Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse dead wood prepared for the Swiss NIR 2021 (GHGI 1990–2019)

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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 National Inventory Report (NIR) 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 is documented in section 2. Since the previous submission, no methodological changes were implemented. The estimates were based on new National Forest Inventory data and revised climate data.

In section 3, the results obtained for the Swiss GHGI 2021 (1990-2019) are presented and discussed. As reported in section 3.1, the total CSC in dead wood, litter, and mineral soil in Swiss forests from 2018 to 2019 was a loss of -0.008 ±0.004 (2SE) Mg C $ha^{-1}a^{-1}$ or 8.770 ±4.948 Gg C a^{-1} (based on 1'159'342.5 ha of productive forest for the period NFI3-4/5 (2015-2019). The pools dead wood (gain of 0.027 ±0.002 Mg C $ha^{-1}a^{-1}$) and litter (loss of -0.037 ±0.001 Mg C $ha^{-1}a^{-1}$) were the primary drivers of the overall C balance. Mineral forest soils were responsible for minor gains of 0.003 ±0.000 Mg C ha^{-1} a^{-1}. For the period 2012-2018, the uncertainty for total CSC was ca. 17.1%. For the same period Norway and Finland where a similar methodology is applied reported uncertainties for the net CSC in dead wood, litter and soil organic matter of 15.5% and 31.5%, respectively.

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 2006):

- Soil organic carbon (SOC)
- Litter
- Dead wood

Following the convention used by Switzerland in its National Inventory Reports and based on the National Forest Inventory definitions, the reported pools comprise

- **Soil**: organic C in mineral soil up to a depth of ca. 100 cm
- **Litter**: non-woody material including foliage, seeds and fruits, fine roots < ca. 5 mm diameter, and fine woody litter, including small branches and tree top < ca. 7 cm diameter and bark of the tree bole; corresponds to LFH (Litter - Fermenting - Humified) layer
- **Dead wood** : stemwood including stump and bole of trees ≥12 cm, large branches ≥ ca. 7 cm and coarse roots > ca. 5 mm;
- **All**: the sum of the above listed pools

***Dead organic matter* (DOM)**: Term is used as defined in IPCC (2006), 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;
    - starting with the NFI4, the methodology changed from a periodic to a continuous survey during which annually one-ninth of all NFI sample plots are visited; plots visited within each annual cycle provide a nationally representative sample
- NFI5: field data collected 2018-2026.

- Change analyses (*Veränderungsauswertungen*):

- NFI1-2: assumed to be representative of the period 1986 to 1995; the change is estimated based on all plots common to the inventories NFI1 and NFI2
- NFI2-3: assumed to be representative of the period 1996 to 2005; the change is estimated based on all plots common to the inventories NFI2 and NFI3
- NFI3-4/5 (2015-2019): assumed to be representative of the period 2006 to 2019; the change is estimated based on the plots common to the inventories NFI3 and the 3-year window 2015-2017 of the NFI4, and the plots common to the inventories NFI4 and NFI5 in the 2-year window 2018-2019

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 annual National Inventory Reports (NIR). Starting with the Swiss NIR (1990-2011; FOEN 2013), the C decomposition model Yasso07 (2011; Tuomi et al. 2009) 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 NIR 2013, Switzerland committed to further improve the model implementation and the accuracy of the estimates of temporal changes in soil, litter, and dead wood. The estimates for these pools for the NIR submission 2021 (1990-2019) is based on the same methodology as the submission in 2020, including the improvements implemented there. New National Forest Inventory (NFI) and revised climate data were available for the simulation (section 2.3.1). The report presents and discusses the estimates of C stocks and CSC for the year 2018/2019 for publication in the upcoming NIR submission of April 2021 (section3).

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

Consistent with good practice outlined in Volumes 1 and 4 of the 2006 IPCC Guidelines for National Greenhouse Gas Inventories, the report addresses the criteria for transparency, consistency, comparability, completeness and accuracy (TCCCA):

Transparency is achieved by documenting data sources, assumptions and methodologies that were used including relevant references. The methodology is described in detail to ensure that results can be reproduced (section 2). 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 and also with the "Revised Supplementary Methods and Good Practice Guidance Arising from the Kyoto Protocol".

Consistency is obtained by relying on data sources and methodologies of the Swiss National Forest Inventory 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.

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 section 2 on Methods and section 3 for results and discussion.

Accuracy is achieved by applying good practice inventory methodologies based on up to-date scientific knowledge, and on country-specific estimates where possible. Results were verified 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 section 2 on Methods and section 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 derivation of input data for the model and its implementation to estimate C stocks and changes in in dead wood and litter (DOM) and in soils of forests in Switzerland. Methodological developments since 2013 are presented in section 2.4 demonstrating efforts of inventory development. The approach to analyse the estimates is described in section 2.5

2.1 Yasso07

Yasso07 (2011; Tuomi et al. 2009) 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. litter and dead wood) 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 (2011; Tuomi et al. 2009). 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 compounds, to a more stable humus compartment (H) and out of the soil (Figure 1, Tuomi et al. 2011) were derived from a global data set (2011; Tuomi et al. 2009). Parameters defining C decomposition rates and C cycling between carbon compartments (Figure 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 (Rantakari et al. 2012; 2011; Tuomi et al. 2009).

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 version 3.5.1 (64 bit; R Core Team 2018) was used for administrating the Yasso07 simulations.

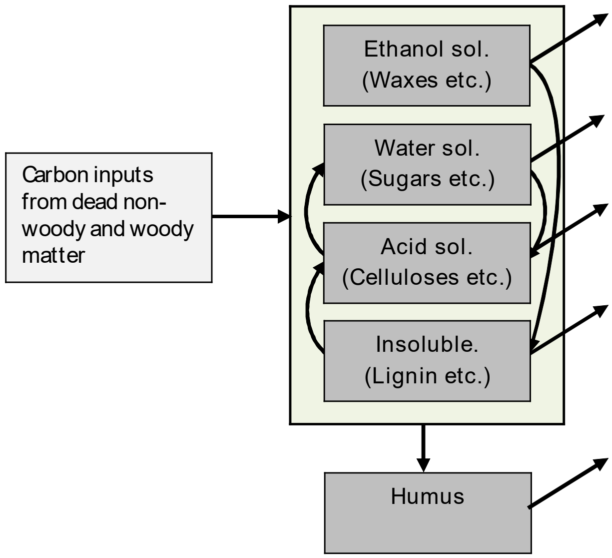

Figure 1. Flow chart of Yasso07 soil carbon model. The boxes represent soil carbon compartments, the arrows carbon flows; only those carbon flows are shown that deviate significantly from zero (adapted from Liski et al. 2009).

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 (2011; Tuomi et al. 2009) to European sites. Didion et al. (2014a) found that no statistically 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 (Figures 2 and 3).

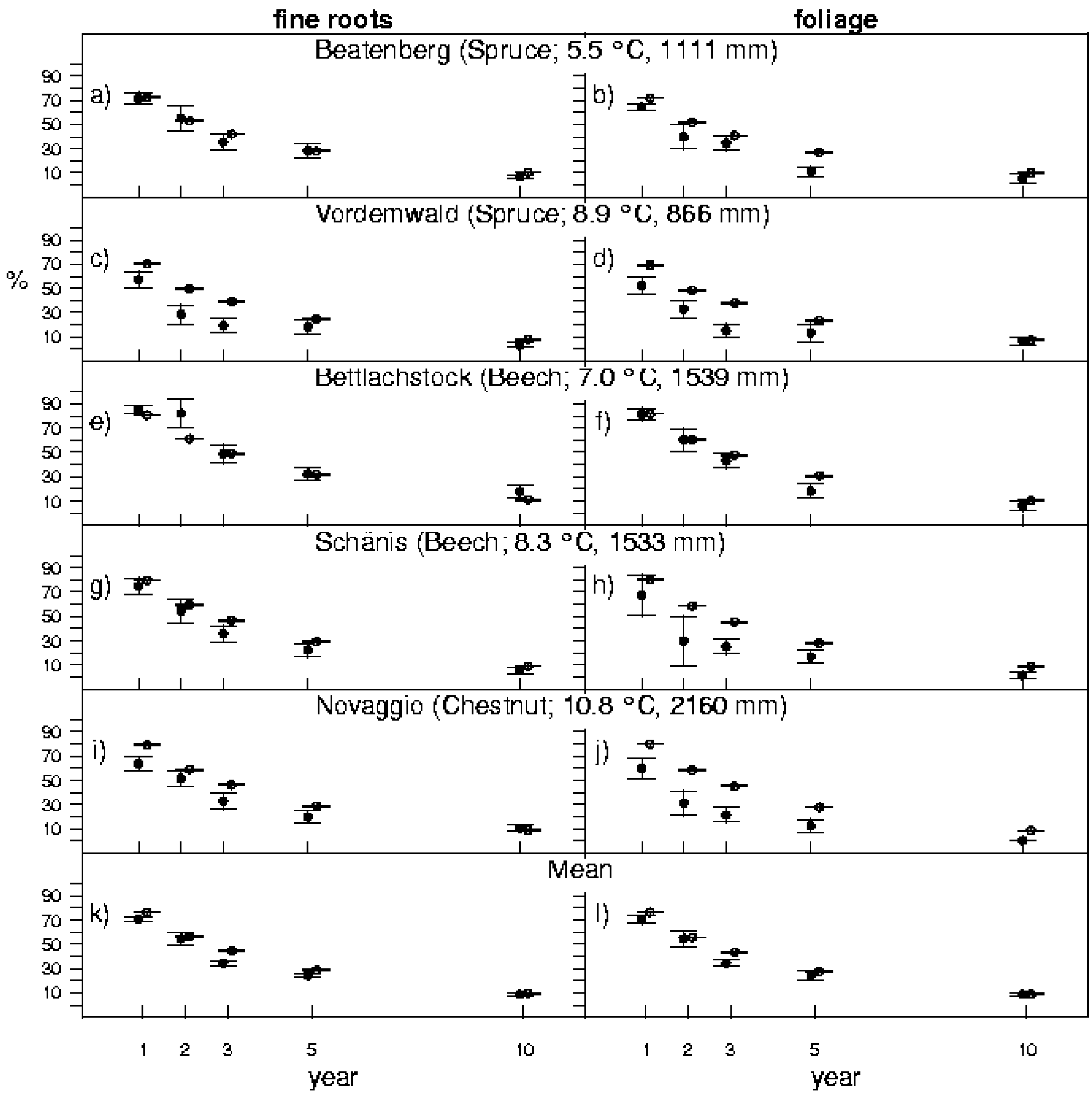

Figure 2. Mean and standard deviation for remaining mass of C [%] in fine root and foliage litter at five forest sites and the mean over all sites. Measured data were based on 20 replicate samples (filled circles). Simulated data were the result of 500 replicate simulations for parameter values of parameter 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).

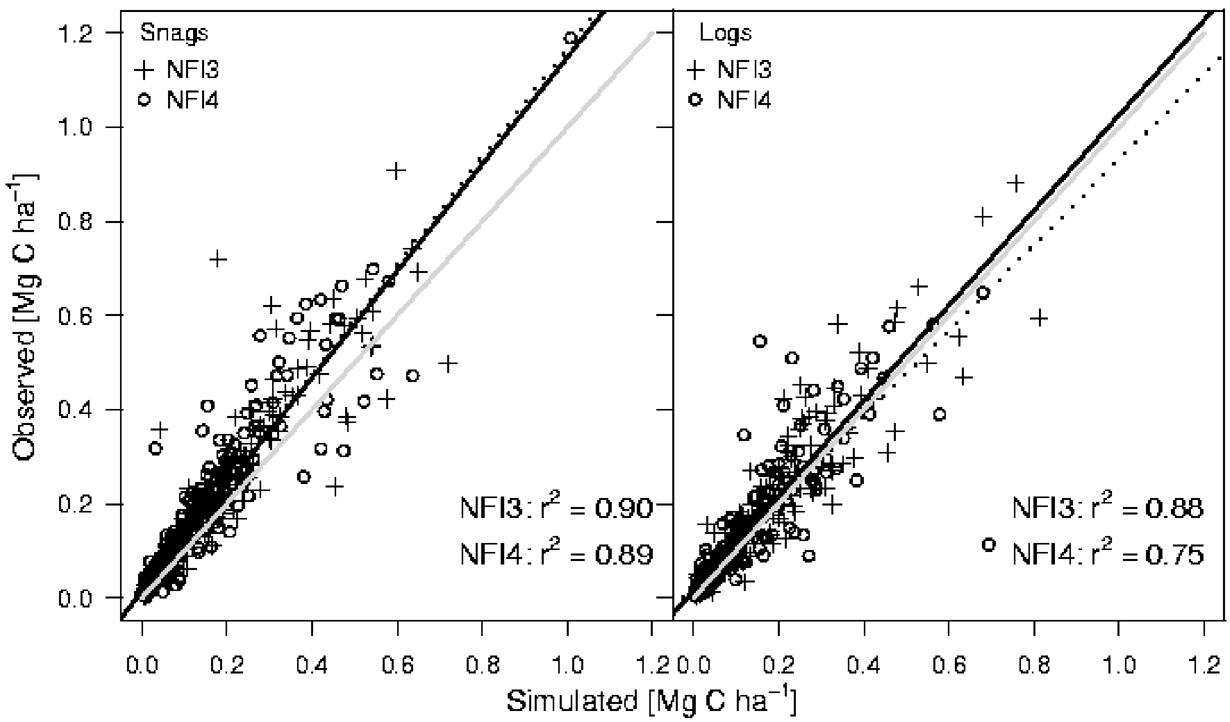

Figure 3. Observed and simulated C stores at NFIs 3 (2004-2006) and 4 (2009-2013) in dead trees that were a) standing (N=379), i.e. snags and b) lying (N=209), i.e. logs at the time of the NFI2 (1993-1995). The solid black line shows the fit at NFI3 and the dashed black line at NFI4. The solid grey line 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 Data and model implementation for estimating C stock changes in DOM and soil of productive forests in Switzerland

2.3.1 *National Forest Inventory*

The Swiss National Forest Inventory (NFI) is the primary source for estimating emission factors for forest land. The inventory is based on permanent sample plots that are revisited in each sampling campaign (Table 1). On each plot living and dead, standing and lying trees and certain shrubs according to a given species list with a diameter at breast height (dbh) > 12 cm (tally trees) are measured in detail (Lanz et al. 2019) providing representative data for further estimation of volume and biomass, among other attributes. The Swiss NFI is now in its 5th cycle. Results of the four completed NFIs are described in EAFV/BFL (1988; NFI1), Brassel and Brändli (1999; NFI2), Brändli (2010; NFI3), and Brändli et al. (2020; NFI4). The inventories NFI1, NFI2 and NFI3 were based on full surveys that were completed within 2 to 3 years and carried out in intervals of approximately 10 years. Since the fourth inventory, which started in 2009, a continuous survey over 9 years is conducted where annually a nationally representative subsample of approximately 12% of the Swiss forests is surveyed and evaluated. Otherwise, the methods to measure data in the field remained identical to the NFI3, including the estimation of total tree biomass, which is based on tree species-specific

- volume estimates of stemwood and branches based on allometries to tree dbh and conversion to biomass using basic wood densities; and
- biomass estimates of foliage and coarse roots based on allometries to tree dbh and wood densities.

Allometries and wood densities were developed using country-specific estimates where possible. Table 2 summarizes the methods to estimate tree volume and biomass. A detailed description of the current methods to estimate volume, biomass, and carbon based on the NFI data can be found in Herold et al. (2019) and Didion et al. (2019).

Table 1. Number of surveyed sample plots and trees in the National Forest Inventories NFI1, NFI2, NFI3, NFI4, and NFI5 (first two years 2018-2019) for accessible forest plots without brush forest; note the NFI5 is carried out in the years 2018 to 2026.

