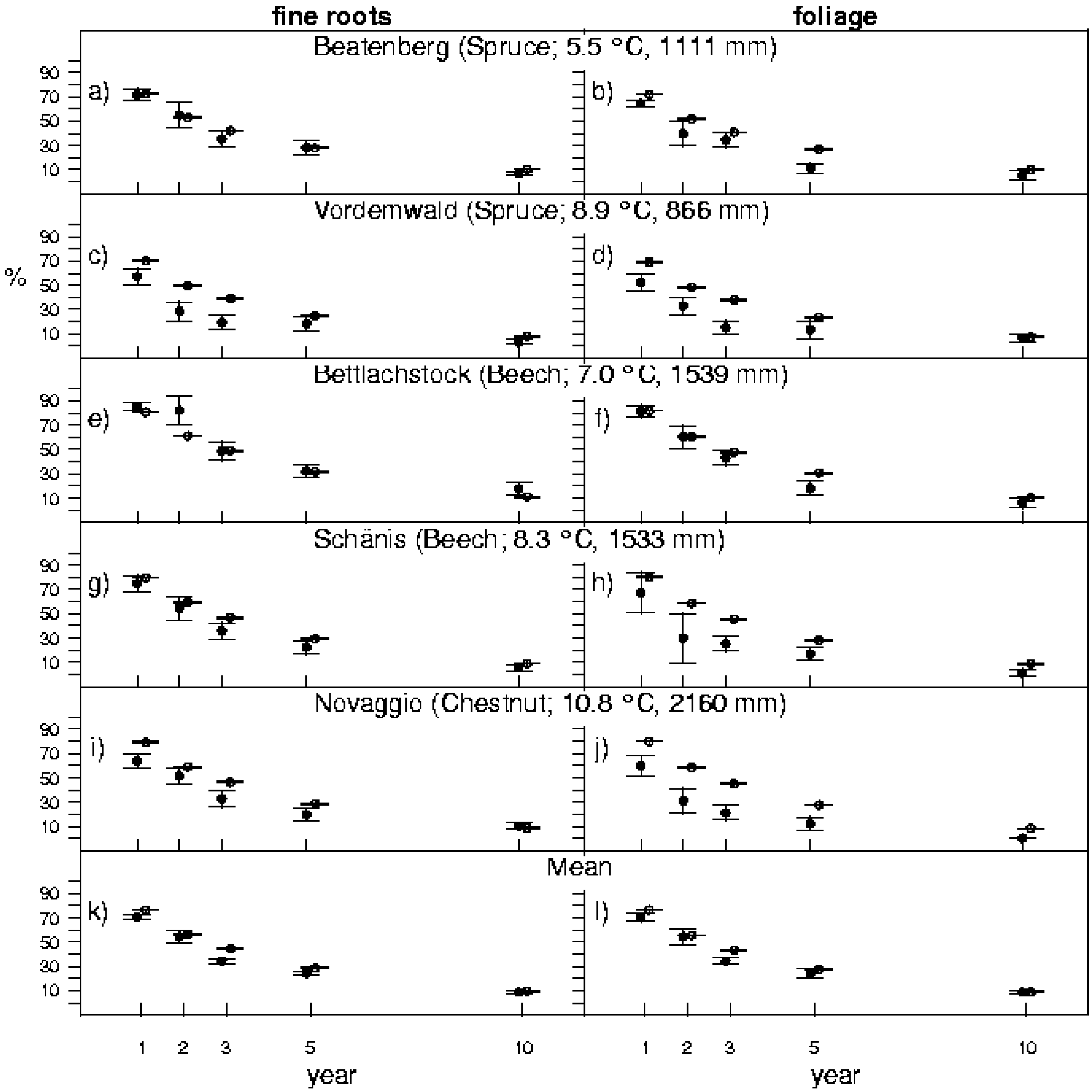

Figure 2. Mean and standard deviation for remaining mass of C [%] in fine root and foliage litter at five forest sites and the mean over all sites. Measured data were based on 20 replicate samples(filled circles). Simulated data were the result of 500 replicate simulations for parameter values of parameter set presented in Rantakari et al. (2012) (open circles). Note that the annual data points are slightly offset for better comparison. For each site the dominant species, annual mean soil temperature measured at 5 cm depth and annual mean throughfall precipitation are given. Figure based on Fig. 2 in Didion et al. (2014a).

