Additional task to NFI 4 module: WSL contribution to the Swiss GHG and Kyoto Tables focused on carbon gains and losses in Swiss forests.

Non-forest areas converted to forest: standing stock, gains and losses in biomass

20.04.2015

Prepared by Esther Thürig and Berthold Traub

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

Commissioned by the Federal Office for the Environment FOEN

Swiss Federal Institute for Forest,
Snow and Landscape Research WSL

Summary

The Swiss National Forest Inventory (NFI) is the basis for calculating living biomass and its changes over time. Until now, the NFI data were not specifically analyzed for biomass stock, gains and losses of forest areas recently converted to forest. Natural forest regeneration due to abandonment of land is not considered to be a direct human-induced activity. In this study, NFI plots representative for 1) natural regenerations and 2) plantations or young forests were selected. Young forests were defined as stands with at least 85% of trees holding a dbh of maximum 20 cm. Based on single tree biomass estimates, standing stock, gains and losses of those stands were calculated and compared with international values. Swiss values of gains for young forests are well in the range of the IPCC default values for average annual increment in stands that were regenerated less than 20 years ago. They are also in the range of the Austrian emission factors for gains in afforested and reforested areas. The German factor for gains in afforested areas is slightly larger. This supports the plausibility of the Swiss estimates for standing stock and gains in natural regenerations, afforestations and young forests.

1 Introduction

Switzerland has committed to report carbon stocks, gains and losses of biomass in its annual greenhouse gas inventory (GHGI) to the United Nations Framework Convention on Climate Change (UNFCCC). Moreover, Switzerland decided to account forest management in the first commitment period of the Kyoto Protocol (FOEN 2006).

International guidelines claim the application, validation and description of best available data and methods (IPCC 2003, IPCC 2006). The Guidelines also ask for continuous improvement of the reporting due to expert review. IPCC (2003) defines afforestation as land-use change from non-forest to forest. Afforestation can be caused either by natural regeneration or by plantation. Default emission factors given by IPCC (2003) differ for those two types of afforestation.

The National Forest Inventory (NFI) is the basis for calculating living biomass and its changes over time (Brändli 2010, Abegg 2014). Until now, the NFI data were not specifically analyzed for biomass stock, gains and losses of forest areas recently converted to forest. NFI forest plots suitable to analyze stock and gains of afforested areas must be non-forest in the first inventory cycle and forest remaining forest in two succeeding inventories. Therefore, at least three repeated NFIs are necessary to estimate gains and losses in recently afforested areas.

In Switzerland, land-use change from non-forest to forest is usually not caused by plantation but by abandonment of agricultural land-use (Rutherford et al. 2008). It falls into the category of natural regeneration and is therefore not counted under Article 3, paragraph 3 of the Kyoto Protocol. These newly forested areas are often characterized by continuously growing trees with a large diversity in diameter at breast height (dbh) and tree age. Afforested stands established by plantation or even-aged young forest stands, however, are more characterized by a large amount of trees in small dbh classes and non or only very view trees in large dbh classes. In this study, NFI plots were selected to represent both types of afforestation.

The aim of this study is to 1) select all NFI plots recently converted to forest that where re-inventoried at least once, 2) extract all plots representative for plantations and young forest, 3) estimate standing stock, gains and losses from the first and the second selection of plots, and 4) compare the results of this study with default factors of IPCC and international estimates of standing stock, gains and losses for afforested areas.

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

The report addresses the criteria for transparency, consistency, comparability, completeness and accuracy (TCCCA):

Transparency is achieved by detailing the various data sets that were used and by providing relevant references. The methodology is described to ensure that results can be reproduced. See methods section.

Consistency is obtained by relying on data sources that are measured and maintained in a consistent manner (Swiss NFI) and that will be available in the future (regulated by law). It was ensured that the methods were applied consistently and that results are reported correspondingly. See methods section.

Comparability is achieved by comparing the results with IPCC default values and well comparable internationally reported values of Germany and Austria. See discussion section for international comparison.

Completeness is reached separately analyzing all forest plots converted to forest and only a selection of plots representative for plantations and even-aged young forests. See results section and discussion.

