Application of the phytomass and elemental stock model "PhytoCalc" under clear-cut conditions

(With 1 Figure and 3 Tables)

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Kahlschlag; Elementvorrat; Bodenvegetation; Deckungsgrad; mittlere Sprosslänge; PhytoCalc.

1. INTRODUCTION

Because of 3–4 times higher elemental contents compared to the stand and its quick turnover, forest understorey phytomass needs to be considered, as it is an indicator for site characteristics and biodiversity as regards the balance of elemental stocks in corresponding ecosystems (BOLTE et al., 2004; KÖLLING AND REHFUSS, 1987; MROTZEK, 1998; NEUMANN and STARLINGER, 2001; PALVIAINEN et al., 2005). Against the background of its nature to act as an elemental source or sink due to changed atmospheric inputs, liming and forest conversion, it is necessary to quantify this contribution especially (HÖGBERG et al., 1986; NYKVIST, 1997; RÖTTGERMANN et al., 2000; SCHMIDT et al., 1989). Unfortunately, destructive harvesting often interferes other projects connected to soil parameters, practically rules out later repetition, is seldom prestigious for areas greater than the harvested ones and generally intensive in time, cost and work. In order to avoid these disadvantages, BOLTE (1999) for the first time advanced older approaches (e. g. KELLOMÄKI, 1974), which focus on relations between ground coverage and dry weight of forest understorey phytomass, by additional consideration of the parameter mean shoot length. Assuming independency between dry weight and elemental contents, stocks of Carbon (C), Nitrogen (N), Potassium (K), Calcium (Ca), Magnesium (Mg), Phosphorus (P) and Sulphur (S) can be assessed by linking the elemental contents to the dry weight of the species.

PhytoCalc 1.3 is originally based on iteratively determined, non-linear species-specific functions of 40 forest understorey species of different stand types at 129 sites of the North-eastern German lowlands. BOLTE (1999) simultaneously merged similar species to distinct habitat groups and set up corresponding habitat group-specific functions. They were found to fit almost as good as the species-specific ones, altogether being more flexible while aiming at regionalisation, since new, yet to be included species can be integrated very simple (BOLTE et al., 2002). Several validations prove PhytoCalc to be an easy, cheap and fast method in assessing forest understorey phytomass in stands, qualifying it to be an optional part of the long-term EU Level II monitoring program (BMELV, 2006). Within its application in the South-western German highlands, the habitat group-specific functions were re-calculated, now using a quasi-linear approach of log- and later retransformed data that alleviates problems due to multiple solutions and heteroscedasticity that non-linear functions are prone to. By an additional integration of 5 new species, PhytoCalc 1.4 was established (BOLTE, 2006).

This study's objective is to check the applicability of PhytoCalc 1.3 with species-specific functions and PhytoCalc 1.4 with habitat group-specific functions under clear-cut conditions in the Central German highlands. Here the balances of energy, matter and water are significantly different compared to the forest stand. The investigations base upon 4 widespread and biomass-rich species at small clear-cuts within even-aged *Picea abies* stands and 1 appropriate species within them. The possible sources of error will be discussed in the following, at the same time also improving upon PhytoCalc by integrating a new species-specific function for juvenile, up to 1 m high *Picea abies*, according to actual needs (RÖHLE et al., 2006) and desirable upgrade endeavours (BOLTE, 2006).

2. MATERIAL AND METHODS

Site description

The investigations took place at 2 sites of the highlands Solling, Lower Saxony, Germany. The altitudes were between 300-500 m above sea level. Despite compensational liming with Mg-containing lime, both the sites are characterized by acidic soil conditions, typical mor-humus and Spodic Dystric Cambisols, consisting of 80 cm loess over sandstone on an average (ELLENBERG et al., 1986). The mean annual precipitation is 1.000 mm and temperatures are about 7 °C. The potential vegetation type is a *Luzulo Fagetum*, actually displaced through a *Galio harcynici-Culto-Piceetum oxalidetosum* respectively *molinietosum* (ZERBE, 1992). At the end of 2003, parts of these stands were transformed into small clear-cuts of about 1 ha in size.