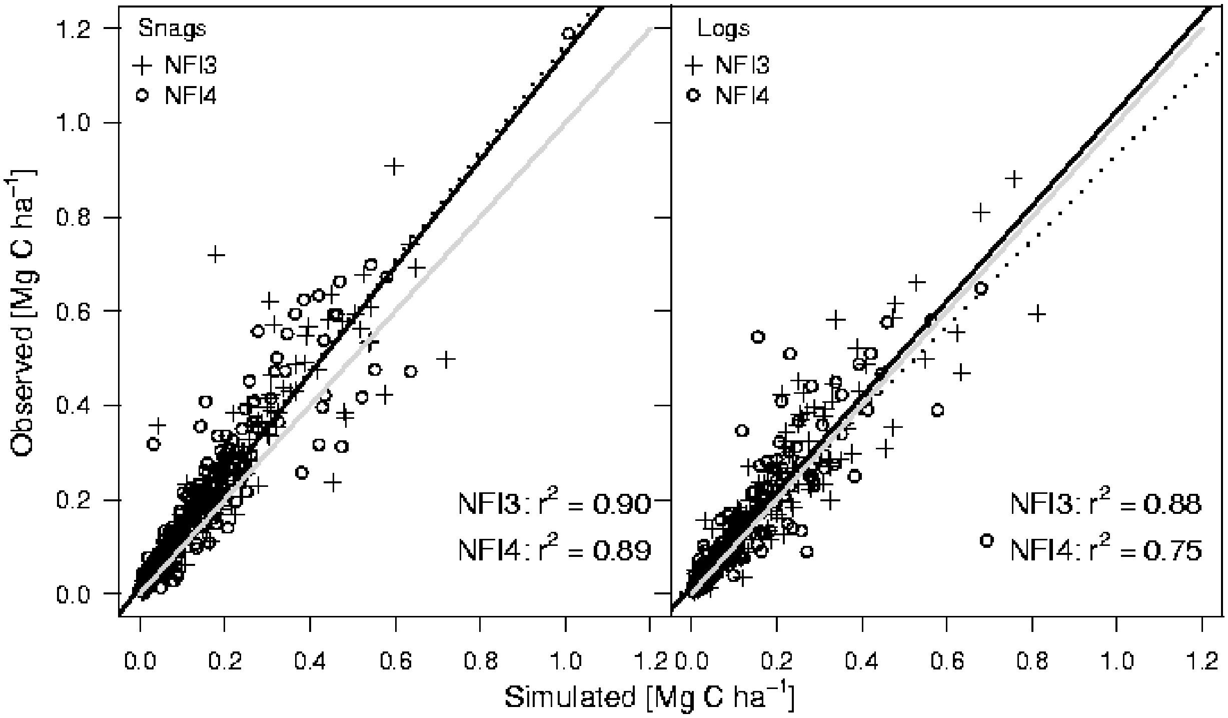

Figure 3. Observed and simulated C stores at NFIs 3 (2004-2006) and 4 (2009-2013) in dead trees that were a) standing (n=379), i.e., snags and b) lying (n=209), i.e., logs at the time of the NFI2 (1993-1995). The solid black line shows the fit at NFI3 and the dashed black line at NFI4. The solid grey line indicates a perfect fit. Reported is the adjusted r^2. Regressions are significant with *p*-values <0.01. The 95% confidence intervals for the slope of the regression line were a) for snags at NFI3 1.098 to 1.174 and at NFI4 1.113 to 1.193, and b) for logs at NFI3 0.960 to 1.063 and at NFI4 0.838 to 0.980. Figure based on Fig. 3 in Didion et al. (2014a).

2.3 Model implementation for estimating C stock changes in DOM and soil of productive forests in Switzerland

To estimate carbon stocks and carbon stock changes in DOM and soil of productive forests in Switzerland, Yasso07 was run on each plot of the Swiss national forest inventory (NFI) that was classified as accessible forest but not shrub forest (*gemeinsam zugänglicher Wald ohne Gebüschwald*) following the definition “productive forest”(Combination Category 12, cf. Tab. 6-6 in FOEN 2017). The simulations were restricted to plots with productive forest throughout the four NFIs (Tab. 1). 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 and constant, aggregated C inputs from the first NFI (NFI1-2_{avg}) 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 (NFI1-2_{avg}) but with annual climate data for the period 1961 to 1985.
c. For the period after 1986 (i.e., start of the period NFI1-2), plot-specific carbon inputs were derived for the three periods between two consecutive NFIs, i.e., NFI1-2, NFI2-3, and NFI3-4 (2011-2015). Current annual plot-specific climate data until the end of 2016 are used.

Table 1. Number of NFI sampling plots per subregion that were available for the Yasso07 simulation to estimate carbon stocks and carbon stock changes in the category "productive forest CC12" as defined in the Swiss Greenhouse gas inventory(cf. Tab. 6-6 in FOEN 2017). Only plots were included that were classified productive forest CC12 throughout the four NFIs.

Elevation class	**Production Region**					**Switzerland**
	Jura	**Plateau**	**Pre-Alps**	**Alps**	**Southern-Alps**	
<601 m	127	322	21	15	43	528
600 – 1200 m	311	251	338	233	112	1245
>1200 m	55	5	147	493	143	843
Total	493	578	506	741	298	2616

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

2.3.1 *Model parameters*

The model parameters presented in Rantakari et al. (2012) were used to drive the simulations. With this parameter set, Yasso07 reproduced observed C losses in decomposing dead wood and litter with a high degree of accuracy (section 2.2). Uncertainty in model parameter values was included in the simulations by random sampling from the distribution of possible parameter vectors (Tab. A-1).

2.3.2 *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 of several climate variables with a spatial resolution of ca. 2.2 km with monthly data since 1961(MeteoSwiss 2017).

For the location of each NFI sampling plot, data for mean monthly absolute temperature [°C] (TabsM) and for monthly precipitation sum [mm] (RhiresM) since 1961 to the current inventory year were extracted from the respective current versions of the gridded data, i.e. TabsM v1.4 (MeteoSwiss 2013a) and RhiresM v1.0 (MeteoSwiss 2013b). Annual mean temperature and precipitation (Fig. 4) 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.