Accuracy is obtained by employing reliable and accurate data. All results were compared with international data and differences were identified and discussed. See discussion section.

2 Methods

In Switzerland, standing stock, gains and losses of forest biomass was derived from individual-trees measured in the National Forest Inventories (NFI) 1 to 4. The first NFI was conducted from 1983 to 1985, NFI 2 from 1993 to 1995, NFI 3 from 2004 to 2006 (Brändli 2010) and NFI 4b from 2009 to 2013 (Abegg 2014). Biomass of all tree compartments (stem-wood over bark including stump, coarse and small branches, needles/leaves, and roots) were estimated based on established allometries for tree compartments (see Thürig and Herold 2013). Estimates for branches, foliage and roots were derived from tree diameter at breast height (dbh) only; for stem-wood over bark including stump also diameter at tree height 7 m (d7) and total tree height was required. Except for roots, the biomass functions were empirically derived from a large number of single tree data from Swiss forest sites (cf. references in Table 1). Gains and losses were also calculated from individual-trees (Thürig and Herold 2013).

Table 1 Allometric biomass functions applied to individual-trees, dependencies and literature.

Tree parts	Input parameter	Nr. of trees	Literature
Stem-wood over bark incl. stump	dbh, d7, tree height	12'000	Kaufmann et al. 2001
Coarse branches (>= 7 cm)	dbh	40'000	Kaufmann et al. 2001
Small branches (< 7 cm)	dbh	40'000	Kaufmann et al. 2001
Needles, Leaves	dbh	400	Perruchoud et al. 1999
Broadleaved Roots	dbh	443	Wutzler et al. 2008
Coniferous Roots	dbh	80	Zell and Thürig 2012

With the NFI 4b, four repeated NFIs are available to estimate emission factors for the Swiss GHGI. From those data, two different sets of repeated measurements could be distinguished. First, plots that were non-forest in the first NFI, and forest in NFI 2 and 3 and second, plots that were non-forest in the second NFI and forest in NFI 3 and 4b. All plots fulfilling at least one of the two conditions were used to calculate biomass in standing stock for the first and the second inventory, and gains and losses between the two measurements. Estimates were given separately for the first data series (non-forest in NFI 1, forest in NFI 2 and 3) and the second data series (non-forest in NFI 2, forest in NFI 3 and 4b). These estimates represent average values of biomass, gains and losses of areas that underwent a land-use change from non-forest to forest without differentiation of the state of the forests and the reasons that caused land-use change.

To estimate emission factors more representative for plantations and young forests, Swiss NFI plots dominated by thin trees were extracted. Young stands were defined as stands with at least 85% of the trees with a dbh smaller or equal to 20 cm. As there is almost no land-use change from non-forest to forest below 600 m above sea level (Abegg 2014), results were stratified for below 1200 m above sea level and above 1200 m. As a consequence of the plot selection, small losses caused by natural mortality or cut of single trees may occur.

3 Results

3.1 All plots converted to forest

Emission factors for biomass, gains and losses for all forest plots converted to forest are presented in Table 2 and Table 3. Table 2 contains the results for all NFI plots that were non-forest in the NFI 1 and forest in NFI 2 and 3. Table 3 contains the results for all NFI plots that were non-forest in NFI 2 and forest in NFI 3 and 4. These results may serve as general emission factors for stock, gains and losses in living biomass for land-use changes from non-forest to forest land. However, the variability shown as simple standard error is very large. This large variation requires caution in applying the estimates for reporting purposes. Moreover, as the estimates contain all plots changing land use from non-forest to forest, they do not exactly represent plantations or young forests. The obtained estimates can, however, be used as indicative values for afforestations in Switzerland, which can be used for reporting or verification purposes.