	NFI1	NFI2	NFI3	NFI4	NFI5
Inventory cycle	1983-1985	1993-1995	2004-2006	2009-2017	2018-2019
Grid size	1 x 1 km	1.4 x 1.4 km	1.4 x 1.4 km	1.4 x 1.4 km	1.4 x 1.4 km
Terrestrial sample plots	10'981	5'679	5'920	6'042	1'358
Tally trees	128'441	67'297	69'960	71'906	16'343

Table 2. Applied allometric biomass functions, dependencies and references. DBH: tree diameter at breast height; D7: diameter at tree height 7 m.

Tree element	Input parameter	Dataset (N trees)	References
Stemwood over bark incl. stump	DBH, D7, Height, Wood density	ca. 38'000	ch. 12.2 in Herold et al. (2019) ch. 14.2 in Didion et al. (2019)
Branches: small (< 7 cm) and large (≥ 7 cm diameter)	DBH, Wood density	14'712	ch. 12.2 in Herold et al. (2019) ch. 14.2 in Didion et al. (2019)
Foliage	DBH	631	Perruchoud et al. (1999) ch. 14.3 in Didion et al. (2019)
Coarse roots (≥ ca. 5 mm in diameter) **- broadleaved trees** **- coniferous trees**	DBH	 443 114	ch. 14.3 in Didion et al. (2019) Wutzler et al. (2008) Zell and Thürig (2013)

Based on data from two consecutive inventories, the annual litter and dead wood production can be estimated. The permanent sample plots of the first three NFIs were visited approximately 10 years apart. The NFI3 was completed in 2006 and litter and dead wood production data for the periods NFI12 and NFI23 were estimated in Didion et al. (2012) and are only updated in case of methodological changes and reported in the respective annual reports. Following the change to a continuous sampling approach with the NFI4, estimates were derived from sample plots that were visited in consecutive years of the NFI4 and the corresponding plots in the NFI3. Since the 5th year of the NFI4, i.e. 2013, a 5-year period is select to obtain a sufficient number of sample plots that ensures statistically robust, accurate and representative estimates, and to minimize the temporal spread between observations in the NFI3 and NFI4. The 5-year periods with the corresponding subset of sample plots are updated every two years to obtain the most current and accurate estimates of biomass stocks, growth, and removals (Table 3). The approach is consistent with IPCC 2006 good practice to continuously improve emissions and removal estimates based on new knowledge. It ensures that the litter and dead wood production estimates used for reporting C stocks and changes in Switzerland's NIR reflect current dynamics in Swiss forest representing, for example, the effects of disturbances. Due to this regular update of the NFI data, the time series since 2006 (i.e. after the end of the NFI3) is regularly recalculated. Due to changes in land use and cover, the number of sample plots classified as productive forest can vary between periods (Table 3 and Table A-1).

For this report, data from the NFI5 are available for the first time providing information for 2018 and 2019. To maintain a 5-year period ensuring accurate litter and dead wood production estimates, estimates are derived from sample plots common to NFI3 and NFI4 based on plots visited in the years 2015 to 2017 as well as sample plots common to NFI4 and NFI5 visited in the years 2018 and 2019, henceforth NFI3-4/5 subset 2015-2019. Once the NFI5 is in its 5th year in 2022, estimates will be based on the common plots of NFI4 and NFI5 only.

Table 3. Number of NFI sample plots in each NFI period where the total for a period represents the common plots of two consecutive NFIs based on which litter and dead wood production are estimated. Note that NFI1, NFI2 and NFI3 were based on full surveys and that the NFI4 and later NFIs have been based on continuous survey over 9 years where annually a nationally representative subsample of approximately 12% of the Swiss forests is surveyed and evaluated. Regularly updated subsets of sample plots selected from the continuous survey are used to represent the most current forest dynamics.

GHGI time series	**Reference**	**NFI period**	**NFI subset[1]**	**forest in previous period**	**Converted to forest since previous period**	**Total for period**
				Number of sample plots		
1990–1995	**Didion et al. (2012)**	**NFI12**	N/A[1]	N/A[2]	N/A[2]	5456[3]
1996–2005		**NFI23**	N/A[1]	5370	211 (0)[3]	5581[3]
2006-2011			2009-2011	1860	107 (0)[3]	1967[3]
2006-2012, recalculated	**Didion et al. (2013)**		2009-2012	2475	138 (0)[3]	2613[3]
2006-2014, recalculated	**Didion et al. (2014b)**		2009-2013	3105	166 (0)[3]	3271[3]
2006-2016, recalculated	**Didion and Thürig (2016)**	**NFI34 (NFI3-4/5[3])**	2011-2015	3115	165 (0)[3]	3280[3]
2006-2018, recalculated	**Didion and Thürig (2018)**		2013-2017	3046	165	3211
2006-2019[3], recalculated	**this report**		2015-2019	3022	199	3221

[1]NFI1, NF2, and NFI3 were based on full surveys; NFI4 and NFI5 are continuous surveys and values are updated regularly

[2]not applicable in this first NFI period

[3]until the revision in Didion and Thürig (2018) the number of sample plots was lower and varied because only plots were considered that had a continuous forest cover since the NFI1

[4]for the period NFI3-4/5 sample plots common to the NFI3 and the sample plots in NFI4 visited in the years 2015 to 2017 and common to NFI4 and NFI5 visited in the years 2018 and 2019 were considered

2.3.2 *C inputs*

Estimates of C inputs for the simulations with Yasso07 were obtained separately for all NFI sample plots classified as accessible forest but not shrub forest (*gemeinsam zugänglicher Wald ohne Gebüschwald*) in two consecutive inventories following the definition "productive forest"

(Combination Category 12, cf. Tab. 6-2 in FOEN 2020). Sample plots were distinguished into forest, i.e. plots with observed tree biomass, and non-forest, i.e. plots without observed tree biomass that were temporarily unstocked. Plot-specific C inputs on forest plots (Forest-C_{in}) were estimated for coniferous and broadleaved tree species for individual tree elements aggregated into three DOM pools:

- Coarse-woody pool comprising i) stemwood[1] of trees ≥12 cm (diameter at breast height; dbh), ii) large branches ≥ ca. 7 cm in diameter, and iii) dead coarse roots > ca. 5 mm in diameter;
- Fine-woody pool comprising i) small branches and twigs < ca. 7 cm in diameter, and ii) bark of the tree bole; and
- Non-woody pool comprising i) foliage incl. seeds and fruits, and ii) fine roots < ca. 5 mm.

The methodology to estimate stemwood, large and small branches, fine and coarse roots, and foliage is described in detail in Didion et al. (2019), for fruits in Didion and Zell (2019), and for bark in Rohner et al. (2019). In summary, individual tree elements are estimated using allometric relationships to tree dbh, wood densities, and C content. The tree state in two consecutive inventories determines the type and quantity of C inputs. It is assumed that trees that are alive in both inventories contribute to C inputs during the whole period, whereas trees that grow above the 12 cm dbh threshold (i.e. they were not measured in first inventory but were alive in the second) and those that died, including harvested trees, are assumed to contribute only for half the period. Turnover rates reflecting the longevity of leaves and needles, seeds and fruits, fine roots, and small branches are used to estimate biomass that is produced annually. Stemwood, large branches, and coarse roots are assumed to accrue only as the result of mortality. Depending on the cause of mortality, i.e. natural or timber harvesting, either the total mass of these tree elements including bark or only the non-merchantable fraction (coarse root, stump, top, and small branches including bark) is considered for C inputs, in addition to leaves and needles, seeds and fruits, fine roots, and small branches (Table 4).

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[1] Stemwood includes stump, bole (merchantable part of the stem with diameter > 7 cm above the stump excluding bark), and top of a tree as defined in the Swiss NFI (Figure 14.1 in Didion et al. 2019).

Table 4. Tree elements considered for C inputs depending on the state of a tree at the end of the period between two consecutive National Forest Inventories.

Tree element	Contribution to C input (tree state)
foliage	alive, natural mortality, harvest
seeds and fruits	alive, natural mortality, harvest
small branches incl. bark	alive, natural mortality, harvest
large branches incl. bark	natural mortality
tree top incl. bark	natural mortality, harvest
tree bole incl. bark	natural mortality
tree stump incl. bark	natural mortality, harvest
coarse roots	natural mortality, harvest
fine roots	alive, natural mortality, harvest

Etzold et al. (2011) verified the accuracy of the estimates with independent data from long-term forest ecosystem research sites.

Current measured data have been available since the NFI1 in 1985. For the spin-up, the development until 1940, and sample plots that were non-forest in 1940 but became forest after 1985 (i.e. classified as productive forest in a NFI period), C inputs of individual sample plots were obtained by using a spatial moving window including data from all forested plots within a 10x10km quadrat. Based on this procedure averaged C inputs were obtained for each plot included in an inventory period, i.e. Forest-C_{in}1-2 $_{avg}$, Forest-C_{in}2-3 $_{avg}$, Forest-C_{in}3-4/5 $_{avg}$. This was necessary to avoid artefacts resulting from simulating individual, temporarily unstocked sample plots without C inputs which were forested in the past. Since 1986 estimates of forest C inputs were obtained separately for each NFI plot to account for local conditions including the prevalent forest management type and natural 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 three DOM pools: Estimates of non-woody and fine-woody litter 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 elements such as branches and result in an increase in the amount of dead wood, NFI measurements show this increase. Since the input of C to the model is derived from NFI 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.

The uncertainty related to the estimation of C inputs was estimated to account for uncertainties in

- applying allometric functions to estimate tree stem volume from measured tree dbh (Berger et al. 2013);
- converting and expanding stem volume to whole tree biomass and estimating litter production (Wutzler and Mund 2007); and
- carbon concentration (Dobbertin and Jüngling 2009).

Based on the mean inputs at each NFI sample plot, the correlation between DOM components, and estimates of uncertainty (Tab. A-2), a distribution of possible inputs was created.

Annual above-ground C inputs on temporarily unstocked sample plots (Non-Forest-C_{in}; Tab. 4) were estimated based on data by Didion (2020) and the assumption that sample plots are covered by dense shrub- and herbaceous vegetation. Based on data by Freschet et al. (2013) for grasses (64%) and Gao et al. (2014) for herbs (50%), annual below-ground biomass was estimated as 50% of above-ground biomass. The estimated mean total Non-Forest-C_{in} which was used for each sample plot corresponded to between 3 and 100 % of the non-woody litter contribution to Forest-C_{in}. The mean contribution of 15 to 25% of the non-woody litter 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.

Table 5 shows the mean and standard deviation of annual C inputs calculated from all sample plots included in a particular NFI-period separately for DOM derived from conifers and broadleaves on forest sample plots as well as for non-woody litter on temporarily unstocked plots.

C inputs for each pool were portioned into the four chemical compartments (AWEN, cf. section 2.1) used by Yasso07 following experimentally derived fractions (Table 6) as discussed in Didion et al. (2014a).

Table 5. Mean and standard deviation of C inputs from trees >12cm dbh over all NFI sample plots simulated with Yasso07 for the GHGI 2021. C inputs are based on averaged (Forest-C_{in}1-2_{avg}, Forest-C_{in}2-3_{avg}, Forest-C_{in}3-4/5_{avg}) and plot-specific (Forest-C_{in}1-2, Forest-C_{in}2-3, Forest-C_{in}3-4/5) data from sample plots classified as forest in a particular NFI period. For sample plots with tree biomass, the mass of carbon in six dead organic matter (DOM) components was estimated for a) coniferous and b) broadleaved tree species. For temporarily unstocked sample plots, c) the mass of carbon was estimated based on non-woody litter produced by a dense herb and shrub cover. C inputs are shown for each NFI period.

a) conifers

NFI data	DOM component												Total	
	Fine roots		Foliage		Fine woody		Coarse-woody (>7 cm diameter)							
							Roots		Branches		Stems			
	Kg C $ha^{-1}a^{-1}$													
Forest-C_{in}1-2 avg	662	±239	1009	±437	311	±129	258	±154	54	±35	48	±31	2342	±539
Forest-C_{in}1-2	721	±644	1118	±1194	337	±322	278	±664	60	±180	53	±158	2567	±1563
Forest-C_{in}2-3 avg	703	±251	1067	±494	329	±140	304	±236	75	±57	66	±50	2544	±623
Forest-C_{in}2-3	752	±684	1158	±1277	350	±343	318	±795	79	±225	70	±198	2727	±1714
Forest-C_{in}3-4/5 avg	697	±260	1214	±652	320	±129	267	±197	86	±60	76	±52	2660	±745
Forest-C_{in}3-4/5	715	±729	1252	±1505	328	±359	271	±769	87	±293	77	±258	2730	±1915

b) broadleaves

NFI data	DOM component												Total	
	Fine roots		Foliage		Fine woody		Coarse-woody (>7 cm diameter)							
							Roots		Branches		Stems			
	Kg C $ha^{-1}a^{-1}$													
Forest-C_{in}1-2 avg	253	±164	603	±397	121	±85	87	±82	29	±24	10	±9	1103	±446
Forest-C_{in}1-2	271	±430	646	±1248	127	±177	92	±315	31	±160	11	±52	1178	±1379
Forest-C_{in}2-3 avg	286	±183	678	±440	127	±85	89	±96	38	±37	12	±10	1230	±495
Forest-C_{in}2-3	302	±487	717	±1438	133	±182	93	±330	40	±172	12	±53	1297	±1575
Forest-C_{in}3-4/5 avg	300	±190	702	±441	127	±83	108	±114	54	±60	19	±16	1310	±504
Forest-C_{in}3-4/5	306	±441	717	±1015	129	±175	109	±404	55	±321	19	±77	1335	±1236

c) non-forest above-ground

	Kg C $ha^{-1}a^{-1}$
Non-Forest-C_{in}1-2	241
Non-Forest-C_{in}2-3	247
Non-Forest-C_{in}3-4/5	245

Table 6. 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

2.3.3 *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 1 km with monthly data since 1961 (MeteoSwiss 2020).

For the location of each NFI sample 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 2016a) and RhiresM v1.0 (MeteoSwiss 2016b). Annual mean temperature and precipitation were calculated as the mean and sum, respectively, of the monthly data extracted for NFI sample plots classified as productive forest in any of the three inventory periods. Annual temperature amplitudes were calculated following the Yasso-methodology (Rantakari et al. 2012) as the semi-amplitude:

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

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 shows the annual temperature and precipitation means for all sites defined as productive forest in any of the three NFI periods (N=5862) and, in comparison, the long-term annual means calculated for the norm periods 1961-1990 and 1981-2010 indicating the increase in temperature. Table A-3 provides additional details.