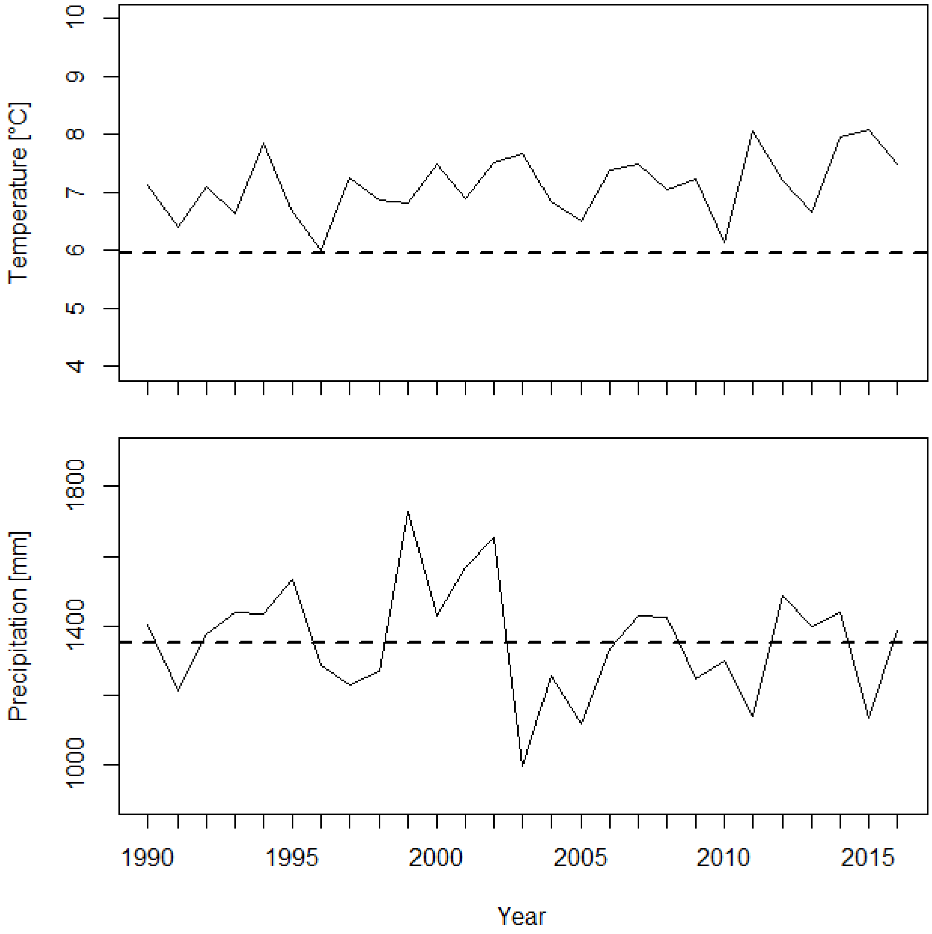

Figure 4. Annual means of temperature and precipitation sums since 1990 compared to the long-term (1961-1990) mean (dashed line) for all considered NFI plots (n=2616).

Table 2. Long-term (1961-1990) mean annual temperature and precipitation sum calculated from the plot-specific data within each region (source: MeteoSwiss 2013a, b).

a) Temperature [°C]

		Production region					**Switzerland**
Elevation class		**Jura**	**Plateau**	**Pre-Alps**	**Alps**	**Southern Alps**	
<601 m	**Min**	6.6	6.6	6.6	3.4	4.3	3.4
	Mean	8.3	8.4	7.9	7.2	9.5	8.4
	Max	9.9	9.9	9.3	9.8	11.7	11.7
601-1200 m	**Min**	3.9	5.9	2.1	-0.6	1.2	-0.6
	Mean	7.0	7.8	6.0	5.0	7.6	6.6
	Max	9.6	9.9	9.7	9.6	11.3	11.3
>1200 m	**Min**	3.8	4.0	1.5	-2.6	-1.5	-2.6
	Mean	5.5	5.4	4.5	2.6	4.8	3.5
	Max	8.0	6.9	8.3	9.3	10.4	10.4
Total	**Min**	3.8	4.0	1.5	-2.6	-1.5	-2.6
	Mean	7.2	8.1	5.6	3.5	6.5	6.0
	Max	9.9	10.0	9.7	9.9	11.7	11.7

b) Precipitation sum [mm]

Elevation class		**Jura**	**Plateau**	**Pre-Alps**	**Alps**	**Southern Alps**	**Switzerland**
<601 m	**Min**	829	824	1110	689	1385	686
	Mean	1064	1082	1413	1177	1746	1147
	Max	1347	1599	1785	1782	2262	2309
601-1200 m	**Min**	877	892	1068	592	1199	592
	Mean	1302	1233	1574	1274	1820	1403
	Max	1811	1805	2255	2208	2292	2476
>1200 m	**Min**	1227	1750	1243	641	1050	641
	Mean	1629	1832	1768	1188	1686	1407
	Max	1987	1924	2311	2216	2315	2521
Total	**Min**	828	824	1048	588	1049	588
	Mean	1277	1154	1624	1215	1745	1353
	Max	1987	1957	2320	2242	2326	2526

2.3.3 *C inputs*

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

- Coarse-woody material comprising i) stemwood of standing dead trees ≥12 cm (diameter at breast height; dbh) and of lying dead trees ≥7 cm dbh, ii) branchwood ≥7 cm in diameter, and iii) dead coarse roots > ca. 5 mm in diameter; and
- Non-woody material comprising iv) foliage incl. fruits, and v) fine roots < ca. 5 mm.