Table 2 **All forest types: Non-forest in NFI 1, forest in NFI 2 and 3. General emission factors for stock, gains and losses in living biomass for land-use change from non-forest to forest ± one standard error, stratified for sea level and production region. Biomass 1 was measured in NFI 2, Biomass 2 was measured in NFI 3.**

Region	Altitude	N	Biomass 1		Biomass 2		Losses		Gains	
			t Biomass ha^{-1}	±	t Biomass ha^{-1}	±	t Biomass ha^{-1} a^{-1}	±	t Biomass ha^{-1} a^{-1}	±
Jura	≤1200	12	197	64	322	88	3.06	1.68	9.32	1.85
	>1201	8	75	10	122	22	0.39	0.37	4.83	1.55
	total	20	148	41	242	58	2.00	1.06	7.52	1.36
Plateau	≤1200	13	301	90	257	56	13.39	6.69	8.47	2.23
	>1201	0	.	.	.	.	.	.	.	.
	total	13	301	90	257	56	13.39	6.69	8.47	2.23
Pre-Alps	≤1200	8	219	106	217	80	8.50	7.58	7.58	1.97
	>1201	23	181	63	252	86	0.55	0.39	5.84	1.68
	total	31	191	54	243	67	2.61	2.08	6.29	1.35
Alps	≤1200	21	86	35	137	37	1.19	0.53	5.06	1.15
	>1201	80	67	9	98	10	0.83	0.29	3.23	0.40
	total	101	71	10	106	11	0.90	0.26	3.61	0.41
Southern Alps	≤1200	15	111	74	133	82	0.69	0.49	2.77	0.82
	>1201	31	67	11	89	12	0.17	0.11	2.01	0.35
	total	46	81	25	103	28	0.34	0.18	2.25	0.36
Switzerland	**≤1200**	**69**	**167**	**32**	**201**	**31**	**4.58**	**1.69**	**6.26**	**0.76**
	>1201	**142**	**86**	**12**	**123**	**16**	**0.61**	**0.18**	**3.48**	**0.39**
Total for Switzerland		211	113	14	148	15	1.92	0.58	4.40	0.37

Table 3 All forest types: Non-forest in NFI 2, forest in NFI 3 and 4b. General emission factors for stock, gains and losses in living biomass for land-use change from non-forest to forest ± one standard error, stratified for sea level and production region. Biomass 1 was measured in NFI 3, Biomass 2 was measured in NFI 4b.

Region	Altitude	N	Biomass 1		Biomass 2		Losses		Gains	
			t Biomass ha^{-1}	±	t Biomass ha^{-1}	±	t Biomass ha^{-1} a^{-1}	±	t Biomass ha^{-1} a^{-1}	±
Jura	≤1200	5	203	63	279	66	4.14	3.70	6.10	3.03
	>1201	2	98	28	122	27	0.00	.	1.78	0.52
	total	7	173	50	234	55	2.96	2.74	4.87	2.29
Plateau	≤1200	4	168	53	158	88	7.79	5.26	8.59	3.53
	>1201	0	.	.	.	.	.	.	.	.
	total	4	168	53	158	88	7.79	5.26	8.59	3.53
Pre-Alps	≤1200	6	194	73	222	81	0.26	0.17	3.58	1.90
	>1201	9	173	47	243	75	0.00	.	6.83	2.57
	total	15	181	41	235	55	0.10	0.08	5.53	1.77
Alps	≤1200	21	153	40	135	36	4.56	2.47	3.00	1.67
	>1201	69	53	9	62	11	0.25	0.15	1.99	0.44
	total	90	76	12	79	12	1.24	0.61	2.22	0.52
Southern Alps	≤1200	16	66	19	97	27	0.51	0.22	4.69	1.70
	>1201	34	40	6	51	9	0.19	0.14	1.96	0.60
	total	50	48	8	66	11	0.30	0.12	2.84	0.70
Switzerland	**≤1200**	**52**	**137**	**22**	**150**	**23**	**3.01**	**1.17**	**4.33**	**0.99**
	>1201	**114**	**60**	**8**	**74**	**10**	**0.21**	**0.10**	**2.37**	**0.40**
Total for Switzerland		166	84	9	98	10	1.09	0.39	2.98	0.42

3.3 Plots representative for plantations and young forests

In Table 4 and Table 5, NFI plots were selected to better represent dbh distributions of plantations and even-aged young forests. Plot restrictions were set to following thresholds: 85% of trees had to feature a dbh with maximum 20 cm. This threshold diminished the number of plots (N). To avoid stochastic estimates of mean and variance, the number of plots for an estimate should not fall below approximately 30 plots. Therefore, results are only displayed for Switzerland, above and below 1200 m above sea level, but not stratified for production regions.