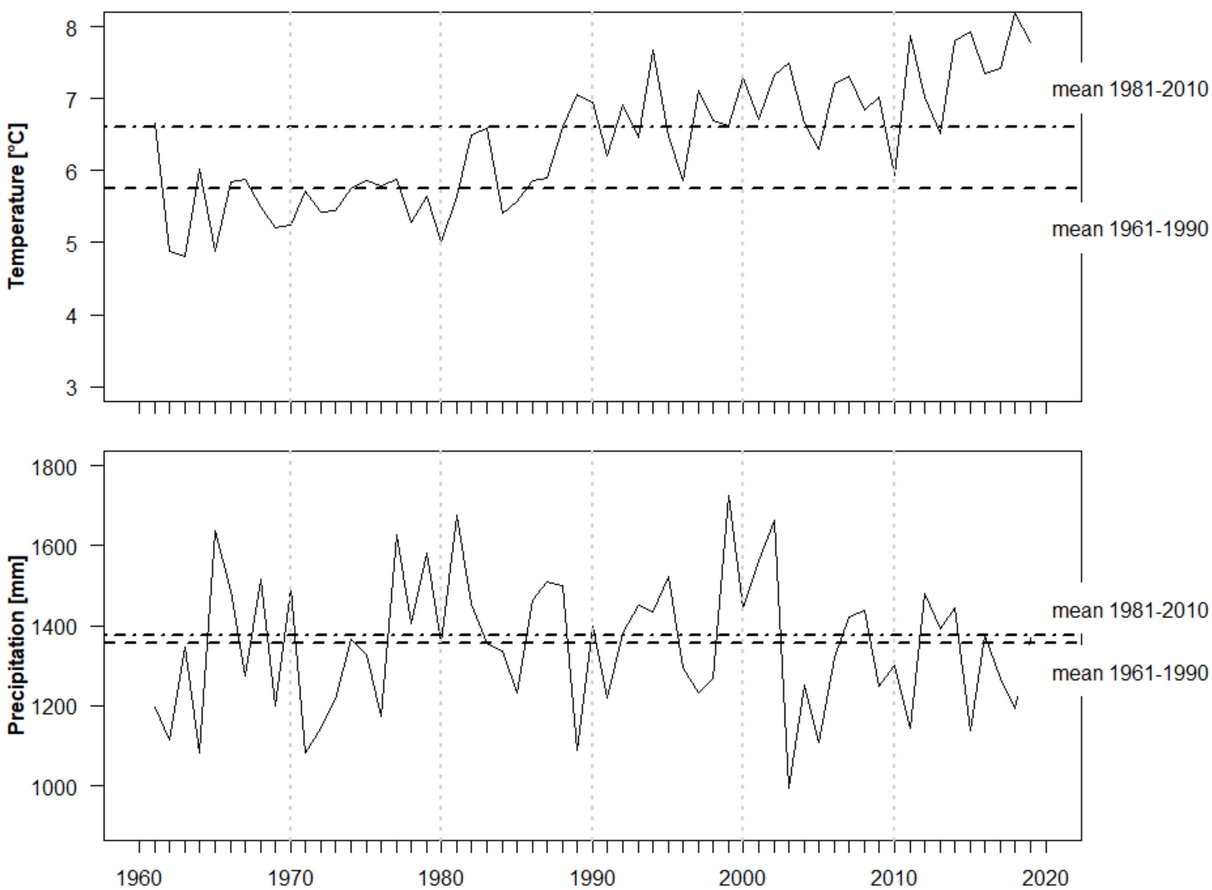

Figure 4. Annual means of temperature and precipitation sums since 1961 for all NFI sample plots classified as productive forest in any of the three NFI periods (N=5862). The long-term means of the norm periods 1961-1990 and 1981-2010 are indicated by the horizontal lines.

2.3.4 *Model implementation*

To estimate carbon stocks and carbon stock changes in DOM and soil of productive forests in Switzerland, Yasso07 was run on each sample plot of the Swiss national forest inventory (NFI) that was Sample plots classified as productive forest were identified individually for each of the three NFI periods (i.e. defined as forest in two or three, respectively consecutive NFIs):

- NFI1-2 (from 1986 to 1995);
- NFI2-3 (from 1996 to 2005); and
- NFI3-4/5 (from 2006 to 2019)

To drive the Yasso07 simulation and to obtain C stock estimates for dead wood, litter and mineral soil in Swiss forests , a model parameter set was selected (section 2.3.5) and plot-specific annual inputs for a) for observed climate (section 2.3.3), and b) non-woody and woody C derived from measured data (sections 2.3.1 and 2.3.2) were used. Section 2.3.2 explains the derivation of C inputs including detail on the contribution of different non-woody and woody tree biomass pools.

The simulation of current C stocks based on the available climate and C inputs was implemented as follows:

a. **Historic C stocks assumed to represent the conditions in 1880**: Established based on the assumption that forest soils C stocks are the result of long-term processes. The year 1880 was used because it corresponds to the first year with a robust estimate of whether a NFI sample plot was forested (Ginzler et al. 2011).
    - Long-term equilibrium soil C stocks: Estimated in a spin-up procedure (cf. Liski et al. 2009) based on mean climate 1961 to 1990 and constant, averaged forest C inputs based on NFI1-2 data (Forest-C_{in}1-2$_{avg}$; section 2.3.2) assuming that C stocks in the soil have accumulated over centuries to millennia (Schlesinger 1990).
    - if a sample plot was not forested in 1880, the spin-up was continued with additional 250 years with constant mean non-forest C inputs representative of dense shrub- and herbaceous vegetation based data from Didion et al. (2018); (Non-Forest-C_{in}1-2; section 2.3.2).

b. **Forest development until 1985**: 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 intermediated states before the start of the first period NFI1-2 in 1986.
    - State 1915 and 1940: In addition to 1880, Ginzler et al. (2011) provided robust estimates of whether a NFI sample plot was forested also for 1915 and 1940. Depending on the classification of a sample plot as forest or non-forest in 1880, 1915, and 1940, C stocks in 1915 and 1940 were estimated based on mean climate 1961 to 1990 and in case of
        - forest in 1880, 1915 and 1940: 60 years simulation with Forest-C_{in}1-2$_{avg}$;
        - forest in 1880 and 1915 but non-forest in 1940: 47 years simulation with Forest-C_{in}1-2$_{avg}$ (i.e. 35 years between 1880 and 1915 and 12 years

between 1916 until halfway of the period 1916 to 1940) and 13 years simulation with Non-Forest-C_{in}1-2;
    - forest in 1880 but non-forest 1915 and in 1940: 17 years simulation with Forest-C_{in}1-2 $_{avg}$, and 43 years simulation with Non-Forest-C_{in}1-2 (i.e. 18 years between from halfway between 1880 and 1915 and 25 years from 1916 to 1940);
    - forest in 1880 but non-forest 1915 and forest again in 1940: 17 years simulation with Forest-C_{in}1-2 $_{avg}$, 30 years simulation with Non-Forest-C_{in}1-2 (i.e. 18 years from halfway between 1880 and 1915 and 12 years from halfway between 1916 and 1940), and 13 years simulation with Forest-C_{in}1-2 $_{avg}$;
    - non-forest in 1880 the procedure was the same as all above listed alternatives in the case of forest in 1880 but with reversed C inputs, ie., Non-Forest-C_{in}1-2 instead of Forest-C_{in}1-2 $_{avg}$ and Forest-C_{in}1-2 $_{avg}$ instead of Non-Forest-C_{in}1-2 in the respective periods.
- State 1985: Depending on the classification in 1940 and the NFI period when a sample plot was first classified as forest, the simulation after 1940 was continued based in mean climate 1961 to 1990 until 1960 and annual climate from 1961 onward in case of
    - forest in 1940 and in NFI1-2: 45 years simulation with Forest-C_{in}1-2 $_{avg}$;
    - forest in 1940 and non-forest in NFI1-2: 22 years simulation with Non-Forest-C_{in}1-2 and 23 years simulation with Forest-C_{in}1-2 $_{avg}$, i.e, halfway of the period 1940 and start of NFI1-2 in 1986;
    - non-forest in 1940 and in NFI1-2 but forest in NFI2-3: 27 years simulation with Non-Forest-C_{in}1-2 and 18 years simulation with constant, averaged forest C inputs based on NFI2-3 data (Forest-C_{in}2-3 $_{avg}$; section 2.3.3), i.e, halfway of the period 1940 and start of NFI2-3 in 1996;
    - non-forest in 1940, in NFI1-2 and in NFI2-3 but forest in NFI3-4/5: 32 years simulation with Non-Forest-C_{in}1-2 and 13 years simulation with constant, averaged forest C inputs based on NFI3- 4/5 data (Forest- C_{in}3- 4/5 $_{avg}$; section 2.3.2), i.e, halfway of the period 1940 and start of NFI3-4/5 in 2006;

c. **Forest development after 1985**: Sample plot-specific annual climate data and, depending on whether a sample plot was forest or non-forest in a particular NFI period, C inputs corresponding to plot-specific forest C inputs for a period (i.e. Forest-C_{in}1-2, Forest-C_{in}2-3, Forest-C_{in}3-4/5 or mean non-forest C inputs for a period (i.e. Non-Forest-C_{in}1-2, Non-Forest-C_{in}2-3, Non-Forest-C_{in}3-4/5).

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.

2.3.5 *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-4).

2.4 Methodological improvements and updates of input data

2.4.1 *Improvements and updates compared to GHGI 2020*

Since the previous submission, no methodological developments were implemented. For the simulations with Yasso07, new estimates of dead wood and litter inputs from the NFI (sections 2.3.1 and 2.3.2), as well as revised climate data were available (section 2.3.3).

- Estimates of dead wood and litter inputs were derived from NFI sample plots common to NFI3 and NFI4 visited in the years 2015 to 2017 as well as from sample plots common to NFI4 and NFI5 visited in the years 2018 and 2019. These are assumed to be representative of the period 2006 to 2019. Compared to the previous GHGI, which was based on NFI data until 2017, the estimates are thus based on more current NFI data.
- MeteoSwiss implemented some minor improvements to its spatial interpolation methodology to derive gridded data from climate stations. Furthermore, gridded data were new available in a 1km resolution as compared to the previously used 2km resolution data. Compared to previous GHGIs the new climate data improve the accuracy of the temperature and precipitation estimates for individual NFI sample plots, which is expected to result also in more accurate estimates of C stocks and CSC.

2.4.2 *List of improvements and updates until GHGI 2020*

GHGI 2020 (section 2.4.1 in Didion 2019)

- No changes.

GHGI 2019 (section 2.4.1 in Didion and Thürig 2018)

- Revision of the selection of NFI sample plots to account also for temporary unstocked plots consistent with the approach for estimating C stock and C stock changes in living biomass.
- Incorporation of fine-woody litter in C inputs of forested plots and of non-forest vegetation in C inputs on temporarily unstocked plots.
- Consideration of forest development since 1880 in the spin-up procedure.

GHGI 2018 (section 2.4.1 in Didion and Thürig 2017)

- No changes.

GHGI 2017 (section 2.4.1 in Didion and Thürig 2016)

- 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 (section 2.3 in Didion and Thürig 2015)

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

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

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

GHGI 2014 (section 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. Table 6). Using this information, the simulated annual C stocks were separated to obtain annual estimates of carbon stored in the soil (sum of C in the H compartment from all tree elements), in litter (i.e. sum C in the AWEN compartments of fine roots, foliage, seeds and fruits, fine-woody litter) and in dead wood (i.e. sum C in the AWEN compartments of stemwood (resp. stump and tree top), branches and coarse roots) were calculated (cf. Appendix I in Didion et al. 2014a; Didion et al. 2012).

Annual estimates of carbon stocks in the soil, litter and dead wood (CWD) pools for each NFI plot were derived from Yasso07 simulations for the period 1989 to 2019. 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*: $Soil_{csc}$, $Litter_{csc}$, CWD_{csc} and the sum (ALL_{csc}); contained in result tables[2] A-6 to A-13 [Mg C $ha^{-1}a^{-1}$].
2) *annual carbon stocks*: Litter and CWD; result tables A-14 to A-17 [Mg C ha^{-1}].

2.5.1 *Spatial stratification*

The LULUCF sector in the Swiss GHGI uses a spatial stratification of land use categories with five production regions and three elevation classes (≤600 m, 601-1200 m, >1200 m; ch. 6.2.2 in FOEN 2020). Consistent with this stratification, sample plot based estimates of C stocks and C stock changes in dead wood, litter and mineral soil in Swiss forests were aggregated by these 15 strata.

[2] see Appendix II for details and nomenclature.

3 Results and Discussion

In the following, the results for CSC and stocks are presented and additional data that are relevant for verification are documented. Results and effects of recalculations are presented for each of the three C pools, i.e. dead wood, litter, and mineral soil. This separation of simulation results is based on the source of the C inputs (section 2.3.2) and their separation into chemical compounds in the Yasso model (section 2.1). This separation may introduce a general error in the pool estimates but does not affect the estimates of combined total C stocks and C stock changes (Didion et al. 2014a). The complete set of result tables of C stock and CSC that were prepared for the Swiss GHGI 2021 (1990-2019) can be found in Appendix II.

3.1 Carbon stock change

The mean total CSC from 2018 to 2019 in dead wood, litter, and mineral soil in Swiss forests was estimated as a loss of ca. -0.008 ±0.004 (2SE) Mg C $ha^{-1}a^{-1}$ (Total for Switzerland in Table 7, ALL_{csc} in Figure 5) based on a total of 3221 sample plots (Table 3). There was a statistically not significant increase in the national mean CSC gain from 2017/2018 to 2018/2019 (Figure 5).

Based on an estimated 1'159'342.5 ha of productive forest obtained based on the respective area of forest land remaining forest land calculated for commonly accessible forest of NFI3 to NFI4 visited in the years 2015 to 2017 and to NFI, and NFI5 visited in the years 2018 and 2019, the total national CSC corresponded to a loss of 8.770 ±4.948 (2SE) Gg C a^{-1} (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. ch. 6.3.1 in FOEN 2020).

Temporal dynamics of annual total CSC since 1990 were dominated by the dead wood and litter pools (Figure 5). Whether CSC corresponds to a gain (removal) or a loss (emission) depended on carbon pools and regions (Table 7 and Tabs. A-6 to A-9 for a complete time series of mean regional CSC).

Table 7. Mean national total (sum of dead wood, litter and soil) carbon stock change ± 2 standard error in 2018/2019 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 $ha^{-1}a^{-1}$											
<601 m	-0.030	±0.016	-0.054	±0.012	0.004	±0.017	0.049	±0.013	-0.007	±0.016	-0.044	±0.009
601-1200 m	0.047	±0.012	-0.042	±0.015	0.004	±0.017	0.049	±0.013	-0.003	±0.009	0.015	±0.007
>1200 m	0.081	±0.025	-0.042	±0.015	-0.038	±0.016	-0.028	±0.010	0.020	±0.014	-0.016	±0.007
Total	0.032	±0.009	-0.049	±0.009	-0.012	±0.012	-0.006	±0.008	0.007	±0.008	-0.008	±0.004

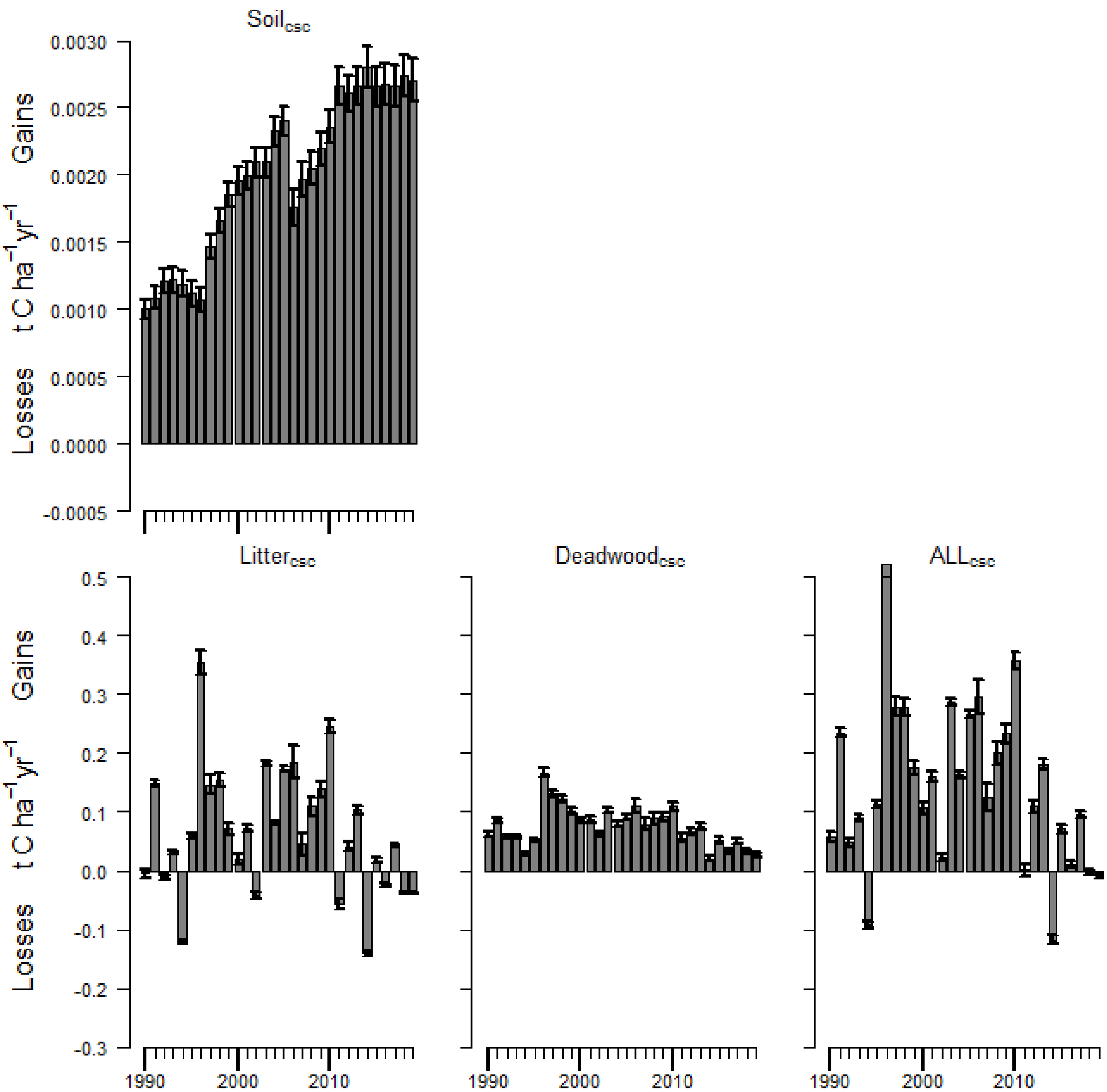

Figure 5. National mean carbon stock change (CSC) since 1990 for three pools soil, litter, dead wood and their sum (ALL) in t C ha^{-1} (equals Mg C ha^{-1}). Note the difference of the y-axis scale between Soil$_{csc}$ and Litter$_{csc}$, Dead wood$_{csc}$ and ALL$_{csc}$, respectively. Negative values indicate C losses, positive values C gains. The error bars indicate the standard error (2SE).