The annually accumulating mass in these five DOM components (cf. 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 (NFI1 through NFI4). 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 dead wood 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 (Tab. A-2), a distribution of possible inputs was created and a combined uncertainty was derived.

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 dead wood, NFI measurements will show this increase. Since the input of C (i.e., the volume of dead wood which is produced in one year) to the model is derived from NFI dead wood 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 dead wood pool.

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. (2014a).

Table 3. C inputs over all NFI plots simulated with Yasso07 for the GHGI 2017 (n=2 616): Mean and standard deviation of mass of carbon in five dead organic matter (DOM) components for coniferous and broadleaved tree species for different simulation periods and for the spin-up procedure. The data for the period between NFIs 3 and 4 were based on common sites NFI3-4 (2011-2015).

a) conifers

Simulation period	NFI data	DOM component					Total
		Fine roots	Foliage	Coarse-woody (>7 cm diameter)			
				Roots	Branches	Stems	
		Kg C $ha^{-1}a^{-1}$					
Spin-up and 1961-1985	**NFI1-2$_{avg}$ (moving window)**	739 ±269	1108 ±505	288 ±166	61 ±43	54 ±38	2250 ±599
1986-1995	**NFI1-2**	768 ±645	1147 ±1133	295 ±662	63 ±175	56 ±154	2329 ±1481
1996-2005	**NFI2-3**	803 ±679	1176 ±1184	355 ±826	93 ±246	82 ±217	2509 ±1629
2006-2016	**NFI3-4 (2011-2015)**	777 ±710	1139 ±1305	375 ±956	101 ±337	89 ±297	2481 ±1823

b) broadleaves

Simulation period	NFI data	DOM component					Total
		Fine roots	Foliage	Coarse-woody (>7 cm diameter)			
				Roots	Branches	Stems	
		Kg C $ha^{-1}a^{-1}$					
Spin-up and 1961-1985	**NFI1-2$_{avg}$ (moving window)**	282 ±169	673 ±414	96 ±85	33 ±27	11 ±11	1095 ±456
1986-1995	**NFI1-2**	266 ±354	633 ±829	90 ±288	33 ±153	10 ±46	1032 ±960
1996-2005	**NFI2-3**	301 ±394	710 ±916	99 ±328	45 ±186	13 ±50	1168 ±1067
2006-2016	**NFI3-4 (2011-2015)**	309 ±385	727 ±894	127 ±458	60 ±312	17 ±81	1240 ±1123

Table 4. Initial fractions for the simulation of foliage and fine root litter and of dead wood 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); see Tab. 3 in Didion et al. (2014a).

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
Dead wood	**Conifers**	0.675	0.0175	0.0025	0.305
	Broadleaves	0.715	0.015	0	0.27

2.4 Methodological improvements

2.4.1 *Methodological changes compared to GHGI 2017*

No methodological changes were implemented for the GHGI 2018 submission. Data on C inputs for the model simulation were the same as in the previous submission. Data on climate for the model simulation included additionally the latest inventory year 2016. More accurate elevation data from a digital elevation model for the NFI sites were used, which resulted in minor shifts of sites in the three elevation classes (≤600 m, 601-1200 m, >1200 m) used in the Swiss GHGI (cf. chapter 6.2.2 in FOEN 2017).

2.4.2 *List of methodological changes and further developments until GHGI 2017*

GHGI 2017 (ch. 2.4.1 in Didion and Thürig 2017)

- Update of NFI sites to derive estimates of C inputs between NFIs 3 and 4.
- Improvements in the accuracy of the estimates of dead wood and litter production.

GHGI 2016 (ch. 2.3 in Didion and Thürig 2015)

- Corrections to the temperature data.
- Use of annual rather than averaged gains and losses estimates.

GHGI 2015 (ch. 2.3 in Didion et al. 2014b)

- Increased accuracy of the dead wood production estimates.
- Additional sites of the NFI4 become available.

GHGI 2014 (ch. 2.3 in Didion et al. 2013)

- Replacement of the model parameter set.
- Corrections to the precipitation data.
- Revision of the litter and dead wood pools used as input to the Yasso07 model.

2.5 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), in litter (i.e., sum C in the AWEN compartments of fine roots and foliage) and in dead wood (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. 2014a). For consistency with previous submissions of Switzerland's NIR (cf. chapter 6.4.2.6 in FOEN 2017), C stock changes were estimated for a) the litter pool representing the Litter - Fermenting – Humified (LFH) layer and b) the CWD pool based on coarse-woody inputs.