Table 4 Only plots converted to young forest defined as at least 85% of trees with dbh <= 20 cm. Biomass stock, gains and losses ± one standard error, stratified for see level. Non-forest in NFI 1, forest in NFI 2 and 3. Biomass 1 was measured in NFI 2, Biomass 2 was measured in NFI 3.

Altitude	N	Biomass 1		Biomass 2		Losses		Gains	
		t Biomass ha^{-1}	±	t Biomass ha^{-1}	±	t Biomass ha^{-1} a^{-1}	±	t Biomass ha^{-1} a^{-1}	±
≤1200	14	15	3	62	13	0.47	0.16	4.60	1.04
>1201	26	18	5	69	15	0.10	0.06	4.17	0.96
Total for Switzerland	40	17	3	66	11	0.23	0.07	4.32	0.72

Table 5 Only plots converted to young forest defined as at least 85% of trees with dbh <= 20 cm. Biomass stock, gains and losses ± their standard error, stratified for see level. Non-forest in NFI 2, forest in NFI 3 and 4b. Biomass 1 was measured in NFI 3, Biomass 2 was measured in NFI 4b.

Altitude	N	Biomass 1		Biomass 2		Losses		Gains	
		t Biomass ha^{-1}	±	t Biomass ha^{-1}	±	t Biomass ha^{-1} a^{-1}	±	t Biomass ha^{-1} a^{-1}	±
≤1200	10	28	9	58	20	0.76	0.37	5.08	1.95
>1201	28	12	2	19	4	0.3	0.17	1.35	0.50
Total for Switzerland	38	16	3	29	7	0.42	0.16	2.33	0.69

To estimate biomass, gains and losses for all available plots simultaneously, the two series were combined in Table 6. For the combined estimates, standard error could not be estimated.

Table 6 Only plots converted to young forest defined as at least 85% of trees with dbh <= 20 cm. Biomass stock, gains and losses ± their standard error, stratified for see level. Non-forest in NFI 1 or 2, forest in NFI 2 and 3 or 3 and 4b.

Altitude	N	Biomass 1		Biomass 2		Losses		Gains	
		t Biomass ha^{-1}	±	t Biomass ha^{-1}	±	t Biomass ha^{-1} a^{-1}	±	t Biomass ha^{-1} a^{-1}	±
≤1200	24	20	4	60	12	0.42	0.11	4.77	1.03
>1201	54	15	3	43	8	0.2	0.09	2.7	0.56
Total for Switzerland	78	16	2	48	7	0.27	0.07	3.34	0.51

4 Discussion

For the analysis of standing stock, gains and losses, forest plots were stratified for above and below 1200 m above sea level. This stratification was chosen because of the dynamics of land-use change from non-forest to forest in Switzerland. These changes often happen due to abandonment of agricultural land use in alpine and subalpine zones. Below 600 m above sea level, almost no natural regeneration can be observed (Rutherford et al. 2008). To derive stratified measures of emission factors in afforestations, 1200 m above sea level is a meaningful stratification benchmark.

4.1 Comparison with international figures

Table 7 provides an overview of IPCC default factors and country specific estimates from neighboring countries.

Table 7 Comparison of Swiss estimates of gains of total carbon from the NFI (Table 6) with the current estimates in the Swiss NIR, the IPCC default values (see Table 8 in this report), and other countries. In the Swiss NIR, estimates are based on expert judgement.