3.1.1 *Dead wood*

The dead wood pool gained C in 2018/2019 (0.027 ±0.002 Mg C $ha^{-1}a^{-1}$; Dead $wood_{csc}$ in Figure 5). Compared to the previous GHGI, the C gain in 2017/2018 of this pool has decreased from 0.042 ±0.002 Mg C $ha^{-1}a^{-1}$ (section 3.1 in Didion 2019) to 0.033 ±0.002 Mg C $ha^{-1}a^{-1}$ (Figure 6). This difference is explained primarily by the update of the NFI data, i.e. deriving estimates based on the NFI3-4/5 subset 2015-2019 instead of the NFI34 subset 2013-2017 (sections 2.3.1 and 2.3.2). The updated data indicated lower coarse-woody inputs for the time since the NFI3 with a mean total of 608 Kg C $ha^{-1}a^{-1}$ (Table 5) compared to a mean total of 647 Kg C $ha^{-1}a^{-1}$ for the previous inventory (Table 3 in Didion 2019). Following the necessary recalculation of the time series, dead wood gains since 2006 were lower than in the previous GHGI (Figure 6).

Since 1990 the pool first 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 has been decreasing slowly releasing stored C as indicated by the decreasing trend of gains in this pool (Figure 5). The trend of decreasing harvesting rates for several years after NFI3 (Table 6-17 in FOEN 2020) further sustained the carbon sink of dead wood as mature trees, which could be harvested, remain in the forest to potentially contribute to the dead wood pool.

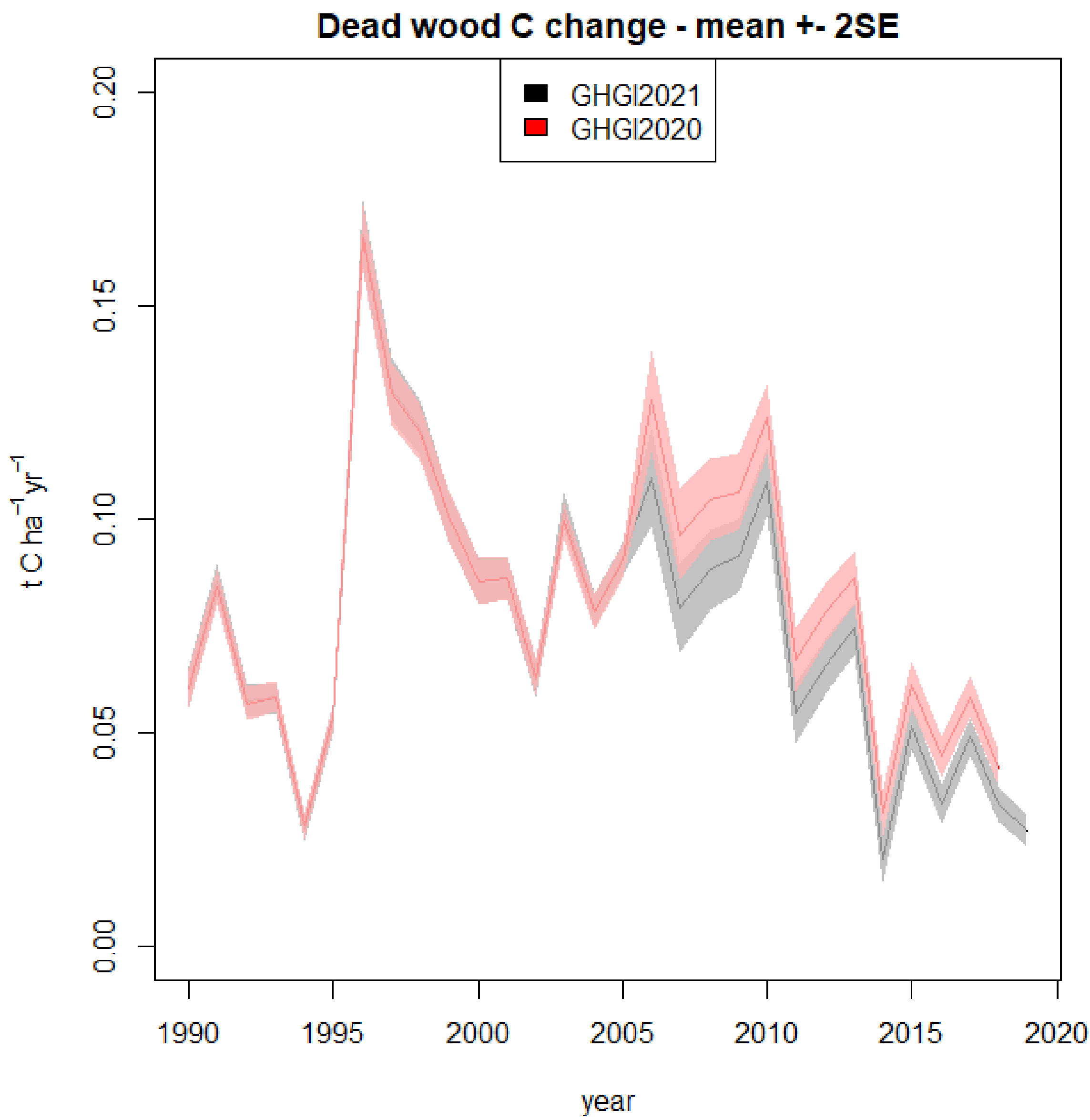

Figure 6. Time series of mean annual C stock change in the dead wood pool estimated for the GHGIs 2020 and 2021.Shaded areas indicate 2 SE of the mean.

3.1.2 *Litter*

The CSC in 2018/2019 in the litter pool constituted a loss of -0.037 ±0.001 Mg C ha^{-1}a^{-1} ($Litter_{csc}$ in Figure 5). This value is similar to the CSC estimated for 2017/2018 (Figure 7). For the previous GHGI, a value of -0.042 ±0.001 Mg C ha^{-1}a^{-1} was estimated for 2017/2018 (section 3.1 in Didion 2019). However, differences between the estimates for this and the previous GHGI were apparent in 2007-2011 (Figure 7) as a consequence of the update of the NFI data, i.e. deriving estimates based on the NFI3-4/5 subset 2015-2019 instead of the NFI34 subset 2013-2017 (sections 2.3.1 and 2.3.2). The update resulted in an increase of the estimated mean total non-woody C input to 2990 Kg C ha^{-1}a^{-1} in this report (Table 5), from 2925 Kg C ha^{-1}a^{-1} for the previous inventory (Table 3 in Didion 2019). The higher inputs did not result in higher gains for the entire time period since 2006 because of the fast decomposition of the readily decomposable material in this pool. The litter pool consists primarily of easily decomposable non-woody material, and the dynamics in this C pool are largely driven by interannual variability in temperature and precipitation (Aerts 1997).

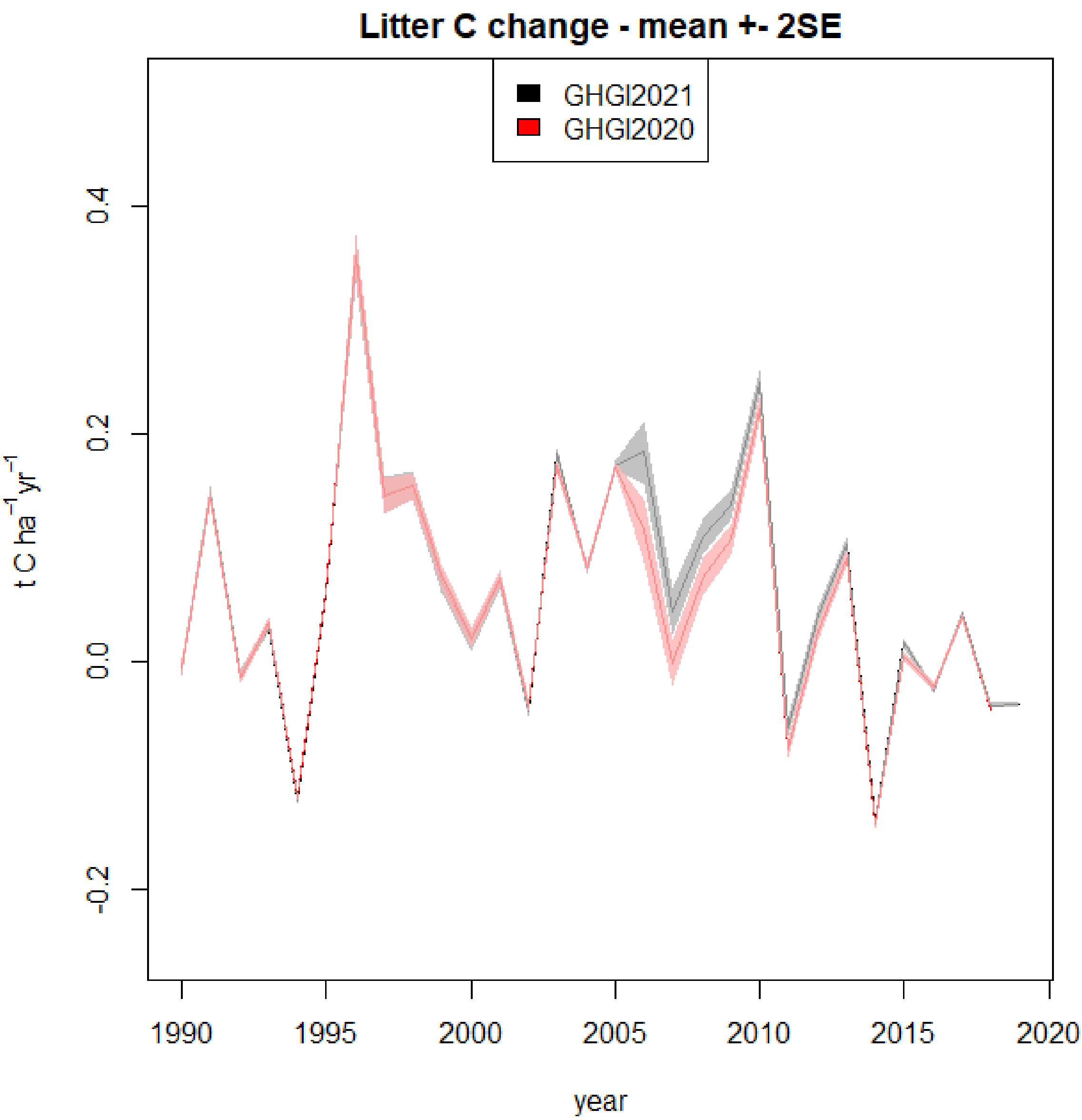

Figure 7. Time series of mean annual C stock change in the litter pool estimated for the GHGIs 2020 and 2021.Shaded areas indicate 2 SE of the mean.

3.1.3 *Mineral soil*

Mineral forest soils continuously gained in C at a comparably moderate rate (0.003 ±0.000 Mg C $ha^{-1}a^{-1}$ in 2018/2019; $Soil_{csc}$ in Figure 5). The change compared to the previous GHGI was statistically not significant (Figure 8) with less than 1 Kg C $ha^{-1}a^{-1}$ difference in the means estimated for the change in 2017/2018. Also, this small difference is below the detection limit of measurements (e.g., Keller et al. 2006). The difference was the result of the changes in the dead wood and litter pools and their resulting C fluxes to the soil pool.

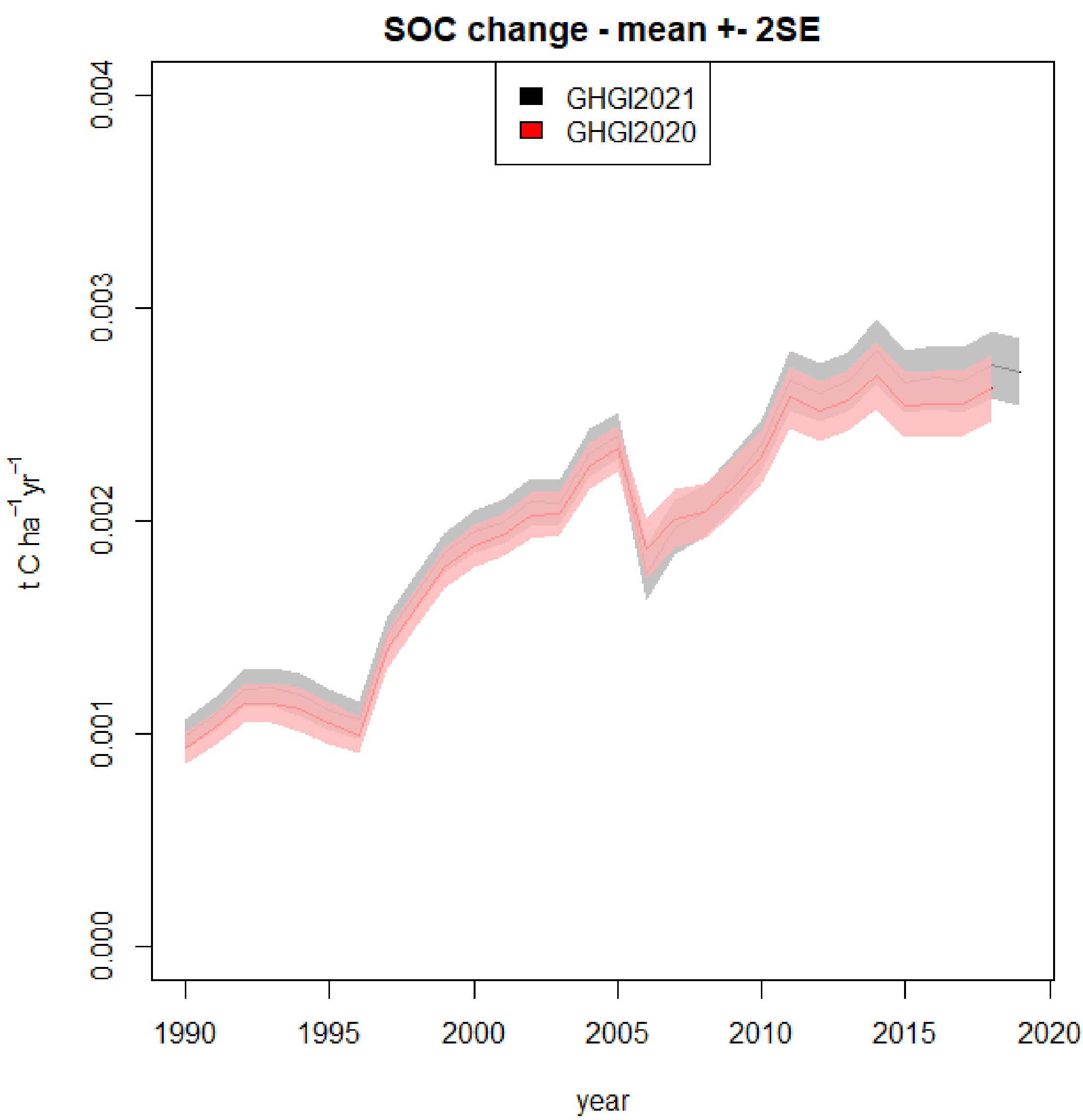

Figure 8. Time series of mean annual C stock change in the mineral soil pool estimated for the GHGIs 2020 and 2021.Shaded areas indicate 2 SE of the mean.