Annual estimates of carbon stocks in the soil, litter and CWD pools for each NFI plot were derived from Yasso07 simulations for the period 1989 to 2016. From the time series of C stocks, the annual change in carbon stock between consecutive years was calculated. Thus, for each pool two time series were obtained with annual means and standard errors (SE) derived from 100 replicate simulations (i.e., 10 parameter vectors and 10 dead wood and litter samples):

1) *annual carbon stock change*: Soil_{csc}, $\text{Litter}_{\text{csc}}$, 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 stocks*: Litter and CWD; result tables 3 [Mg C ha^{-1}] and 4 [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 4 (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 6.3.1 in FOEN 2017).

3 Results and Discussion

The complete set of result tables of C stock and CSC that were prepared for the Swiss GHGI 2018 (1990-2016) 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.

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[1] see Appendix II for details and nomenclature.

3.1 Carbon stock change

The mean total CSC in 2016 in soil, litter, and dead wood was estimated as a gain of ca. 0.003 ±0.004 (1SE) Mg C $ha^{-1}a^{-1}$ (Total Switzerland in Tab. 5, ALL_{csc} in Fig. 5). This corresponded to a national gain of 3 364 ±4 189 Mg C a^{-1} based on 1 155 547 ha of productive forest as derived for the period 2006-2016, i.e. the period between NFIs 3 and 4 (Tab. A-3). The approximately 90% decrease in the total CSC gain from 2014-2015 to 2015-2016 (Fig. 5) was primarily due to, on average, slightly lower temperature and moderately higher precipitation in 2016 than in 2015 (cf. Fig. 4),which resulted in a higher decomposition rate.

Temporal dynamics in the litter pool dominated annual total CSC since 1990 (Fig. 5). The CSC in 2016 in the litter pool constituted a loss of -0.038 ±0.002 Mg C $ha^{-1}a^{-1}$ ($Litter_{csc}$ in Fig. 5). For reporting purposes, the litter pool corresponds to the organic (LFH) layer and consists of only non-woody material, the dynamics in this C pool are largely driven by interannual variability in temperature and precipitation (Aerts 1997).

The dead wood pool gained C in 2015 (0.040 ±0.003 Mg C $ha^{-1}a^{-1}$; Dead $wood_{csc}$ in Fig. 5). The pool lost C during the period NFI1-2 and then gained in C as result of the storm Lothar, which occurred in 1999 (i.e. between NFIs 2 and 3). The storm caused large scale mortality across Swiss forests and although the majority of the felled trees were removed, the dead wood volume increased significantly. As particularly the larger sized felled trees decay slowly (Didion et al. 2014a), the storm resulted in a sustained C sink in dead wood. The additional dead wood pool which resulted from the storm will slowly release the stored C over the coming decades.

Mineral forest soils continuously gained in C at a comparably moderate rate (0.001 ±0.0001 Mg C $ha^{-1}a^{-1}$ in 2015; $Soil_{csc}$ in Fig. 5).

Whether CSC corresponds to a gains (removal) or a loss (emission) depended on carbon pools and regions (Tabs. 5 and A-5 to A-8 and A-13 to A-16 for a complete time series of mean areal [Mg C $ha^{-1}a^{-1}$] and mean absolute CSC [Mg C a^{-1}]).

Table 5. Mean national total (sum of dead wood, litter and soil) carbon stock change ± 1 standard error in 2016 stratified into 3 elevation classes and 5 NFI-production regions. Negative values C losses, positive values C gains.

Elevation class	**Production region**					**Switzerland**
	Jura	**Plateau**	**Pre-Alps**	**Alps**	**Southern Alps**	
	Mg C $\text{ha}^{-1}\text{a}^{-1}$					
<601 m	-0.027 ±0.012	-0.032 ±0.011	-0.119 ±0.025	0.051 ±0.046	0.135 ±0.021	-0.018 ±0.008
601-1200 m	0.036 ±0.007	-0.053 ±0.012	0.012 ±0.012	0.064 ±0.012	0.038 ±0.014	0.017 ±0.005
>1200 m	-0.091 ±0.009	-0.053 ±0.012	-0.160 ±0.012	0.032 ±0.010	0.064 ±0.015	-0.004 ±0.007
Total	0.005 ±0.006	-0.041 ±0.008	-0.044 ±0.009	0.042 ±0.008	0.065 ±0.009	0.003 ±0.004