Experimental design

The 6 investigated species were: *Oxalis acetosella* L., *Digitalis purpurea* L., *Deschampsia flexuosa* (L.) Drejer, *Pteridium aquilinum* (L.) Kuhn, *Rubus idaeus* L. and juvenile, up to 1 m high *Picea abies* (L.) Karsten, whereas the first and last ones were assigned to the even-aged *Picea abies* stand and the others to the small clear-cuts. The ground coverage was categorised into 5 classes: 0% to 20%, > 20% to 40%, > 40% to 60%, > 60% to 80% and > 80% to 100%. Altogether 120 samples, 4 repetitions for each class and each species, were taken. The corresponding plots to be surveyed and harvested were chosen to meet these requirements.

Sampling and preparation

All proceedings were conducted according to BOLTE (1999), meaning that a frame of 1 m^2, divided into 4 subsections of same size, was used for *Digitalis purpurea*, *Pteridium aquilinum*, *Rubus idaeus* and *Picea abies*. The **ground coverage** (%) was estimated visually in steps of 5% for each subsection and then averaged. Additionally, the elongated length (cm) of 5 flowering/taller shoots and 5 non-flowering/smaller shoots were measured, having at most 40 values to be averaged to **mean shoot length (cm)**. After that, the whole frame was completely harvested including all the above-ground standing, living and dead plant material (= phytomass) of the pertaining species. *Oxalis acetosella* and *Deschampsia flexuosa* were treated similarly in a frame of 0,25 m^2 without subsections. Here the elongated length (cm) of 10 flowering/taller shoots and 10 non-flowering/smaller shoots were measured. Harvesting took

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place between the 13th and 26th of July for *Oxalis acetosella*, between 11th and 13th of July for *Digitalis purpurea*, between 11th and 28th of July for *Deschampsia flexuosa*, on 6th September for *Pteridium aquilinum*, on 7th September for *Rubus idaeus* and on 28th July for *Picea abies*.

For some of the *Oxalis acetosella* and *Deschampsia flexuosa* plots, the estimated ground coverages were digitally proven according to BOLTE et al. (2002), using top view pictures taken with a digital camera. Thus, slight trends of underestimation for *Oxalis acetosella* and overestimation for *Deschampsia flexuosa* might have to be considered in the discussion, but further calculations are still based on the nevertheless resilient field data, which should remain unaffected by additional statistical effects as far as possible, keeping e. g. distortions of the pictures and user bias here in mind.

All samples were oven-dried to obtain dry weights. The dry weights of *Oxalis acetosella* and *Deschampsia flexuosa* were extrapolated to 1 m². Except of 5 *Picea abies* samples, afterwards the phytomasses were shredded, aliquots were ground with an agate

Tab. 1

Data material. Rep. = repetition, GC = ground coverage, MSL = mean shoot length, f/t = flowering/taller, n-f/s = non-flowering/smaller, DW = dry weight.

Die verwendeten Daten. Rep. = Wiederholung, GC = Deckungsgrad, MSL = mittlere Sprosslänge, f/t = blühend/größer, n-f/s = nicht blühend/kleiner, DW = Trockengewicht.