3.1.4 *Uncertainty*

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 2.3.2) as well as the uncertainty in the Yasso parameters (section 2.3.5) were addressed by applying a Monte-Carlo approach based on 100 replicate simulation (section 2.5). Following the change in the NFI4 from periodic to a continuous survey (sections 2.3.1 and 2.3.2), dead wood and litter inputs for the period NFI3-4 were derived based on shifting sample of sample plots common to NFI3 and multi-annual NFI4 and NFI 5 subsets, respectively.

This change in sample plots introduced additional variability, which was taken into account to obtain an uncertainty estimate corresponding to approximately the second commitment period of the Kyoto Protocol. The thus obtained double standard errors for the dead wood, litter and mineral soil C in the Swiss GHGI were 16.6%, 96.7, %, and 37.0%, respectively. The total uncertainty of the carbon stock change in DOM and mineral soil was estimated as 17.1%. This is in the range of uncertainty estimates in countries where Yasso07 is also applied. For example, Norway reports an uncertainty of 15.5%, which applied to both the DOM and mineral soil pools (chapter 6.4.1.2 in Norwegian Environment Agency 2019), and Finland reports an uncertainty of 31.5% in the net CSC in DOM and mineral soil (Lehtonen and Heikkinen 2016; chapter 6.4.3.2 in Statistics Finland 2019).

3.2 Carbon stocks

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 underestimates the national stock derived from the NFI by ca. 8% (). Differences are expected because the dead wood pools are not fully comparable regarding their composition: C inputs to the model may not precisely correspond to dead wood falling from trees. Also, 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. Further, 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. Generally, at the national level, the observed change in coarse dead wood C stocks in Switzerland between NFIs 3 and 4 was reproduced accurately by the model (Table 8) considering the uncertainty in the stocks.

Table 8. Mean and standard error of carbon stored in dead wood 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 2013-2017 for NFI4. Percent change was calculated based on the respective means.

NFI3				**NFI4**				**Change**	
Mg C ha^{-1}								%	
NFI		**Yasso07**		**NFI**		**Yasso07**		**NFI**	**Yasso07**
7.34	±0.3	6.69	±0.1	7.99	±0.2	7.09	±0.1	6.9	6.0

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. 75% of the stock reported by Moeri (2007); cf. Table 9. This difference is not surprising since the simulated values do not include litter from herbs, shrubs and trees <12 cm dbh. Currently only estimates of above-ground biomass of herbs and shrubs are available (Didion 2020). Work is ongoing to obtain estimates of below-ground biomass and annual turnover of this vegetation layer. A quantification of foliage litter produced by tree saplings with a measurable dbh, i.e. with height >130 cm is under investigation.

Table 9. 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 1990-2018.

Moeri 2007	**Yasso07**
Mg C ha^{-1}	
18.1 ±0.6	13.17 ±0.2

The variability in litter C stocks between regions is greater in the measured data from Moeri (2007) than in the simulated data. 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 standard error in Table 9.

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 (Eckmeier et al. 2010; Nussbaum et al. 2012, 2014; Zanelli et al. 2006), 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), and 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). Simulated soil C stocks were highly variable and did not show a clear correlation to environmental variables such as elevation. This is consistent with results from a study in the Bernese Alps by Hoffmann et al. (2014) who found a large unexplained variability in SOC stocks not correlated with environmental variables.

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 litter from the trees <12 cm dbh and from the herb- and shrub layer. This extends on the study by (Didion 2020) which provided a consistent methodology to obtain estimates of above-ground biomass of plants in the herb- and dwarf shrub layer on NFI sites. These activities will improve the accuracy of the simulated estimates (planned for the first submission (GHGI 2023) under the Paris agreement).
- Review of the litter production estimates, including turnover rates (planned for the first submission (GHGI 2023) under the Paris agreement).
- 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 (planned for the first submission (GHGI 2023) under the Paris agreement).

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

- ongoing research and collaboration with other countries where currently Yasso07 is applied as well, i.e. Finland, Norway, and Austria and WSL;
- international workshops - participants from six countries met in February 2020 in Vienna, and it is planned to repeat this annually.

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References

Aerts R (1997) Climate, Leaf Litter Chemistry and Leaf Litter Decomposition in Terrestrial Ecosystems: A Triangular Relationship. Oikos 79:439-449. doi:10.2307/3546886

Berger A, Gschwantner T, McRoberts RE, Schadauer K (2013) Effects of Measurement Errors on Individual Tree Stem Volume Estimates for the Austrian National Forest Inventory. Forest Science

Brändli U-B (ed) (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,

Brändli U-B, Abegg M, Allgaier Leuch B (eds) (2020) Schweizerisches Landesforstinventar: Ergebnisse der vierten Erhebung 2009-2017. [Results of the forth Swiss National Forest Inventory 2009-2017] Swiss Federal Research Institute for Forest, Snow and Landscape Research, Birmensdorf (ZH) and Federal Office for the Environment (FOEN), Bern,

Brassel P, Brändli U-B (1999) Schweizerisches Landesforstinventar: Ergebnisse der Zweitaufnahme 1993-1995. Paul Haupt Verlag, Bern

de Wit HA, Palosuo T, Hylen G, Liski J (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 (2019) Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse deadwood prepared for the Swiss GHGI 2020 (1990-2018). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M (2020) Extending harmonized national forest inventory herb layer vegetation cover observations to derive comprehensive biomass estimates. For Ecosyst 7:16. doi:10.1186/s40663-020-00230-7

Didion M, Baume M, Giudici F, Schneuwly J (2018) Herb layer cover and biomass data from Swiss forests. Swiss Federal Research Institute WSL, Birmensdorf. doi: http://dx.doi.org/10.16904/envidat.52

Didion M, Frey B, Rogiers N, Thürig E (2014a) Validating tree litter decomposition in the Yasso07 carbon model. Ecological Modelling 291:58-68. doi:http://dx.doi.org/10.1016/j.ecolmodel.2014.07.028

Didion M, Herold A, Thürig E (2019) Whole Tree Biomass and Carbon Stock. In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Managing Forest Ecosystems, vol 35. Springer International Publishing, Cham, pp 243-248. doi:10.1007/978-3-030-19293-8_14

Didion M, Kaufmann E, Thürig E (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/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M, Kaufmann E, Thürig E (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/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M, Kaufmann E, Thürig E (2014b) 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). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M, Thürig E (2015) Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse deadwood prepared for the Swiss GHGI 2016 (1990-2014). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M, Thürig E (2016) Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse deadwood prepared for the Swiss GHGI 2017 (1990-2015). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M, Thürig E (2017) Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse deadwood prepared for the Swiss GHGI 2018 (1990-2016). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M, Thürig E (2018) Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse deadwood prepared for the Swiss GHGI 2019 (1990-2017). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf. avl. online at www.bafu.admin.ch/bafu/en/home/topics/climate/state/data/climate-reporting.html

Didion M, Zell J (2019) Model of Carbon Cycling in Dead Organic Matter and Soil (Yasso07). In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Managing Forest Ecosystems, vol 35. Springer International Publishing, Cham, pp 281-284. doi:10.1007/978-3-030-19293-8_18

Dobbertin M, Jüngling E (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

EAFV (Eidgenössische Anstalt für das forstliche Versuchswesen), BFL (Bundesamt für Forstwesen und Landschaftsschutz) (eds) (1988) Schweizerisches Landesforstinventar: Ergebnisse der Erstaufnahme 1982-1986. Berichte der Eidgenöss. Forsch. Anst. Wald Schnee Landsch. 305. Eidg. Anstalt für das forstliche Versuchswesen, Birmensdorf

Eckmeier E, Egli M, Schmidt MWI, Schlumpf N, Nötzli M, Minikus-Stary N, Hagedorn F (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. doi:http://dx.doi.org/10.1016/j.geoderma.2010.07.006

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

Etzold S, Helfenstein J, Thimonier A, Schmitt M, Waldner P (2014) Final Report: The role of the forest understory within the forest nutrient and carbon cycle of LWF sites. 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) (2020) Switzerland's Greenhouse Gas Inventory 1990–2018. National Inventory Report including reporting elements under the Kyoto Protocol. Submission of April 2020 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

Freschet GT et al. (2013) Linking litter decomposition of above- and below-ground organs to plant–soil feedbacks worldwide. Journal of Ecology 101:943-952. doi:10.1111/1365-2745.12092

Gao Y, Cheng J, Ma Z, Zhao Y, Su J (2014) Carbon storage in biomass, litter, and soil of different plantations in a semiarid temperate region of northwest China. Annals of Forest Science 71:427-435. doi:10.1007/s13595-013-0355-z

Ginzler C, Brändli U-B, Hägeli M (2011) Waldflächenentwicklung der letzten 120 Jahre in der Schweiz. Schweizerische Zeitschrift fur Forstwesen 162:337-343. doi:10.3188/szf.2011.0337

Herold A, Zell J, Rohner B, Didion M, Thürig E, Rösler E (2019) State and Change of Forest Resources. In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Managing Forest Ecosystems, vol 35. Springer International Publishing, Cham, pp 205-230. doi:10.1007/978-3-030-19293-8_12

Hoffmann U, Hoffmann T, Jurasinski G, Glatzel S, Kuhn NJ (2014) Assessing the spatial variability of soil organic carbon stocks in an alpine setting (Grindelwald, Swiss Alps). Geoderma 232-234:270-283. doi:https://doi.org/10.1016/j.geoderma.2014.04.038

IPCC (2006) 2006 IPCC Guidelines for National Greenhouse Gas Inventories Volume 4 Agriculture, Forestry and Other Land Use. Available at: http://www.ipcc-nggip.iges.or.jp/public/2006gl/vol4.html. IGES, Japan

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

Lanz A, Fischer C, Abegg M (2019) Sampling Design and Estimation Procedures. In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Springer International Publishing, Cham, pp 39-92. doi:10.1007/978-3-030-19293-8_2

Lehtonen A, Heikkinen J (2015) Uncertainty of upland soil carbon sink estimate for Finland. Canadian Journal of Forest Research:1-13. doi:10.1139/cjfr-2015-0171

Lehtonen A, Heikkinen J (2016) Uncertainty of upland soil carbon sink estimate for Finland. Canadian Journal of Forest Research 46:310-322. doi:10.1139/cjfr-2015-0171

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

MeteoSwiss (Federal Office of Meteorology and Climatology) (2016a) Monthly and Yearly Mean Temperature: TabsM and TabsY. Federal Office of Meteorology and Climatology MeteoSwiss, Zurich. avl. online at https://www.meteoswiss.admin.ch/content/dam/meteoswiss/de/service-und-publikationen/produkt/raeumliche-daten-temperatur/doc/ProdDoc_TabsM.pdf

MeteoSwiss (Federal Office of Meteorology and Climatology) (2016b) Monthly and Yearly Precipitation: RhiresM and RhiresY. Federal Office of Meteorology and Climatology MeteoSwiss, Zurich. avl. online at https://www.meteoswiss.admin.ch/content/dam/meteoswiss/de/service-und-publikationen/produkt/raeumliche-daten-niederschlag/doc/ProdDoc_RhiresM.pdf

MeteoSwiss (Federal Office of Meteorology and Climatology) (2020) Spatial Climate Analyses. https://www.meteoswiss.admin.ch/home/climate/swiss-climate-in-detail/raeumliche-klimaanalysen.html. Accessed 28.07. 2020

Moeri AC (2007) Kohlenstoffvorräte in Schweizer Waldböden unter besonderer Berücksichtigung der organischen Auflage. Universität Zürich

Norwegian Environment Agency (2019) Greenhouse Gas Emissions 1990-2017, National Inventory Report.

Nussbaum M, Papritz A, Baltensweiler A, Walthert L (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, Papritz A, Baltensweiler A, Walthert L (2014) Estimating soil organic carbon stocks of Swiss forest soils by robust external-drift kriging. Geosci Model Dev Discuss 6:7077-7116. doi:10.5194/gmdd-6-7077-2013

Peltoniemi M et al. (2007) Models in country scale carbon accounting of forest soils. Silva Fennica 41:575–602

Perruchoud D, Kienast F, Kaufmann E, Bräker OU (1999) 20th Century Carbon Budget of Forest Soils in the Alps. Ecosystems 2:320-337

R Core Team (2018) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Rantakari M et al. (2012) The Yasso07 soil carbon model – Testing against repeated soil carbon inventory. Forest Ecology and Management 286:137-147. doi:10.1016/j.foreco.2012.08.041

Rohner B, Fischer C, Herold A, Rösler E (2019) Assortments. In: Fischer C, Traub B (eds) Swiss National Forest Inventory – Methods and Models of the Fourth Assessment. Managing Forest Ecosystems, vol 35. Springer International Publishing, Cham, pp 231-242. doi:10.1007/978-3-030-19293-8_14

Schlesinger WH (1990) Evidence from chronosequence studies for a low carbon-storage potential of soils. Nature 348:232-234

Statistics Finland (2019) Greenhouse gas emissions in Finland 1990-2017. National Inventory Report under the UNFCCC and the Kyoto Protocol. Statistics Finland,

Tuomi M, Laiho R, Repo A, Liski J (2011) Wood decomposition model for boreal forests. Ecological Modelling 222:709-718. doi:10.1016/j.ecolmodel.2010.10.025

Tuomi M et al. (2009) Leaf litter decomposition—Estimates of global variability based on Yasso07 model. Ecological Modelling 220:3362-3371. doi:10.1016/j.ecolmodel.2009.05.016

Wutzler T, Mund M (2007) Modelling mean above and below ground litter production based on yield tables. Silva Fennica 41:559-574

Wutzler T, Wirth C, Schumacher J (2008) Generic biomass functions for Common beech (Fagus sylvatica) in Central Europe: predictions and components of uncertainty. Canadian Journal of Forest Research 38:1661-1675. doi:10.1139/X07-194

Zanelli R, Egli M, Mirabella A, Abdelmoula M, Plötze M, Nötzli M (2006) `Black' soils in the southern Alps: clay mineral formation and transformation, X-ray amorphous Al phases and Fe forms. Clays and Clay Minerals 54:703-720. doi:10.1346/ccmn.2006.0540606

Zell J, Thürig E (2013) Root biomass functions for the GHG reporting under the UNFCCC and under the KP in Switzerland. Swiss Federal Institute for Forest, Snow and Landscape Research WSL,

Appendix I: Additional data

Table A-1. Number of NFI sample plots per subregion per NFI period in the category “productive forest CC12” as defined in the Swiss Greenhouse gas inventory (cf. Tab. 6-2 in FOEN 2020). Note that for the period NFI3-4/5 sample plots common to NFI3 and sample plots in NFI4 visited in the years 2015 to 2017 as well as sample plots common to NFI4 and NFI5 visited in the years 2018 and 2019 were considered.