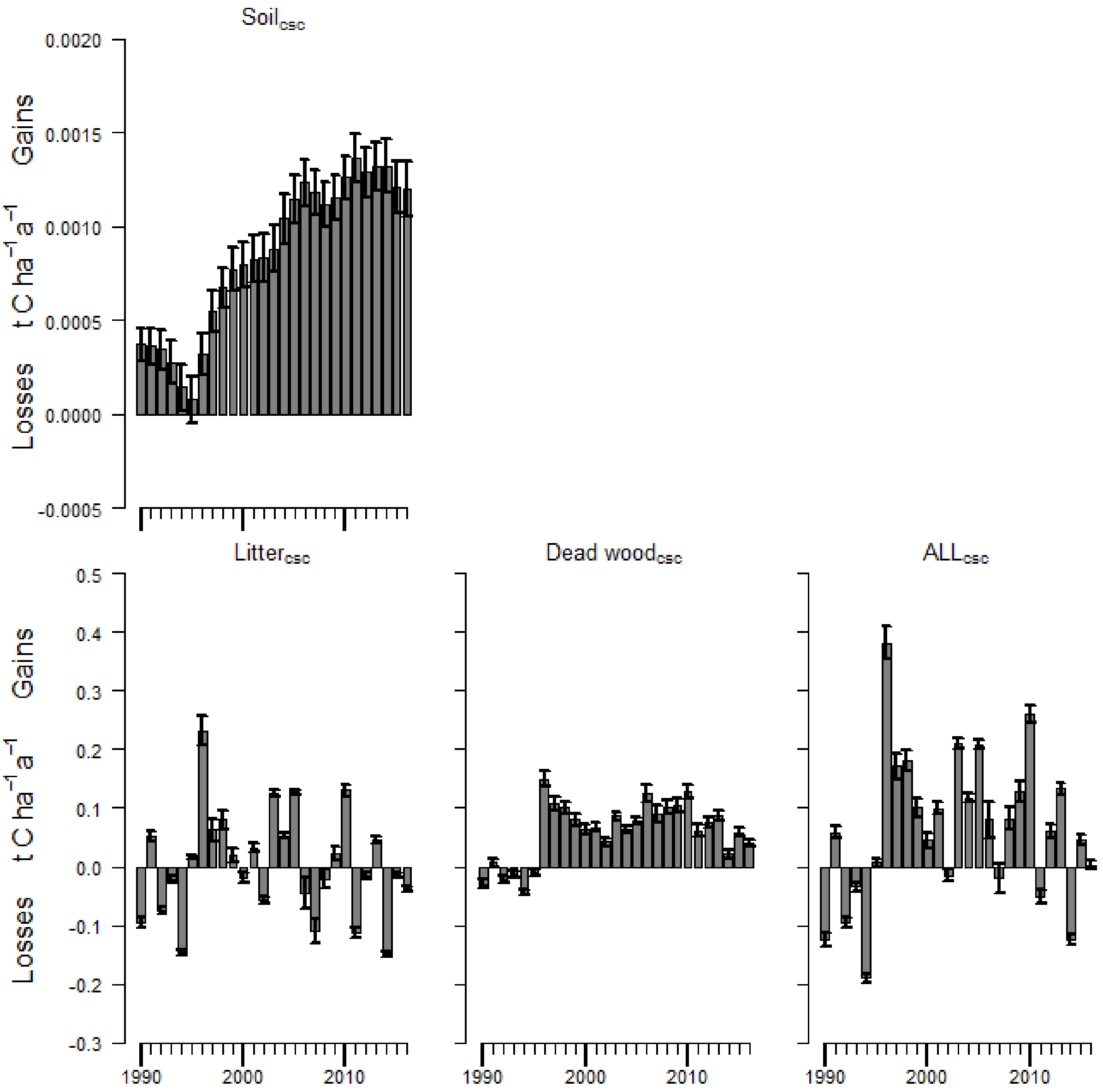

Figure 5. National mean carbon stock change (CSC) for three pools soil, litter, dead wood and their sum (ALL) in t C ha^{-1} (equals Mg C ha^{-1}). Note the difference of the y-axis scale between Soil$_{csc}$ and Litter$_{csc}$, Dead wood$_{csc}$ and ALL$_{csc}$, respectively. Negative values indicate C losses, positive values C gains. The error bars indicate the standard error (2SE).

Uncertainty of annual changes in C stock is primarily driven by the annual variability in litter and dead wood inputs (Lehtonen and Heikkinen 2015). This variability (section 2.3.3) as well as the uncertainty in the Yasso parameters (section 2.3.1) were taken into account in the estimation of C stock changes in Swiss forests. The double standard error resulting from uncertainty in C inputs and in model parameters was estimated over the length of the first commitment period of the Kyoto Protocol in order to account for annual variability. The double standard error for the dead wood, litter and mineral soil C in the Swiss GHGI were 28.6%, 105.3, %, and 24.5%, respectively. The total uncertainty of the carbon stock change in DOM and mineral soil was estimated as 42.7%. This is in the range of uncertainty estimates in countries where Yasso07 is also applied. For example, Norway reports an uncertainty of 15.5% (1SE), which applied to both the DOM and mineral soil pools (chapter 6.4.1.2 in Norwegian Environment Agency 2017), and Finland reports an uncertainty of 31.5% (2SE) in the net CSC in DOM and mineral soil (Lehtonen and Heikkinen 2016, chapter 6.4.3.2 in Statistics Finland 2017).

3.2 Carbon stocks

In the Swiss NFI, estimates of coarse dead wood C stocks based on measured tree volume are available since the NFI3. The simulated national mean dead wood C stock overestimates the national stock derived from the NFI by ca. 30% (Tab. 6). The C stocks are also overestimated in three (four in the NFI3) of the five production regions. In the Southern-Alps, the particular climate characterized by highly variable precipitation pattern with extended periods of drought interrupted by heavy rainfall events (cf. Didion et al. 2011) limits the accuracy of model results. This is not surprising since NFI data are associated with uncertainty (cf. Didion et al. 2014a), 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 dead wood. Nevertheless, the simulated stocks are plausible since they are in good agreement with NFI estimates of national mean dead wood C stocks that are based on the observed full volume of dead wood pieces (i.e., not accounting for observed damage), i.e., 8.16 ±0.27 Mg C ha^{-1} at NFI4 compared to 8.94 ±0.05 (Tab. 6).