Species	Rep.	GC class %	GC accurate %	--------- MSL (cm) --------- f/t	n-f/s	all	DW	C	N	K	Ca	Mg	P	S
								g/m²						
	1	> 80 up to 100	100,0	10,8	10,5	10,6	48,00	22,90	1,63	1,11	0,54	0,28	0,14	0,13
	2		95,0	7,9	8,8	8,4	38,40	18,37	1,33	0,89	0,43	0,23	0,12	0,10
	3		90,0	10,9	9,9	10,4	35,60	16,94	1,22	0,87	0,40	0,22	0,11	0,10
	4		85,0	8,7	7,4	7,7	32,80	15,62	0,86	0,53	0,35	0,17	0,07	0,06
	1	> 60 up to 80	75,0	8,0	9,2	8,6	24,00	11,32	0,80	0,52	0,26	0,13	0,06	0,06
	2		70,0	7,2	8,5	7,9	25,60	12,31	0,86	0,50	0,26	0,15	0,08	0,07
	3		65,0	7,4	8,2	7,9	20,40	9,84	0,69	0,45	0,16	0,10	0,06	0,05
	4		65,0	9,5	9,0	9,3	21,20	10,25	0,66	0,42	0,24	0,13	0,06	0,05
Oxalis acetosella	1	> 40 up to 60	55,0	8,5	8,4	8,5	25,60	12,11	0,87	0,63	0,30	0,15	0,08	0,07
	2		55,0	7,5	8,9	8,5	25,60	12,33	0,98	0,54	0,27	0,15	0,09	0,07
	3		50,0		7,0	7,0	18,80	9,15	0,54	0,31	0,16	0,07	0,04	0,04
	4		45,0	8,4	6,8	7,3	19,60	9,25	0,51	0,36	0,22	0,11	0,04	0,04
	1	> 20 up to 40	40,0	11,0	6,7	7,1	14,80	7,14	0,45	0,28	0,10	0,06	0,03	0,03
	2		30,0	7,9	8,9	8,4	12,40	5,93	0,44	0,24	0,11	0,06	0,03	0,04
	3		25,0	8,0	8,9	8,8	9,60	4,56	0,32	0,15	0,10	0,06	0,04	0,03
	4		25,0	9,0	8,6	8,8	11,60	5,67	0,41	0,22	0,13	0,07	0,04	0,03
	1	0 up to 20	20,0	3,0	8,6	7,7	9,20	4,28	0,25	0,16	0,12	0,06	0,02	0,02
	2		15,0	5,9	9,0	7,7	6,80	3,04	0,22	0,11	0,07	0,04	0,03	0,02
	3		10,0	9,0	7,9	8,0	4,80	2,27	0,16	0,09	0,05	0,03	0,02	0,01
	4		5,0	6,0	10,0	9,1	4,00	1,79	0,12	0,07	0,04	0,02	0,01	0,01
	1	> 80 up to 100	91,3	103,8	23,4	63,6	277,00	130,05	4,08	6,32	3,29	0,93	0,85	0,38
	2		83,8	80,2	25,7	53,6	322,00	152,03	5,08	5,38	3,39	1,18	0,74	0,47
	3		83,8	99,6	22,6	61,1	374,80	177,41	4,65	6,11	3,69	1,44	0,74	0,45
	4		81,3	122,5	26,1	81,2	607,90	296,42	8,09	9,43	5,66	1,80	1,02	0,66
	1	> 60 up to 80	70,0	99,4	19,8	69,5	492,10	234,84	6,60	6,87	5,57	2,03	1,04	0,62
	2		68,8	105,8	26,4	66,1	257,30	126,03	3,58	3,44	2,88	1,09	0,58	0,36
	3		65,0	114,2	35,8	62,9	227,70	111,20	3,78	2,49	1,81	0,66	0,31	0,30
	4		61,3	108,9	19,5	72,6	384,90	183,31	3,96	6,44	3,22	1,06	0,85	0,33
Digitalis purpurea	1	> 40 up to 60	60,0	91,6	21,6	55,7	387,90	184,77	6,78	8,71	4,51	1,38	1,30	0,54