Elevation class	NFI period	Production Region					Switzerland
		Jura	Plateau	Pre-Alps	Alps	Southern-Alps	
<601 m	NFI1-2	247	664	36	34	95	1076
	NFI2-3	247	665	35	39	96	1082
	NFI3-4/5	134	385	18	19	59	615
600 – 1200 m	NFI1-2	607	467	643	484	260	2461
	NFI2-3	612	470	642	485	265	2474
	NFI3-4/5	335	245	354	277	158	1369
>1200 m	NFI1-2	115	13	350	1155	286	1919
	NFI2-3	122	13	370	1207	313	2025
	NFI3-4/5	67	6	218	751	195	1237
Total	NFI1-2	969	1144	1029	1673	641	5456
	NFI2-3	981	1148	1047	1731	674	5581
	NFI3-4/5	536	636	590	1047	412	3221

References

FOEN (Federal Office for the Environment) (2020) Switzerland’s Greenhouse Gas Inventory 1990–2018. National Inventory Report including reporting elements under the Kyoto Protocol. Submission of April 2020 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

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

	Conifers	Broadleaves
Allometry[1]	11	11
Biomass Conversion and Turnover[2]	18	18
Carbon content[3]	0.35	0.25
Total[4]	21.1	21.1

[1] based on Berger, A., T. Gschwantner, R. E. McRoberts, and K. Schadauer. 2013. Effects of Measurement Errors on Individual Tree Stem Volume Estimates for the Austrian National Forest Inventory. Forest Science.

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

[3] 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.

[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. Mean annual temperature and precipitation sum of the norm-period 1981-2010 calculated from the plot-specific data within each region for NFI sample plots in the category "productive forest CC12" (N=5862) as defined in the Swiss Greenhouse gas inventory (cf. Tab. 6-2 in FOEN 2020). Source: MeteoSwiss (2016a; 2016b).

a) Temperature [°C]

		Production region					Switzerland
Elevation class		**Jura**	**Plateau**	**Pre-Alps**	**Alps**	**Southern Alps**	
<601 m	**Min**	7.8	7.3	6.6	7.1	6.6	6.5
	Mean	9.2	9.1	9.0	9.3	10.5	9.3
	Max	10.7	10.8	10.1	10.4	12.5	12.5
601-1200 m	**Min**	4.5	6.1	4.1	3.2	4.2	3.2
	Mean	7.4	8.4	7.0	7.0	8.2	7.5
	Max	10.2	10.1	10.0	10.1	11.9	11.9
>1200 m	**Min**	4.5	4.9	2.1	-1.2	-0.6	-1.2
	Mean	5.7	5.4	5.0	3.7	5.0	4.3
	Max	7.5	6.1	8.1	9.6	9.0	9.6
Total	**Min**	4.4	4.9	2.1	-1.2	-0.6	-1.2
	Mean	7.6	8.8	6.3	4.7	7.0	6.6
	Max	10.7	10.8	10.1	10.4	12.5	12.5

b) Precipitation sum [mm]

Elevation class		**Jura**	**Plateau**	**Pre-Alps**	**Alps**	**Southern Alps**	**Switzerland**
<601 m	**Min**	837	829	1060	643	1336	643
	Mean	1089	1095	1395	1141	1723	1163
	Max	1438	1889	1902	1700	2266	2357
601-1200 m	**Min**	907	920	1070	557	962	557
	Mean	1355	1257	1572	1267	1793	1423
	Max	1930	1879	2251	2229	2391	2524
>1200 m	**Min**	1278	1648	1228	497	915	497
	Mean	1727	1911	1774	1220	1713	1429
	Max	2116	2129	2408	2237	2401	2596
Total	**Min**	837	829	1041	496	915	496
	Mean	1336	1171	1638	1231	1745	1376
	Max	2118	2129	2408	2257	2422	2608

References

FOEN (Federal Office for the Environment) (2020) Switzerland's Greenhouse Gas Inventory 1990–2018. National Inventory Report including reporting elements under the Kyoto Protocol. Submission of April 2020 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

MeteoSwiss (Federal Office of Meteorology and Climatology). 2016a. Monthly and Yearly Mean Temperature: TabsM and TabsY. Federal Office of Meteorology and Climatology MeteoSwiss, Zurich.

MeteoSwiss (Federal Office of Meteorology and Climatology). 2016b. Monthly and Yearly Precipitation: RhiresM and RhiresY. Federal Office of Meteorology and Climatology MeteoSwiss, Zurich.

Table A-4. 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

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

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.

Appendix II: Data prepared for Switzerland's GHGI 2021 (1990-2019)

Table A-5. List of result tables that were included in the data delivery from 31.07.2020. The associated Excel file presents the relevant data based on averaged annual stocks and stock changes.

Table	Table name	Content
A-6	Annual C stock change [Mg C $ha^{-1}a^{-1}$]	Mean CWD pool stock change
A-7		Mean LFH pool stock change
A-8		Mean Soil pool stock change
A-9		Mean stock change for ALL pools
A-10		Standard error CWD pool stock change
A-11		Standard error LFH pool stock change
A-12		Standard error Soil pool stock change
A-13		Standard error stock change for ALL pools
A-14	Annual C stock [Mg C ha^{-1}]	Mean CWD pool stock
A-15		Mean LFH pool stock
A-16		Standard error CWD pool stock
A-17		Standard error LFH pool stock

NOTE:
1) The following strata were combined due to a low number of sites in NFI3-4; for time series consistency the strata were combined for the complete time series: a) elevation classes 601-1200m and >1200m in production region 2 'Central Plateau'; b) elevation classes <601m and 601-1200m in production region 3 'Pre-Alps; and c) elevation classes <601m and 601-1200m in production region 4 'Alps (cf. ch. 6.4.2.2 in FOEN 2020).
2) Table values were rounded to 6 decimal places.
3) Negative values for CSC indicate a C sink, positive values a C source.

References

FOEN (Federal Office for the Environment) (2020) Switzerland's Greenhouse Gas Inventory 1990–2018. National Inventory Report including reporting elements under the Kyoto Protocol. Submission of April 2020 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

Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse dead wood prepared for the Swiss NIR 2022 (GHGI 1990–2020)

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Supplement 1 to the report Didion (2020a): “Data on soil carbon stock change, carbon stock and stock change in surface litter and in coarse dead wood prepared for the Swiss NIR 2021 (GHGI 1990–2019)”

18 June 2021

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Commissioned by the Federal Office for the Environment FOEN

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 National Inventory Report (NIR) 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 Since the previous submission (Didion 2020; FOEN 2021), no methodological changes were implemented and no new NFI data were available. Compared to Didion (2020), the time series of C stock and CSC was extended with estimates for the year 2020 by simulations based on measured climate data for 2020 keeping all other parameters constant. This document is an abbreviated version of previous reports presenting only the data for the inventory year 2020. The complete set of result tables of C stock and CSC that were prepared for the Swiss GHGI 2022 (1990-2020) can be found in Appendix I. Detailed information is available in Didion (2020) on the consistency with IPCC reporting criteria (section 1.1), the methodology (section 2) including verification, and the uncertainty of the estimates (section 3.1.4).

The total CSC in dead wood, litter, and mineral soil in Swiss forests from 2019 to 2020 was a loss of -0.065 ±0.004 (2SE) Mg C ha^{-1} a^{-1} (Total for Switzerland in Table 1, changeCall in Figure 1). This corresponds to an increased loss compared to the national mean CSC in 2018/2019 (-0.008 ±0.004 (2SE) Mg C ha^{-1} a^{-1}), which was primarily due to the increased losses in the litter pool that could not be compensated by the gains in the dead wood pool.

The dead wood pool gained C in 2019/2020, i.e.0.012 ± 0.002 Mg C ha^{-1} a^{-1} (changeCd in Figure 1). Compared to the previous GHGI, this presents a decrease in the C gain from 0.027 ± 0.002 Mg C ha^{-1} a^{-1} in 2018/2019. This difference can be explained by the continuing decrease of the large dead wood pool that accumulated as a result of the storm Lothar in 1999 (see Didion 2020). The pool is however still a sink since due to decreased harvest rates in the period NFI3-4/5 compared to the previous period NFI23, more dead wood is available as fewer trees are removed from the forest.

The CSC in the litter pool in 2019/2020 constituted a loss of -0.080 ± 0.001 Mg C ha^{-1} a^{-1} (changeCh in Figure 1). This value is corresponds to a doubling of losses compared to 2018/2019 (- 0.037 ± 0.001 Mg C $ha^{-1}a^{-1}$). The cause for this result is the more favorable climate in 2020 compared to 2019 with higher temperature and still sufficient moisture (Figure 5), which increased the decomposition of the easily decomposable non-woody material (Aerts 1997).

Mineral forest soils continuously gained in C at a comparably moderate rate (0.003 ±0.000 Mg C ha^{-1} a^{-1} in 2019/2020; (changeCs_m in Figure 1). The change compared to the previous GHGI was statistically not significant (Figure 4) with less than 1 Kg C ha^{-1} a^{-1} difference in the means estimated for the change in 2018/2019. Also, this small difference is below the detection limit of measurements (e.g., Keller et al. 2006). The difference was the result of the changes in the dead wood and litter pools and their resulting C fluxes to the soil pool.

Table 1. Mean national total (sum of dead wood, litter and soil) carbon stock change ± 2 standard errors in 2019/2020 for productive forest (CC12; see ch. 6.4.1 in FOEN 2021) stratified into 3 elevation classes and 5 NFI-production regions. Negative values C losses, positive values C gains.

NFI	**elevation**	**Net change** [t C ha^{-1} yr^{-1}]			
		2018/2019		2019/2020	
1	1	-0.030	±0.007	-0.075	±0.014
1	2	0.047	±0.005	-0.049	±0.010
1	3	0.081	±0.011	-0.020	±0.021
2	1	-0.054	±0.005	-0.095	±0.010
2	2	-0.042	±0.007	-0.139	±0.013
2	3	-0.042	±0.007	-0.139	±0.013
3	1	0.004	±0.007	-0.122	±0.015
3	2	0.004	±0.007	-0.122	±0.015
3	3	-0.038	±0.007	-0.129	±0.014
4	1	0.049	±0.006	-0.015	±0.012
4	2	0.049	±0.006	-0.015	±0.012
4	3	-0.028	±0.004	-0.055	±0.009
5	1	-0.007	±0.007	0.011	±0.015
5	2	-0.003	±0.004	0.018	±0.008
5	3	0.020	±0.006	0.022	±0.013
Switzerland		-0.008	±0.002	-0.065	±0.004

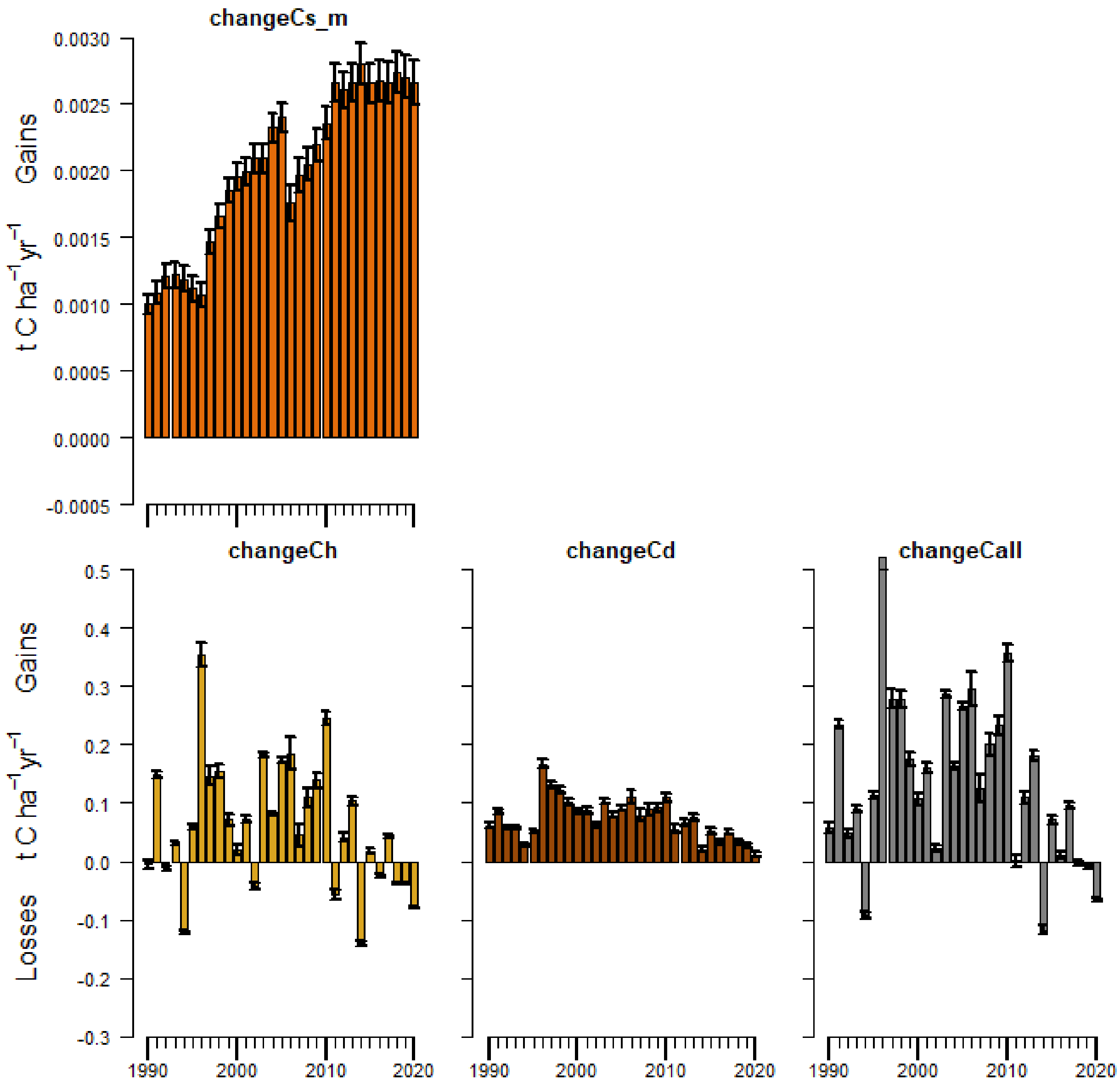

Figure 1. National mean carbon stock change since 1990 for three pools soil (changeCs_m), litter (changeCh), dead wood (changeCd) and their sum (changeCall) in t C ha^{-1} (equals Mg C ha^{-1}). Note the difference of the y-axis scale between soil and litter, dead wood and the sum, respectively. Negative values indicate C losses, positive values C gains. The error bars indicate the standard error (2SE).