Country	Description	Stratification	Gain total carbon (t C ha^{-1} a^{-1})
Switzerland	This study	<1201 m a.s.l.	2.4 ± 0.5
	This study	>1200 m a.s.l.	1.4 ± 0.3
Swiss NIR (FOEN 2015, Table 6-26)	Expert judgement	<601 m a.s.l.	1.63
	Expert judgement	601-1200m a.s.l.	1.09
	Expert judgement	>1200 m a.s.l.	0.57
IPCC (Table 8)	Temperate forests	Conifers	2.1
	Temperate forests	Broadleaved	2.8
	Boreal forests	Conifers	1.1
	Boreal forests	Broadleaved	1.0
Austrian NIR (Umweltbundesamt 2014)	Including plantation and natural regeneration	-	1.207
German NIR (UBA 2014, Table 348)	Afforestation and reforestation	-	1.8

IPCC default factors

Assuming a Tier 1 approach, the IPCC Guidelines for National Greenhouse Gas Inventories (IPCC 2006) and the IPCC Good Practice Guidance for LULUCF (IPCC 2003) give default factors for reporting gains and losses of aboveground biomass in case of land use change. For temperate forests, default values of IPCC (2006, Table 4.9) are referenced to IPCC (2003). For boreal forests, no default values are given in IPCC (2006) for deciduous trees. Therefore, default values were taken from IPCC (2003). With the IPCC (2006) default factors for root-shoot ratio (see Table 8), aboveground biomass can be converted to total living biomass as reported by Switzerland and other nations.

IPCC (2003) default values of average annual increment less than 20 years after natural regeneration in extensively managed forests (no plantation, no site preparation, no fertilization; Table 3.A.1.5) are shown in Table 7. For temperate forests, the IPCC (2003) default emission of average annual increment (=gains; 4.2-5.8 t ha^{-1} a^{-1} in total biomass) are well comparable with the Swiss the emission factors for change of non-forest to young forest or plantations below 1200 m (Table 4 to Table 6; 4.6-5.08 t ha^{-1} a^{-1} in total biomass). For boreal forests, the IPCC default emission of average annual increment (2.1 t ha-1 a-1 in total biomass) are comparable with the Swiss emission factors for

young-forests or plantations above 1200 m (1.35-4.17 t ha^{-1} a^{-1} in total biomass). This comparison shows that the Swiss emission factors representative for young forests and plantations vary a lot, but the average value over all inventories is well within the range of the IPCC (2003) default value.

Table 8 **IPCC default values of average annual increment less than 20 years after natural regeneration in extensively managed temperate forests (IPCC 2003; no plantation, no site preparation, no fertilization; Table 3.A.1.5). Root-shoot ratio was taken from IPCC (2006; Table 4.4). To estimate total carbon values, carbon fraction was taken from IPCC (2006; Table 4.3). Range of possible values in brackets.**

		Gain aboveground biomass	Root-shoot ratio (Table 3.A. 1.8)	Gain total biomass	Carbon fraction	Gain total carbon
		t ha^{-1} a^{-1}		t ha^{-1} a^{-1}	t C (t d.m.)$^{-1}$	t C ha^{-1} a^{-1}
Temperate forests						
	Coniferous	3 (0.5 – 6.0)	0.40 (0.21-1.06)	4.2	0.51 (0.47-0.55)	2.1
	Broadleaf	4 (0.5 – 8.0)	0.46 (0.12-0.93)	5.8	0.48 (0.46-0.50)	2.8
Boreal forests (Eurasia)						
	Coniferous	1.5 (-)	0.39 (0.23-0.96)	2.1	0.51 (0.47-0.55)	1.1
	Broadleaf	1.5 (1.0-2.0)	0.39 (0.23-0.96)	2.1	0.48 (0.46-0.50)	1.0

IPCC (2006) default factors for plantation are again much higher than the factors for natural regeneration. This is caused by site preparation, fertilization and fast growing species. In Switzerland, plantations are not performed with fast growing species. Moreover, fertilization is forbidden by law in all forest area. Default factors of IPCC (2006) for plantation are therefore much too high and cannot be applied in Switzerland.

Country specific factors

In the Austrian National Inventory Report (Umweltbundesamt 2014), the annual net C stock change in living biomass (dbh>0 cm) for afforested and reforested areas for 2008 to 2012 was 1.207 t C ha^{-1} a^{-1}. This value is almost the same compared to that used in previous submissions of Austria (1.176 t C ha^{-1} a^{-1}). Assuming a carbon content of 0.5 (IPCC 2003), this amounts to 2.4 t biomass ha^{-1} a^{-1}. There is no differentiation between plantation and natural regeneration in the Austrian National Inventory Report. The Austrian emission factor is in the range of the IPCC emission factor for boreal forests and the Swiss factor for areas above 1200 m. Austria decided that all land-use change from and to forests are considered to be direct human induced. Therefore, Austria accounts for natural regenerations under Article 3.3 of the Kyoto Protocol (Umweltbundesamt 2014).