	2		46,3	103,9	21,9	77,8	335,70	161,68	4,25	3,40	2,44	1,25	0,50	0,40
	3		45,0	88,5	17,9	64,1	309,70	148,21	4,69	5,09	2,84	1,20	0,57	0,43
	4		43,8	98,9	19,4	80,9	222,30	105,85	2,81	2,67	2,07	0,81	0,41	0,28
	1	> 20 up to 40	37,5	111,4	20,3	46,9	131,90	62,88	1,52	2,40	1,14	0,37	0,26	0,14
	2		23,8	76,0	26,0	56,6	106,30	50,80	1,66	1,73	0,93	0,35	0,25	0,15
	3		21,3	86,7	19,9	34,2	72,10	34,42	0,83	1,30	0,71	0,24	0,17	0,07
	4		21,3	93,4	17,0	87,0	156,60	76,00	2,47	1,94	1,27	0,40	0,16	0,20
	1	0 up to 20	20,0	74,9	22,9	44,3	67,90	33,26	1,13	0,69	0,51	0,18	0,09	0,08
	2		18,8	124,7	22,3	38,4	97,70	47,05	1,12	1,52	0,91	0,29	0,23	0,11
	3		11,3	65,2	24,0	65,2	37,70	17,76	0,54	0,60	0,41	0,16	0,09	0,05
	4		8,8	109,0		109,0	91,30	44,28	1,42	0,97	1,18	0,43	0,19	0,12
	1	> 80 up to 100	95,0		27,5	27,5	85,60	41,43	1,71	1,31	0,13	0,11	0,11	0,11
	2		90,0	63,7	17,7	40,7	198,80	96,23	2,83	1,80	0,26	0,25	0,17	0,17
	3		85,0		22,1	22,1	62,80	30,22	1,32	1,03	0,08	0,08	0,09	0,08
	4		85,0		24,1	24,1	57,20	27,94	1,22	0,84	0,08	0,07	0,07	0,08
	1	> 60 up to 80	80,0		24,9	24,9	55,60	26,96	1,04	0,68	0,08	0,06	0,07	0,07
	2		75,0		21,3	21,3	73,20	35,31	1,50	1,08	0,10	0,09	0,11	0,09
	3		70,0		22,2	22,2	49,60	24,06	1,04	0,75	0,06	0,06	0,07	0,07
	4		70,0		19,7	19,7	45,60	22,03	1,04	0,72	0,06	0,06	0,06	0,07
Deschampsia flexuosa	1	> 40 up to 60	60,0	61,9	17,9	39,9	216,40	104,77	2,15	1,76	0,23	0,21	0,14	0,15
	2		50,0		22,4	22,4	34,00	16,44	0,77	0,49	0,05	0,05	0,05	0,05
	3		50,0	60,5	14,5	37,5	201,20	97,44	2,17	1,71	0,22	0,21	0,14	0,14
	4		50,0	57,6	11,9	34,8	126,80	61,06	1,38	1,03	0,15	0,13	0,08	0,10
	1	> 20 up to 40	40,0	53,3	13,3	33,3	274,80	132,57	2,34	2,57	0,17	0,16	0,13	0,16
	2		40,0	50,9	18,0	34,5	41,20	19,60	0,82	0,69	0,06	0,06	0,06	0,05
	3		30,0	52,8	9,2	31,0	102,80	49,64	0,84	0,69	0,10	0,07	0,04	0,06
	4		25,0	63,7	9,5	36,6	127,60	60,33	1,16	0,85	0,12	0,08	0,07	0,08
	1	0 up to 20	20,0	58,2	9,9	34,1	110,80	53,32	0,95	1,05	0,08	0,07	0,06	0,07
	2		15,0	44,9	7,4	26,2	43,60	20,93	0,46	0,32	0,06	0,04	0,03	0,03
	3		10,0	51,8	9,4	30,6	50,40	24,00	0,51	0,46	0,04	0,04	0,02	0,03
	4		10,0	60,6	11,6	36,1	70,40	33,85	0,59	0,72	0,04	0,04	0,04	0,04