The observed change in coarse dead wood C stocks in Switzerland between NFIs 3 and 4 was reproduced accurately by the model (Tab. 6) considering the uncertainty in the stocks. Mainly as a consequence of the lower number of available plots within a region (cf. Tab. 1), the agreement between simulated and observed stocks and stock change in the production regions is poor.

Table 6. Mean and standard error of carbon stored in dead wood (CWD) based on observations in NFIs 3 and 4 and simulated dead wood carbon stock with Yasso07; the simulated stock was calculated as the mean of the annual stocks in years 2004-2006 for NFI3 and 2011-2015 for NFI4. Percent change was calculated based on the respective means.

Region	**NFI3**		**NFI4**		**Change**	
	Mg C ha^{-1}				%	
	NFI	**Yasso07**	**NFI**	**Yasso07**	**NFI**	**Yasso 07**
Jura	4.49 ±0.38	6.46 ±0.07	5.98 ±0.5	7.43 ±0.08	33.2	15.0
Central Plateau	4.81 ±0.47	11.11 ±0.11	4.71 ±0.35	12.04 ±0.12	-2.1	8.4
Pre-Alps	8.28 ±0.66	11.02 ±0.12	8.24 ±0.63	11.45 ±0.12	-0.5	3.9
Alps	7.18 ±0.44	7.55 ±0.07	8.41 ±0.46	8.13 ±0.09	17.1	7.7
Southern-Alps	4.85 ±0.50	2.40 ±0.06	6.17 ±0.57	3.18 ±0.10	27.2	32.5
Switzerland	6.16 ±0.23	8.21 ±0.04	6.95 ±0.22	8.94 ±0.05	12.8	8.9

For verification of the litter C stocks, the simulated data were compared with observed data from Moeri (2007). These data rather than data from Nussbaum et al. (2012) are used since Nussbaum et al. (2012) placed little confidence in their method. At the national level Moeri and Nussbaum et al. report similar C stocks in the litter pool, i.e., 18.1 ±0.61 and 16.73 ±0.83 Mg C $ha^{-1}a^{-1}$, respectively.

The simulated national mean litter C stock was ca. 60% of the stock reported by Moeri (2007); cf. Tab. 7. This difference is not surprising since the simulated values do not include non-woody litter inputs from the herb and shrub layers and fine woody litter inputs from trees, i.e. twigs and small branchwood <7 cm. Based on preliminary data from Didion et al. (2017), field layer vegetation including herbs, grasses, ferns and dwarf-shrubs contribute 816.7 ±2.5 Kg C $ha^{-1}a^{-1}$ based on estimates for 2616 NFI sites considered in this GHGI (cf. Tab. 1). Relative to the current estimate of total annual C inputs (cf. Tab. 3), field layer and fine woody litter contribute additionally between 4 to 100% or on average ca. 20% to annual litter turnover on NFI sites. This is consistent with de Wit et al. (2006) who reported that C 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. Etzold et al. (2014) found that understory vegetation contributed on average ca. 12% (0.1 to 36.8%) to the total observed annual C turnover at six sites of the Swiss Long-term Forest Ecosystem Research Programme LWF. Muukkonen and Mäkipää (2006) estimated the C inputs from herb- and shrub vegetation in Finnish forests to be in the range of 500 to 660 Kg C ha^{-1} a^{-1}. Thus, the simulated value for the national mean litter C stock can be considered as a reliable and plausible estimate (Tab. 7).

Table 7. Mean and standard error of 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 litter carbon stock with Yasso07; the simulated stock was calculated as the long-term mean over the period 1990-2016.

Region	Moeri 2007	Yasso07
	Mg C ha^{-1}	
Jura	9.71 ±1.78	9.33 ±0.07
Central Plateau	9.5 ±0.57	9.70 ±0.06
Pre-Alps	17.3 ±1.02	10.97 ±0.08
Alps	33.4 ±2.37	12.58 ±0.09
Southern-Alps	22.3 ±3.67	9.54 ±0.11
Switzerland	18.1 ±0.61	10.67 ±0.04

The variability in litter 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 regional averages, 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.

Under the considerations explained previously, the estimates of dead wood and litter C stocks derived with Yasso07 agree with observations and are plausible, certainly at the national level. Since observed C decomposition was reproduced highly satisfactory with Yasso07 (Didion et al. 2014a), confidence can be placed in the reported stocks and stock changes in the litter and dead wood pools.