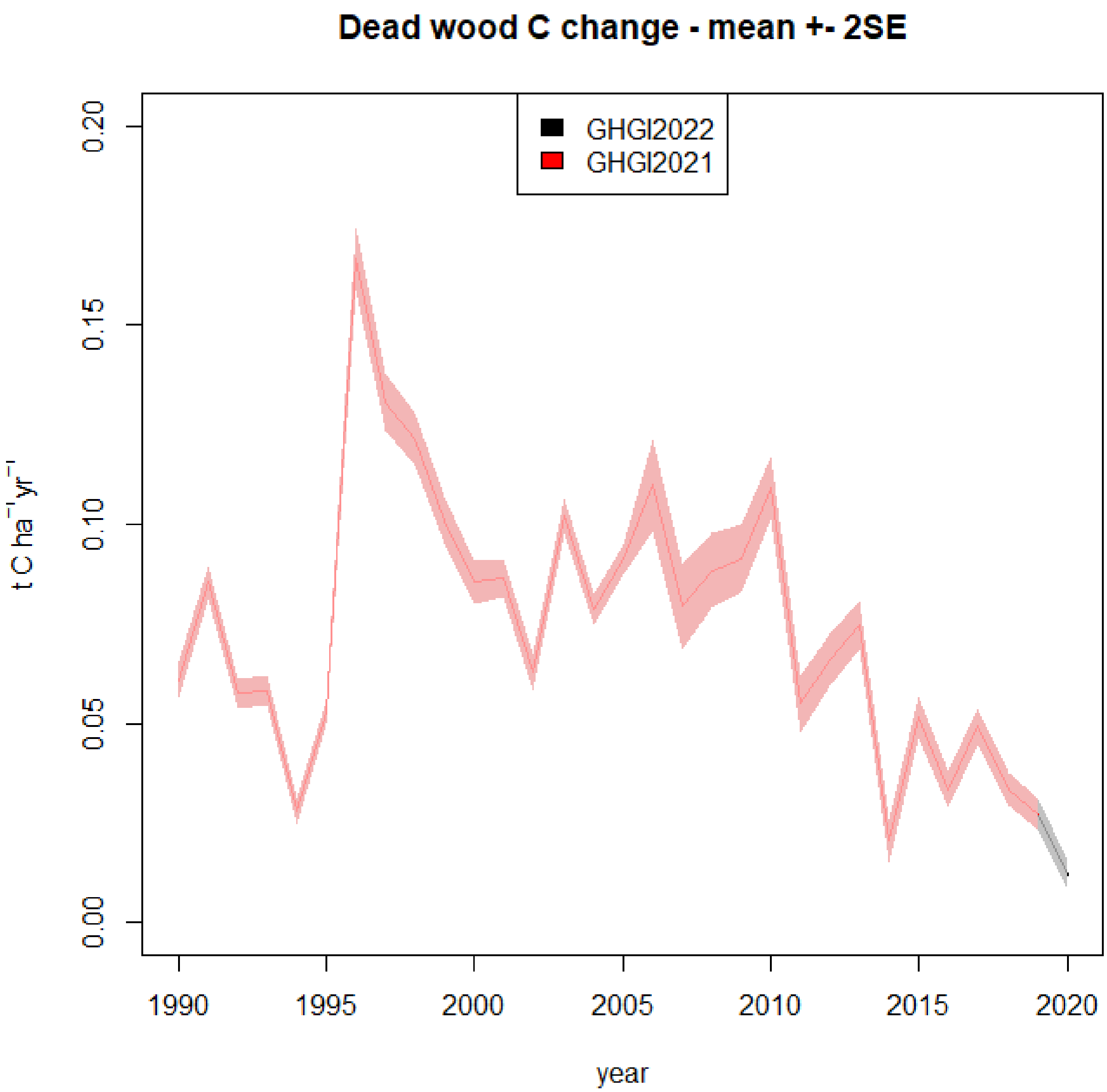

Figure 2. Time series of mean annual C stock change in the dead wood pool estimated for the GHGIs 2021 and 2022.Shaded areas indicate 2 SE of the mean. Note that there was no change in the time series 1990-2019.

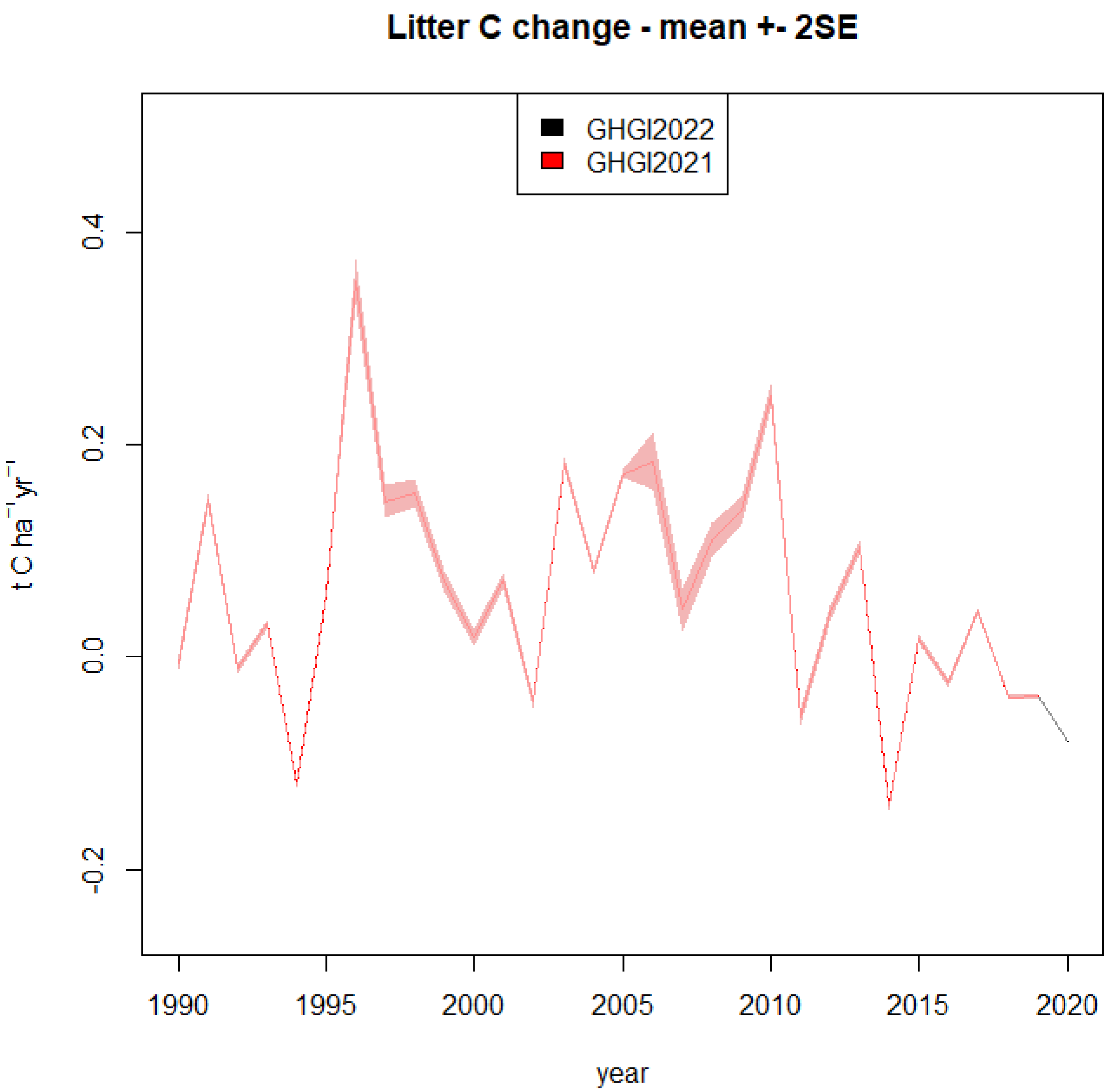

Figure 3. Time series of mean annual C stock change in the litter pool estimated for the GHGIs 2021 and 2022.Shaded areas indicate 2 SE of the mean. Note that there was no change in the time series 1990-2019.

Figure 4. Time series of mean annual C stock change in the mineral soil pool estimated for the GHGIs 2021 and 2022.Shaded areas indicate 2 SE of the mean. Note that there was no change in the time series 1990-2019.

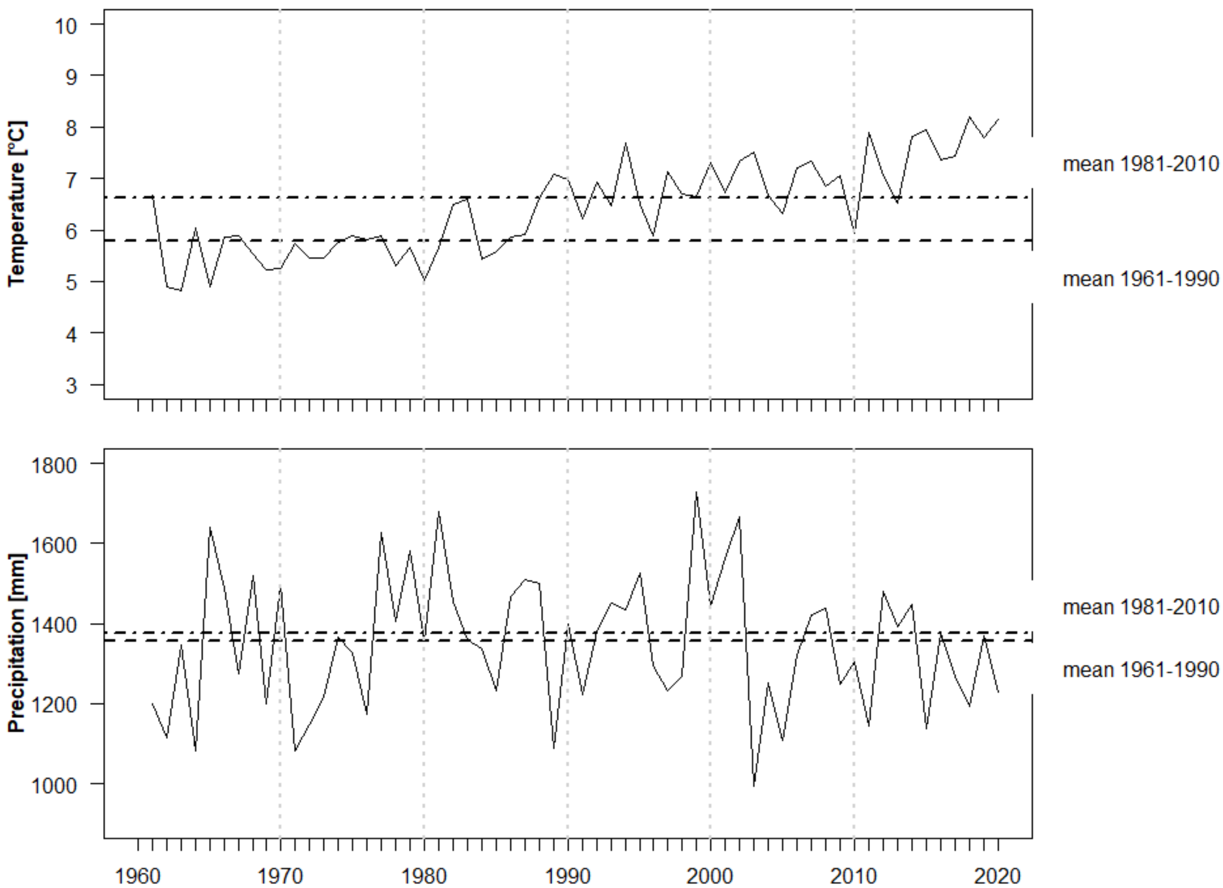

Figure 5. Annual means of temperature and precipitation sums since 1961 for all NFI sample plots classified as productive forest in any of the three NFI periods (N=5862). The long-term means of the norm periods 1961-1990 and 1981-2010 are indicated by the horizontal lines.

Acknowledgements

I am grateful to Nele Rogiers at FOEN for valuable discussions and comments on this report. The NFI team at WSL and in particular Erik Roesler is acknowledged for data collection, data base management and general support with NFI data-related questions.

References

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Appendix I: Data prepared for Switzerland's GHGI 2022 (1990-2020)

Table A-1. List of result tables that were included in the data delivery from 18.06.2021. The associated Excel file presents the relevant data based on averaged annual stocks and stock changes.

Table	Table name	Content
A-6	Annual C stock change [Mg C $ha^{-1}a^{-1}$]	Mean CWD pool stock change
A-7		Mean LFH pool stock change
A-8		Mean Soil pool stock change
A-9		Mean stock change for ALL pools
A-10		Standard error CWD pool stock change
A-11		Standard error LFH pool stock change
A-12		Standard error Soil pool stock change
A-13		Standard error stock change for ALL pools
A-14	Annual C stock [Mg C ha^{-1}]	Mean CWD pool stock
A-15		Mean LFH pool stock
A-16		Standard error CWD pool stock
A-17		Standard error LFH pool stock

NOTE:
1) The following strata were combined due to a low number of sites in NFI3-4; for time series consistency the strata were combined for the complete time series: a) elevation classes 601-1200m and >1200m in production region 2 'Central Plateau'; b) elevation classes <601m and 601-1200m in production region 3 'Pre-Alps; and c) elevation classes <601m and 601-1200m in production region 4 'Alps (cf. ch. 6.4.2.2 in FOEN 2021).
2) Table values were rounded to 6 decimal places.
3) Negative values for CSC indicate a C sink, positive values a C source.

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02 June 2022

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In an effort to improve Switzerland's GHG accounting with regard to the criteria for transparency, consistency, comparability, completeness and accuracy Since the NIR submission 2021 (Didion 2020; FOEN 2021), no methodological changes were implemented and no new NFI data were available. Compared to the data in supplement 1 for the NIR submission 2022 in Didion (2020), the time series of C stock and CSC was extended with estimates for the year 2021 by simulations based on measured climate data for 2021 keeping all other parameters constant. This document thus presents only the data for the inventory year 2021. The complete set of result tables of C stock and CSC that were prepared for the Swiss GHGI 2023 (1990-2021) can be found in Appendix I. Detailed information is available in Didion (2020) on the consistency with IPCC reporting criteria (section 1.1), the methodology (section 2) including verification, and the uncertainty of the estimates (section 3.1.4).

The total CSC in dead wood, litter, and mineral soil in Swiss forests from 2020 to 2021 was a gain of -0.105 ±0.004 (2SE) Mg C ha^{-1} a^{-1} (Total for Switzerland in Table 1, changeCall in Figure 1). The change to a gain compared to the loss in the national mean CSC in 2019/2020 (-0.065 ±0.004 (2SE) Mg C ha^{-1} a^{-1}), was primarily due to the cooler weather in 2021 (Figure 2; MeteoSwiss 2022) reducing the decay rate (Aerts 1997; Bani et al. 2018).

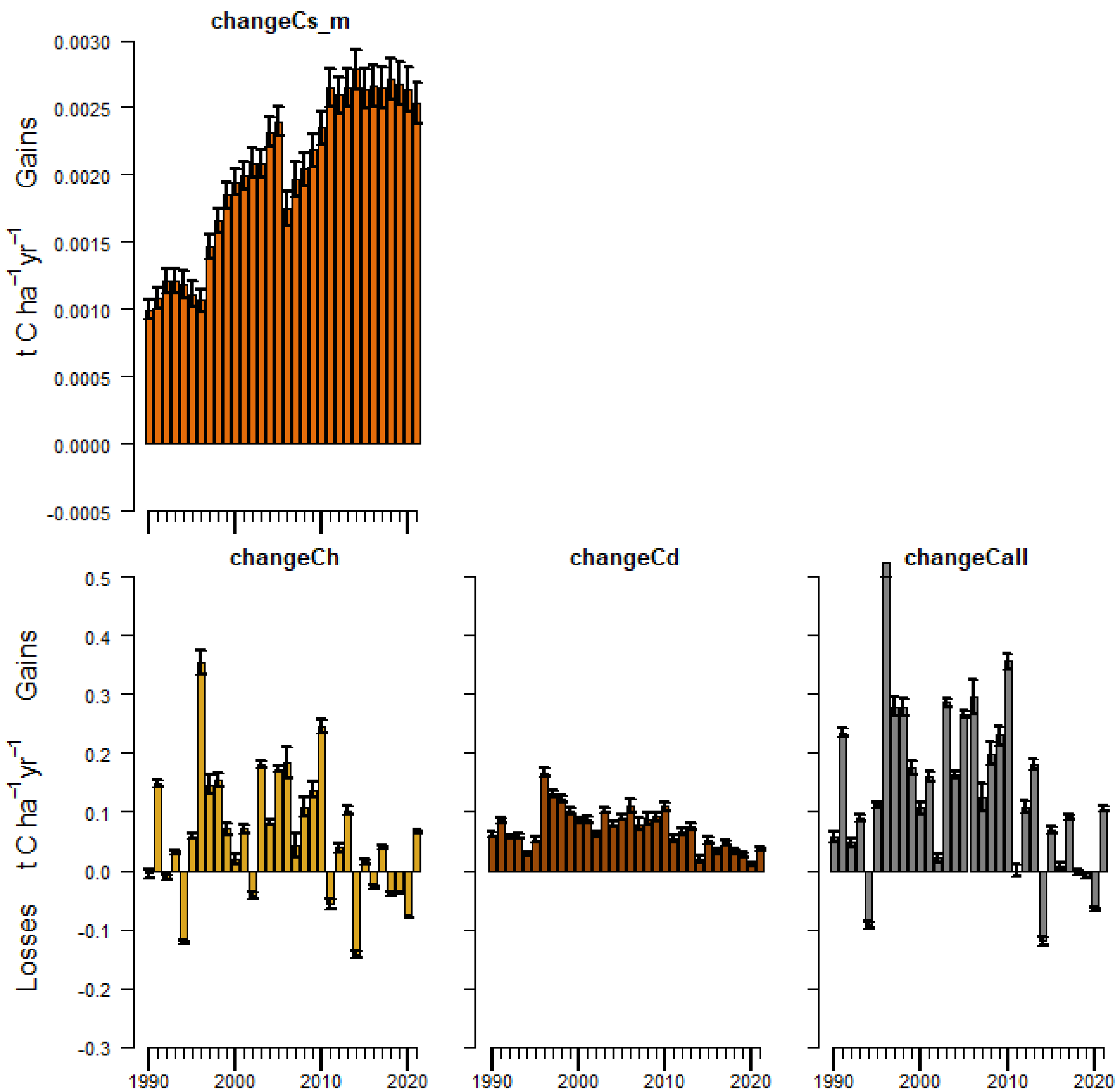
The dead wood pool gained C in 2020/2021, i.e.0.037 ± 0.003 Mg C ha^{-1} a^{-1} (changeCd in Figure 1 and time series Fig. 3). Compared to the previous GHGI, this presents an increase in the C gain from 0.012 ± 0.003 Mg C ha^{-1} a^{-1} in 2019/2020.