Tab. 1

Continuation.

Fortsetzung.

Species	Rep.	GC class %	GC accurate %	MSL (cm) f/t	MSL (cm) n-f/s	MSL (cm) all	DW	C (g/m²)	N (g/m²)	K (g/m²)	Ca (g/m²)	Mg (g/m²)	P (g/m²)	S (g/m²)
Pteridium aquilinum	1	> 80 up to 100	93,8		102,4	102,4	707,40	359,35	10,60	8,00	3,07	1,97	0,56	1,29
	2		85,0		79,2	79,2	382,60	192,71	4,91	6,31	1,90	0,88	0,35	0,75
	3		85,0		113,1	113,1	551,80	277,54	6,97	8,76	2,23	1,07	0,51	1,05
	4		82,5		101,8	101,8	492,50	250,36	7,42	4,42	2,60	1,38	0,44	1,00
	1	> 60 up to 80	78,8		84,3	84,3	390,00	196,81	5,34	3,75	1,89	1,03	0,37	0,76
	2		76,3		70,8	70,8	326,10	163,60	4,59	5,51	1,34	0,63	0,39	0,56
	3		67,5		84,3	84,3	372,00	188,09	5,20	5,32	1,79	1,13	0,37	0,80
	4		63,8		66,5	66,5	253,20	128,44	4,21	4,15	1,10	0,59	0,28	0,55
	1	> 40 up to 60	57,5		125,1	125,1	445,60	223,62	5,92	5,00	1,91	0,99	0,48	0,81
	2		55,0		68,3	68,3	212,60	109,64	2,90	1,04	0,92	0,49	0,17	0,32
	3		52,5		83,9	83,9	240,60	121,75	2,61	1,76	1,07	0,45	0,20	0,43
	4		48,8		74,8	74,8	162,00	82,38	2,23	2,98	0,65	0,32	0,39	0,29
	1	> 20 up to 40	40,0		68,9	68,9	140,90	71,08	1,99	1,93	0,67	0,31	0,16	0,35
	2		40,0		72,4	72,4	197,30	98,99	3,14	3,03	0,87	0,45	0,24	0,37
	3		26,3		71,5	71,5	97,80	49,23	1,55	1,13	0,49	0,24	0,13	0,27
	4		23,8		60,0	60,0	69,70	35,66	1,09	1,10	0,37	0,13	0,11	0,11
	1	0 up to 20	17,5		54,0	54,0	41,00	20,93	0,50	0,32	0,20	0,08	0,03	0,08
	2		17,5		73,6	73,6	43,50	21,96	0,77	0,73	0,21	0,10	0,06	0,07
	3		16,3		52,3	52,3	41,80	21,29	0,56	0,53	0,15	0,07	0,03	0,09
	4		8,8		49,4	49,4	28,70	14,56	0,56	0,11	0,14	0,06	0,03	0,05
Rubus idaeus	1	> 80 up to 100	95,0		70,3	70,3	453,50	220,98	7,13	5,61	4,78	1,51	0,85	0,40
	2		93,8		76,6	76,6	531,70	260,37	7,86	5,93	5,60	1,62	0,96	0,45
	3		88,8		59,4	59,4	463,60	230,32	8,16	5,03	4,64	1,46	0,80	0,46
	4		85,0		79,6	79,6	369,00	182,21	5,87	4,69	4,40	1,38	0,96	0,38
	1	> 60 up to 80	76,3		78,2	78,2	429,20	214,45	4,53	3,23	2,87	0,76	0,49	0,27
	2		72,5		77,8	77,8	225,30	112,49	4,31	2,55	2,36	0,74	0,59	0,24
	3		70,0		67,9	67,9	281,10	140,72	3,42	2,15	2,11	0,62	0,35	0,20
	4		61,3		59,6	59,6	251,20	125,98	3,29	2,06	2,00	0,55	0,30	0,20
	1	> 40 up to 60	58,8		36,8	36,8	138,10	69,43	1,94	1,04	1,05	0,42	0,19	0,13
	2		56,3		42,5	42,5	154,90	77,75	2,11	1,15	1,14	0,47	0,20	0,13
	3		56,3		66,5	66,5	233,10	117,08	3,00	1,26	1,93	0,76	0,25	0,18
	4		43,8		39,7	39,7	107,20	51,97	2,27	2,01	2,39	0,52	0,40	0,17
	1	> 20 up to 40	32,5		48,5	48,5	76,30	37,95	1,24	0,89	0,64	0,26	0,10	0,07
	2		26,3		33,5	33,5	54,70	27,19	1,14	0,88	0,39	0,15	0,07	0,06
	3		23,8		36,9	36,9	65,80	33,62	1,14	0,79	0,52	0,21	0,10	0,07
	4		21,3		27,4	27,4	44,50	22,39	0,61	0,34	0,26	0,12	0,06	0,04
	1	0 up to 20	17,5		27,1	27,1	31,00	15,48	0,58	0,37	0,17	0,11	0,05	0,03
	2		17,5		28,7	28,7	51,80	26,21	0,91	0,40	0,39	0,16	0,07	0,05
	3		11,3		24,4	24,4	12,90	6,57	0,34	0,14	0,08	0,07	0,02	0,02
	4		10,0		25,6	25,6	28,00	14,15	0,46	0,18	0,20	0,12	0,04	0,03
Picea abies	1	> 80 up to 100	93,8		71,9	71,9	919,70	468,00	9,01	3,12	4,12	0,84	0,95	0,55
	2		83,8		64,5	64,5	580,20	295,70	5,48	1,77	2,73	0,46	0,54	0,34
	3		81,3		68,3	68,3	663,00	341,63	7,15	2,37	2,59	0,54	0,70	0,43
	4		81,3		63,8	63,8	565,50							
	1	> 60 up to 80	75,0		61,6	61,6	626,70	320,73	6,09	1,72	2,47	0,48	0,57	0,38
	2		75,0		58,9	58,9	687,90							
	3		71,3		67,4	67,4	770,20	392,36	6,56	2,03	3,26	0,61	0,62	0,40
	4		66,3		50,1	50,1	566,90							
	1	> 40 up to 60	53,8		76,4	76,4	539,70							
	2		52,5		44,4	44,4	361,70							
	3		52,5		44,2	44,2	345,70	176,93	3,59	1,05	1,44	0,30	0,41	0,22
	4		52,5		49,9	49,9	383,70	198,39	3,77	1,10	1,82	0,31	0,35	0,22
	1	> 20 up to 40	36,3		32,8	32,8	188,00	96,86	1,92	0,55	0,82	0,21	0,24	0,12
	2		36,3		45,2	45,2	358,40	185,28	3,13	0,84	1,34	0,31	0,29	0,20
	3		35,0		32,6	32,6	189,60	97,67	2,09	0,55	0,78	0,20	0,21	0,13
	4		27,5		31,9	31,9	212,20	110,23	2,04	0,52	0,74	0,18	0,22	0,12
	1	0 up to 20	15,0		27,3	27,3	94,80	49,25	0,84	0,28	0,30	0,08	0,09	0,05
	2		13,8		28,4	28,4	93,80	48,37	0,85	0,27	0,36	0,08	0,10	0,05
	3		13,8		29,0	29,0	98,00	51,42	0,92	0,25	0,38	0,08	0,09	0,05
	4		11,3		21,7	21,7	90,10	46,70	0,81	0,26	0,32	0,09	0,11	0,05