Due to the incomplete knowledge of the origin of the high soil carbon stocks in Switzerland (Zanelli et al. 2006, Eckmeier et al. 2010, Nussbaum et al. 2012, 2014), they cannot be reproduced by models yet. Hence, only changes in soil C stocks derived from the Yasso07 are used for reporting purposes under the UNFCCC and the Kyoto Protocol. 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 minimum detection limit of repeated soil carbon stock 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 0.76 Mg C ha^{-1}. This was less than the 2.3 Mg C ha^{-1} reported by Hagedorn (2010), who used measured data from soil profiles. However, the correlation of the Yasso07 estimates with elevation was stronger, i.e. $r = 0.38$ ($p < 0.01$) 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. Planned and anticipated improvements to the application in Switzerland for the coming years include:

- Improving the completeness of the litter inputs by accounting for the contribution of a) fine-woody litter <7 cm and b) litter from the herb- and shrub layer. A field study (Didion et al. 2017) was recently completed which will provide estimates on biomass turnover of plants in the herb- and shrub layer of NFI sites. These activities will improve the accuracy of the simulated estimates (planned for submission GHGI 2019.
- Revising the selection of NFI plots to account for recently afforested sites (planned for submission GHGI 2019).
- Improving accounting of uncertainty resulting from the spin-up procedure (planned for submission GHGI 2019).
- Quantifying the effect of uncertainty associated with the spatially interpolated temperature and precipitation data on CSC estimates. MeteoSwiss is releasing in 2018 ensembles of daily precipitation which quantifies uncertainties arising from the limited sampling of the spatial distribution by the station network. Since the data are not recommended for users with high requirements in long-term consistency, the utility of the data for the simulations of CSC in dead wood, litter and, soil needs to be investigated. A consideration of this source of uncertainty in the GHGI is planned for submission GHGI 2019).
- Investigating the validity of the further development of Yasso07 for application in Switzerland. The new model version Yasso15 includes, among other, a new parameter set that is expected to improve the sensitivity of the simulated decomposition to temperature and precipitation. This occurs in close collaboration with other countries where currently Yasso07 is applied as well, i.e. Finland, Norway, and Austria (ongoing).
- Implementing knowledge gained in the project “Drivers of C stabilization in Swiss Forest soils” (anticipated for submission GHGI 2020).
- Improving the uncertainty estimates for litter production by revising allometries and by estimating tree compartments using a Monte-Carlo approach. This is expected to improve the accuracy of the estimates of C stocks and C stock changes (anticipated for submission GHGI 2020).
- Examining the suitability of Yasso07 and Yasso15 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 (anticipated for submission GHGI 2021).

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

- “Kohlenstoffstabilisierung in Mineralböden im Schweizer Wald” (Drivers of C stabilization in mineral forest soils in Switzerland in collaboration with S. Gosheva and F. Hagedorn, WSL;
- “Kernfäule” (heart rot) by J. Wunder, WSL;
- “Carbon sources and sinks in agricultural soils” by C. Wüst und S. Keel, 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.

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Appendix I: Additional data

Table A-1. Maximum a posteriori (MAP) estimators and standard errors for the parameter vectors of the parameter set developed by Rantakari et al. (2012), which was validated for simulating dead wood 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

References

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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. 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.

[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 3.1 in chapter 3 'Uncertainty' in IPCC, 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T. and Tanabe K. (eds). IGES, Japan. (avl. at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/pdf/1_Volume1/V1_3_Ch3_Uncertainties.pdf).

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 4 (annual tranches 2011 to 2015).

Elevation class	**Production region**										**Switzerland**	
	Jura		**Plateau**		**Pre-Alps**		**Alps**		**Southern Alps**			
	ha	**± %**	**ha**	**± %**	**ha**	**± %**	**ha**	**± %**	**ha**	**± %**	**ha**	**± %**
<601 m	48664.09	8	127342.57	4	8536.46	20	6982.19	22	18180.81	13	209706.11	3
601-1200 m	124831.84	3	97139.07	5	133705.58	4	99135.52	5	50458.81	7	505270.81	2
>1200 m	26224.1	11	3275.08	33	73984.93	6	258746.16	2	78340.08	5	440570.35	2
Total	199720.02	1	227756.72	1	216226.97	2	364863.87	1	146979.7	2	1155547.28	1

Appendix II: Data prepared for Switzerland's GHGI 2017 (1990-2015)

Table A-4. List of result tables that were included in the data delivery from 14.07.2014. The associated Excel file presents the relevant data based on averaged annual stocks and stock changes.

Table	Table name	Content
A-5	Annual C stock change [Mg C $ha^{-1}a^{-1}$]	Mean CWD pool stock change
A-6		Mean LFH pool stock change
A-7		Mean Soil pool stock change
A-8		Mean stock change for ALL pools
A-9		Standard error CWD pool stock change
A-10		Standard error LFH pool stock change
A-11		Standard error Soil pool stock change
A-12		Standard error stock change for ALL pools
A-13	Annual absolute C stock change [Mg C a^{-1}]	Mean CWD pool stock change
A-14		Mean LFH pool stock change
A-15		Mean Soil pool stock change
A-16		Mean stock change for ALL pools
A-17		Standard error CWD pool stock change
A-18		Standard error LFH pool stock change
A-19		Standard error Soil pool stock change
A-20		Standard error stock change for ALL pools
A-21	Annual C stock [Mg C ha^{-1}]	Mean CWD pool stock
A-22		Mean LFH pool stock
A-23		Standard error CWD pool stock
A-24		Standard error LFH pool stock
A-25	Annual absolute C stock [Mg C]	Mean CWD pool stock
A-26		Mean LFH pool stock
A-27		Standard error CWD pool stock
A-28		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 4b of 1 155 547.28ha (cf. Tab. A-3).
4) Negative values for CSC indicate a C sink, positive values a C source.