The CSC in the litter pool in 2020/2021 constituted a gain of 0.066 ± 0.002 Mg C ha^{-1} a^{-1} (changeCh in Figure 1 and time series Fig. 4). In 2019/2020, the litter pool was a net source with losses of - 0.080 ± 0.001 Mg C $ha^{-1}a^{-1}$. The easily decomposable non-woody material responds stronger to changes in environmental conditions and was more affected by the less favorable weather that caused a reduced decay rate.

Mineral forest soils continuously gained in C at a comparably moderate rate (0.003 ±0.000 Mg C ha^{-1} a^{-1} in 2020/2021; **(**changeCs_m in Figure 1 and time series Fig. 5). The change compared to the previous GHGI was statistically not significant (Figure 5) with less than 1 Kg C ha^{-1} a^{-1} difference in the means estimated for the change in 2019/2020. Also, this small difference is below the detection limit of measurements (e.g., Keller et al. 2006).

Table 1. Mean national total (sum of dead wood, litter and soil) carbon stock change ± 2 standard errors in 2019/2020 and 2020/2021 for productive forest (CC12; see ch. 6.4.1 in FOEN 2021) stratified into 3 elevation classes and 5 NFI-production regions. Negative values C losses, positive values C gains.

NFI	**elevation**	**Net change** [t C ha^{-1} yr^{-1}]			
		2019/2020		2020/2021	
1	1	-0.075	±0.014	-0.055	±0.013
1	2	-0.049	±0.010	-0.019	±0.010
1	3	-0.020	±0.021	0.134	±0.015
2	1	-0.095	±0.010	0.163	±0.013
2	2	-0.139	±0.013	0.073	±0.015
2	3	-0.139	±0.013	0.116	±0.007
3	1	-0.122	±0.015	0.023	±0.011
3	2	-0.122	±0.015	0.134	±0.014
3	3	-0.129	±0.014	0.163	±0.015
4	1	-0.015	±0.012	0.120	±0.013
4	2	-0.015	±0.012	0.178	±0.010
4	3	-0.055	±0.009	0.023	±0.006
5	1	0.011	±0.015	0.105	±0.024
5	2	0.018	±0.008	0.160	±0.014
5	3	0.022	±0.013	0.173	±0.015
Switzerland		-0.065	±0.004	0.105	±0.004



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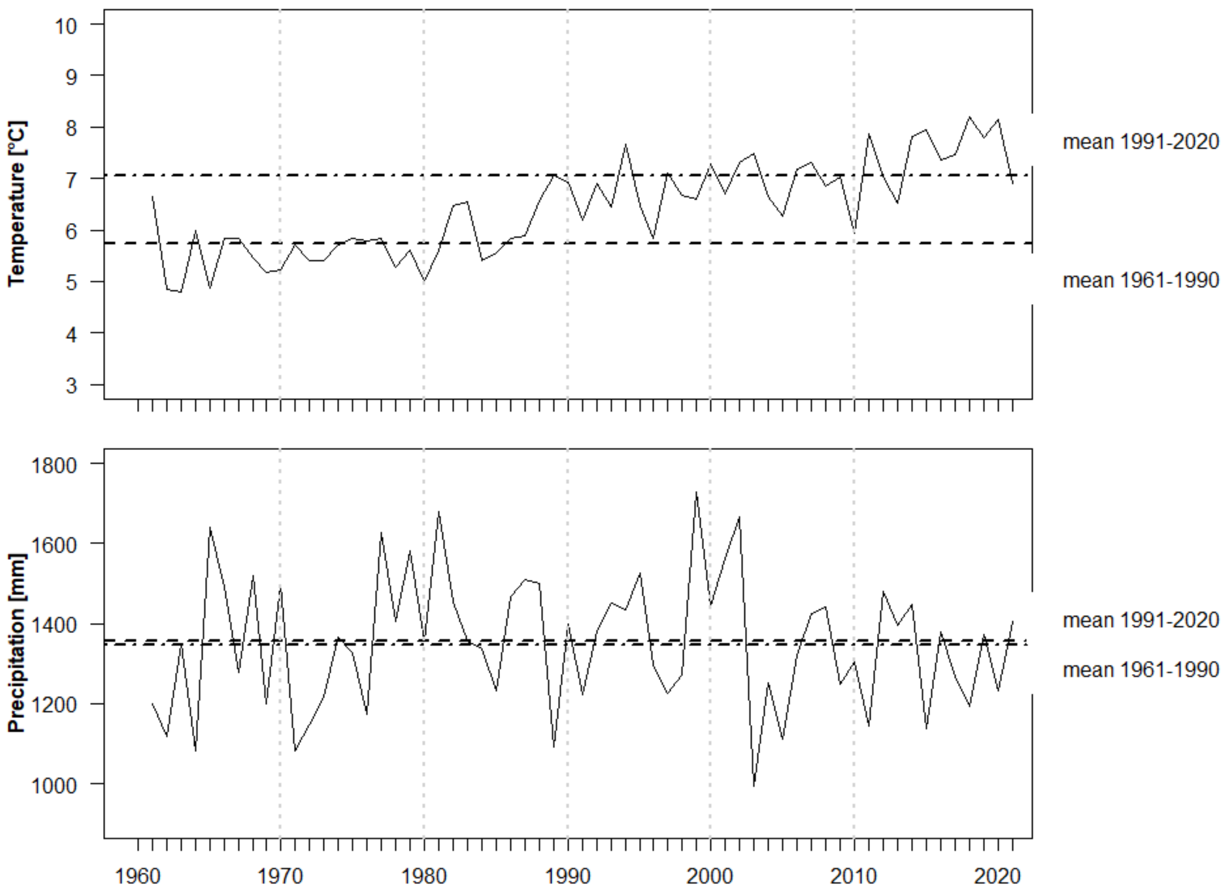

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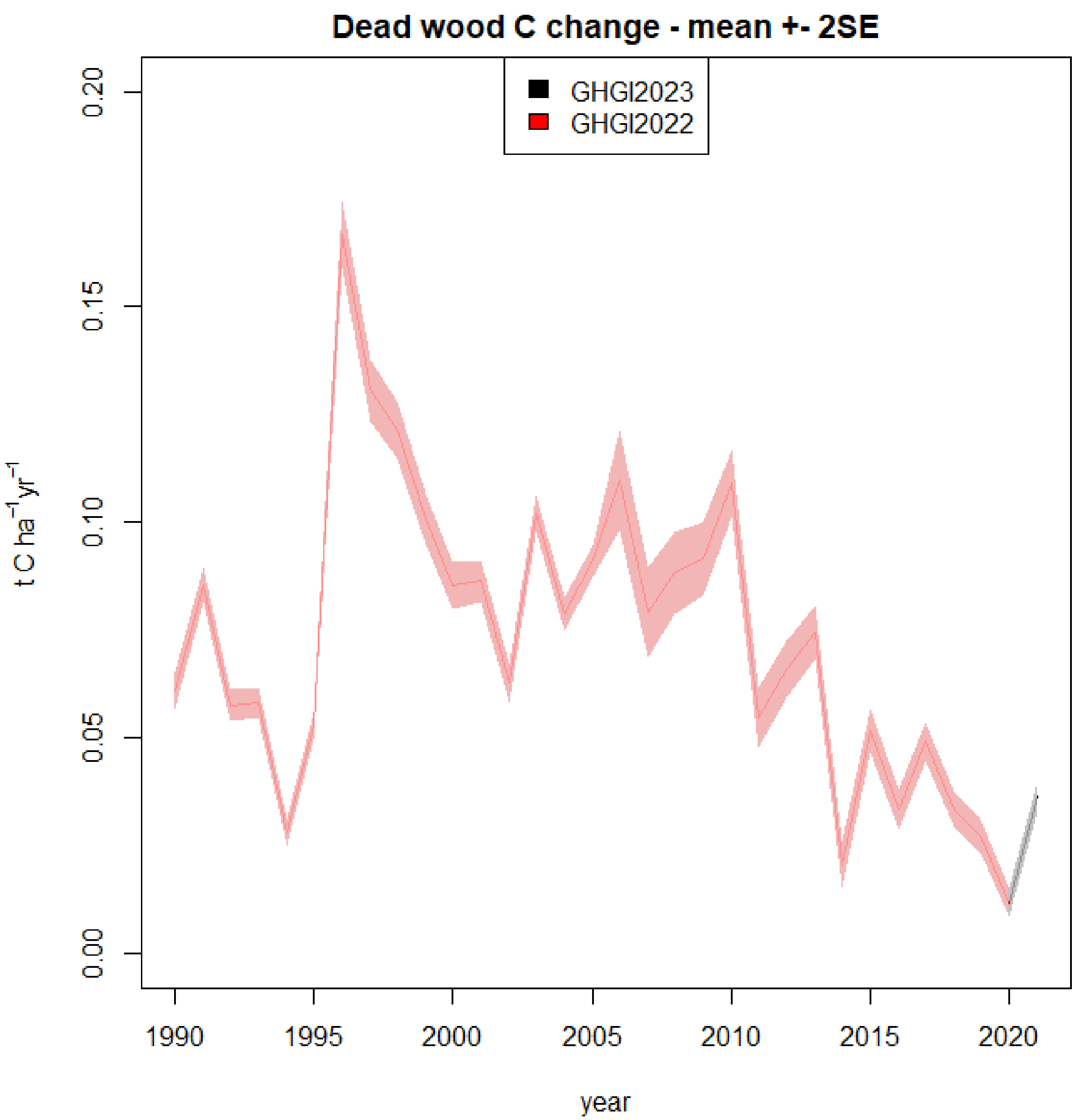

Figure 3. Time series of mean annual C stock change in the dead wood pool estimated for the GHGIs 2022 and 2023. Negative values indicate C losses, positive values C gains. Shaded areas indicate 2 SE of the mean. Note that there was no change in the time series 1990-2020.

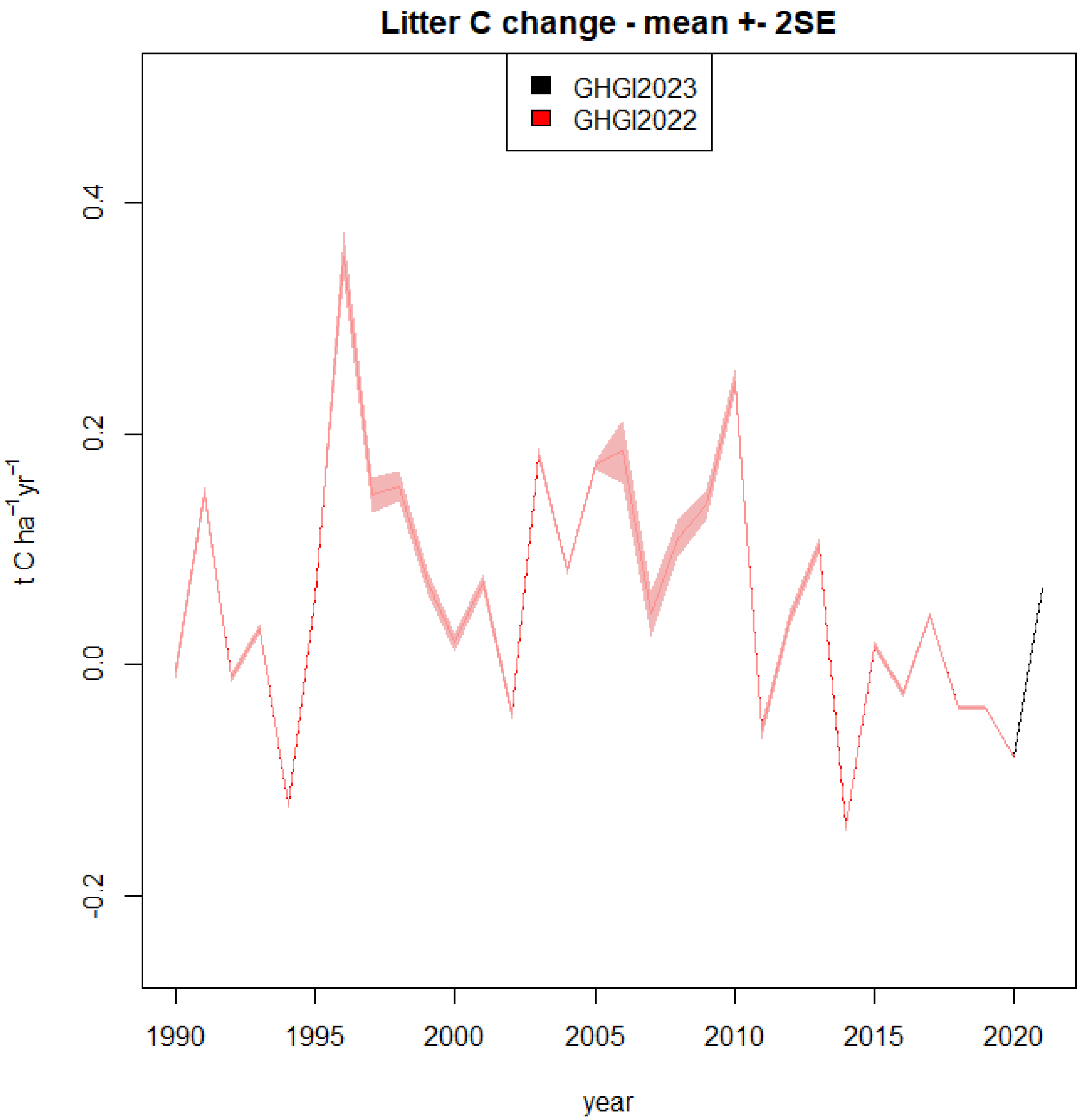

Figure 4. Time series of mean annual C stock change in the litter pool estimated for the GHGIs 2022 and 2023. Negative values indicate C losses, positive values C gains. Shaded areas indicate 2 SE of the mean. Note that there was no change in the time series 1990-2020.

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Bani A et al. (2018) The role of microbial community in the decomposition of leaf litter and deadwood. Applied Soil Ecology 126:75-84. doi:https://doi.org/10.1016/j.apsoil.2018.02.017

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MeteoSwiss (Federal Office of Meteorology and Climatology) (2022) Klimabulletin Jahr 2021. Zürich

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