ball mill and analysed for C, N (CN-Analyser, firm: HEKAtech, method: incineration with adjacent chromatography), K, Ca, Mg, P and S (ICP-Spectrometer IRES, firm: Thermo Instruments, method: pressure digestion with adjacent spectrometry) (KÖNIG and FORTMANN, 2006). Elemental stocks per plot were calculated by relating the elemental contents to their corresponding dry weight (*Tab. 1*).

Statistical analyses

The dry weight model in PhytoCalc is based on equation (I). Elemental stocks can be obtained by combining this dry weight model multiplicative with an elemental model (II). PhytoCalc 1.3 uses species-specific functions for *Oxalis acetosella*, *Deschampsia flexuosa*, *Pteridium aquilinum* and *Rubus idaeus*. For *Digitalis purpurea*, the habitat group-specific function of a great herb has to be used, since there is no species-specific function yet. Using PhytoCalc 1.4 with its habitat group-specific functions, *Digitalis purpurea* remained a great herb and the other species were assigned to as followed according to BOLTE (2006): *Oxalis acetosella* = small herb, *Deschampsia flexuosa* = small grass, *Pteridium aquilinum* = great fern and *Rubus idaeus* = small shrub (*Tab. 2*). *Picea abies* is not included any where.

$$DW = a * GC^b * MSL^c \qquad \text{(I)}$$

with: DW = dry weight (g/m²); GC = ground coverage (%); MSL = mean shoot length (cm); a, b, c = constants

$$ST = a * GC^b * MSL^c * \frac{E_{C,N,K,Ca,Mg,P,S}}{100} \qquad \text{(II)}$$

with, differing to (I): ST = elemental stock (g/m²); E = percentage of the element at dry weight.

New species-specific functions can be determined iteratively with STATISTICA 6.0 and Levenberg-Marquardt's method analogue to PhytoCalc 1.3, looking for minimized sums of deviation between measured and modelled dry weights. The quality of these new functions is represented through coefficients of determination from the variance of the measured and new modelled data pairs along the first bisecting line.

3. RESULTS

By recording the visually estimated ground coverages and the measured mean shoot length at the plots into PhytoCalc 1.3 and 1.4 by using the functions in *Tab. 2*, measured and modelled dry weights and elemental stocks can be compared with each other and amongst each other.

Measured vs. modelled (PhytoCalc 1.3 or PhytoCalc 1.4) dry weights and elemental stocks

The modelled dry weights underestimate the measured ones clearly (*Fig. 1*). Due to the multiplicative connection to the dry weight model, the elemental model can enforce, confirm or balance this trend - as the internal PhytoCalc element contents are smaller, the same or higher than the measured ones (*Tab. 2*). Visually appreciated, PhytoCalc 1.3 seems to be applicable for *Oxalis acetosella* K and *Deschampsia flexuosa* K, Ca, P and S. Analogue, PhytoCalc 1.4 seems to be applicable for *Deschampsia flexuosa* Ca, P and S. But this means only 5 elemental stocks out of 35 (7 elements, 5 species) can be appropriately represented by at least one of the PhytoCalc versions.

The measured percentages of the elements at dry weight differ from those of both PhytoCalc versions between –58% and +108%. Only for C were they found to be low throughout. Looking only at differences > ± 50%, there is +67% Ca and +108% Mg in *Oxalis acetosella* and –58% N, –51% K and –55% S, but +56% Ca in *Digitalis purpurea*.