In Germany, the emission factor for above- and belowground biomass for afforested and reforested areas was 3.6 t Biomass ha^{-1} a^{-1} (UBA 2014, Table 348) for the year 2011. This factor is larger than the factors from Austria, Switzerland, and the IPCC default value.

The comparison with IPCC and country-specific data supports the plausibility of the Swiss estimates for standing stock and gains in natural regenerations, afforestations and young forests.

5 Literature

Abegg, M., Speich, S., Brändli, U.-B., Lanz, A., Meile, R., Rösler, E., 2012. Fourth national forest inventory - Results of the NFI4 2009-2011 (LFI4a). Swiss Federal Institute for Forest, Snow and Landscape Research WSL, Birmensdorf.
http://www.lfi.ch/resultate/anleitung.php?lang=de
[10.04.2015]

Brändli, U.-B. (Red.) 2010. Schweizerisches Landesforstinventar. Ergebnisse der dritten Aufnahme 2004-2006. [Results of the third Swiss national forest inventory 2004-2006]. Eidgenössische Forschungsanstalt für Wald, Schnee und Landschaft, Birmensdorf. Bundesamt für Umwelt, Bern, 312 S. http://www.lfi.ch/publikationen/publ/lfi3.php?lang=de
[10.04.2015]

FOEN 2006. Switzerland's Initial Report under Article 7, paragraph 4 of the Kyoto Protocol. Federal Office for the Environment, Bern. Including the Update following the UNFCCC review (FCCC/IRR/2007/CHE).
http://www.bafu.admin.ch/climatereporting/03211/index.html?lang=en
[10.04.2015]

IPCC 2003. Good Practice Guidance for Land Use, Land-Use Change and Forestry (IPCC GPG LULUCF).
http://www.ipcc-nggip.iges.or.jp/public/gpglulucf/gpglulucf.htm
[10.04.2015]

IPCC 2006. 2006 IPCC Guidelines for National Greenhouse Gas Inventories. Intergovernmental Panel on Climate Change. http://www.ipcc-nggip.iges.or.jp/public/2006gl/index.htm
[10.04.2015]

Kaufmann E. 2001. Estimation of standing timber, growth and cut. In: Brassel, P.; Lischke, H. (eds) Swiss National Forest Inventory: Methods and Models of the Second Assessment. Birmensdorf, Swiss Federal Research Institute WSL. 162–196.

Perruchoud, D.; Kienast, F.; Kaufmann, E.; Bräker, O.U., 1999: 20th century carbon budget of forest soils in the Alps. Ecosystems 2: 320–337.

Rutherford, G. N., P. Bebi, P. J. Edwards, and N. E. Zimmermann. 2008. Assessing land-use statistics to model land cover change in a mountainous landscape in the European Alps. Ecological Modelling **212**:460-471.

Thürig E, Herold A. 2013. Recalculation of emission factors in Swiss forests for the Swiss GHGI. Internal documentation of technical adjustments of data delivery and more recent data. 10 pp.
http://www.bafu.admin.ch/climatereporting/00545/01913/index.html?lang=en
[10.04.2015]

Umweltbundesamt 2014. Anderl M, Freudenschuß A, Haider S et al. Austria‘s National Inventory Report 2014. Reports, Bd. REP-0475. Umweltbundesamt, Wien.

UBA 2014. Federal Environment Agency. National Inventory Report for the German Greenhouse Gas Inventory 1990 - 2012. Submission under the United Nations Framework Convention on Climate Change and the Kyoto Protocol 2014.

Wutzler T, Wirth C, Schumacher J. 2008. Generic biomass functions for common beech (Fagus sylvatica) in Central Europe: predictions and components of uncertainty. Can. J. For. Res. 38: 1661–1675.

Zell J, Thürig E. 2012. Root biomass functions for the GHG reporting under the UNFCCC and under the KP in Switzerland. Internal report. 12 p.