Besides C with at most 2,3%, the coefficients of variation of the measured percentages of the elements at dry weight are clearly higher (about 8–44%), especially for *Deschampsia flexuosa* and *Rubus idaeus*.

Modelled (PhytoCalc 1.3) vs. modelled (PhytoCalc 1.4) dry weights and elemental stocks

Differences in dry weights and elemental stocks between both PhytoCalc versions made up to 48% for *Oxalis acetosella*, 63% for *Digitalis purpurea*, 18% for *Deschampsia flexuosa*, 25% for *Pteridium aquilinum* and 55% for *Rubus idaeus*, always referring to the maximum of both values. Dry weights and elemental stocks thus can be partly more than double as high as or half as low as when modelled with the respectively other PhytoCalc version. Even on an average, the differences are always > 10%, except for *Pteridium aquilinum*.

Further Findings

Picea abies was considered as one while setting up the new species-specific function, but branches have in average –103% N, –37% Ca, –50% P and –89% S than needles. For C, K and Mg the differences are < 10%.

The quality of the new functions has to be rated as good for *Oxalis acetosella*, *Pteridium aquilinum*, *Rubus idaeus* and *Picea abies* and acceptable for *Digitalis purpurea* (*Tab. 3*), when using, deviating to *Tab. 2*, to the bisecting line referred coefficients of determination. The values of *Deschampsia flexuosa* are lower and only for dry weight and C, Ca and Mg stocks acceptable.

Tab. 2

PhytoCalc 1.3 (BOLTE, 1999), PhytoCalc 1.4 (BOLTE, 2006) and the functions of this study to assess dry weights (g/m²) and elemental stocks (g/m²) of forest understorey phytomass. SSF = species-specific function, HGSF = habitat group-specific function. The number of samples, the dry weight and elemental model base upon (n), the coefficients of determination for the dry weight model (R^2), the standard deviations for the percentages of the elements at dry weight (±) and comparable references (without abbreviation = phytomass, PL = plant litter, L = (current year) leaves) as published by BOLTE (1999) are also given. n. a. = not available.

PhytoCalc 1.3 (BOLTE, 1999), PhytoCalc 1.4 (BOLTE, 2006) und die Funktionen der vorliegenden Untersuchung zur Abschätzung von Trockengewichten (g/m²) und Elementvorräten (g/m²) der Bodenvegetation. SSF = artenspezifische Funktion, HGSF = wuchsgruppenspezifische Funktion. Gegeben sind außerdem: die Probenanzahl n, auf der Trockengewichts- und Elementvorratsmodell basieren, die Bestimmheitsmaße R^2 für das Trockengewichtsmodell, die Standardabweichungen für die Anteile der Elemente am Trockengewicht (±) und vergleichbare Literaturquellen (ohne Abkürzung = Phytomasse, PL = Streu, L = (einjährige) Blätter) in Anlehnung an BOLTE (1999). n. a. = keine Daten verfügbar.

		Dry weights model					Elemental model							
Species	Model	n	a	b	c	R²	n	C	N	K	Ca	Mg	P	S
Oxalis acetosella	PhytoCalc 1.3, SSF	60	0,15204580	1,10904514	0,00000000	0,92	n. a.	45,02 ± 0,91	3,31 ± 0,66	3,09 ± 0,71	0,62 ± 0,20	0,27 ± 0,07	0,37 ± 0,14	0,28 ± 0,07
	PhytoCalc 1.4, HGSF	90	0,03731000	0,75559000	1,18965000	0,84	n. a.	45,02 ± 0,91	3,31 ± 0,66	3,09 ± 0,71	0,62 ± 0,20	0,27 ± 0,07	0,37 ± 0,14	0,28 ± 0,07
	This study	20	0,17134500	0,92870200	0,52997900	0,97	20	47,49 ± 1,09	3,22 ± 0,33	1,96 ± 0,29	1,04 ± 0,14	0,56 ± 0,08	0,29 ± 0,05	0,25 ± 0,03
	Literature								*2,61-3,22*	*2,70-3,02*	*1,31*	*0,28*	*0,33-0,40*	*0,16*
Digitalis purpurea	PhytoCalc 1.3, HGSF	149	0,00367860	1,51583605	0,80573571	0,80	n. a.	45,02 ± 0,91	3,31 ± 0,66	3,09 ± 0,71	0,62 ± 0,20	0,27 ± 0,07	0,37 ± 0,14	0,28 ± 0,07
	PhytoCalc 1.4, HGSF	199	0,02123000	1,03835000	0,86312000	0,78	n. a.	45,02 ± 0,91	3,31 ± 0,66	3,09 ± 0,71	0,62 ± 0,20	0,27 ± 0,07	0,37 ± 0,14	0,28 ± 0,07
	This study	20	0,03709300	0,86159000	1,31415800	0,89	20	47,96 ± 0,63	1,40 ± 0,20	1,52 ± 0,36	0,97 ± 0,16	0,35 ± 0,06	0,21 ± 0,06	0,12 ± 0,02
Deschampsia flexuosa	PhytoCalc 1.3, SSF	95	0,10948923	0,89000659	0,76979286	0,89	n. a.	46,45 ± 1,07	1,74 ± 0,42	1,68 ± 0,46	0,21 ± 0,07	0,12 ± 0,04	0,16 ± 0,05	0,17 ± 0,05
	PhytoCalc 1.4, HGSF	158	0,06066000	0,93892000	0,85098000	0,89	n. a.	46,45 ± 1,07	1,74 ± 0,42	1,68 ± 0,46	0,21 ± 0,07	0,12 ± 0,04	0,16 ± 0,05	0,17 ± 0,05
	This study	20	0,01749500	0,25979700	2,24551700	0,77	20	48,19 ± 0,36	1,48 ± 0,58	1,14 ± 0,36	0,11 ± 0,03	0,10 ± 0,03	0,09 ± 0,04	0,10 ± 0,03
	Literature							*50,10 (PL)*	*0,71-2,84*	*0,61-2,73*	*0,15-0,43*	*0,05-0,19*	*0,09-0,25*	
Pteridium aquilinum	PhytoCalc 1.3, SSF	48	0,00033372	1,26339698	1,53905306	0,96	n. a.	47,48 ± 1,08	2,04 ± 0,31	2,02 ± 0,37	0,37 ± 0,11	0,26 ± 0,13	0,20 ± 0,08	0,17 ± 0,05
	PhytoCalc 1.4, HGSF	48	0,00068000	1,09909000	1,52020000	0,95	n. a.	47,48 ± 1,08	2,04 ± 0,31	2,02 ± 0,37	0,37 ± 0,11	0,26 ± 0,13	0,20 ± 0,08	0,17 ± 0,05
	This study	20	0,01829500	1,20000200	1,07552000	0,99	20	50,64 ± 0,37	1,45 ± 0,20	1,25 ± 0,43	0,46 ± 0,04	0,23 ± 0,03	0,11 ± 0,04	0,19 ± 0,03
	Literature								*2,44-3,21 (L)*	*1,83-3,36 (L)*	*0,48-0,81 (L)*	*0,21-0,70 (L)*	*0,12-0,23 (L)*	
Rubus idaeus	PhytoCalc 1.3, SSF	50	0,00032242	0,96576588	2,22503923	0,92	n. a.	47,62 ± 0,97	1,85 ± 0,43	0,96 ± 0,44	0,65 ± 0,26	0,27 ± 0,09	0,16 ± 0,06	0,11 ± 0,02
	PhytoCalc 1.4, HGSF	50	0,03421000	0,99625000	0,98869000	0,84	n. a.	47,62 ± 0,97	1,85 ± 0,43	0,96 ± 0,44	0,65 ± 0,26	0,27 ± 0,09	0,16 ± 0,06	0,11 ± 0,02
	This study	20	0,07811300	1,65695800	0,28060600	0,97	20	49,94 ± 0,67	1,64 ± 0,37	1,03 ± 0,33	0,88 ± 0,36	0,33 ± 0,09	0,17 ± 0,07	0,10 ± 0,02
	Literature								*1,00* *2,10-3,09 (L)*	*1,00* *1,49-2,37 (L)*	*0,60* *0,62-1,52 (L)*	*0,40* *0,26-1,00 (L)*	*0,10* *0,13-0,29 (L)*	
Picea abies	This study	20	1,11725700	0,71366000	0,78774100	0,97	20	51,53 ± 0,44	0,96 ± 0,07	0,29 ± 0,03	0,40 ± 0,05	0,09 ± 0,01	0,10 ± 0,01	0,06 ± 0,01

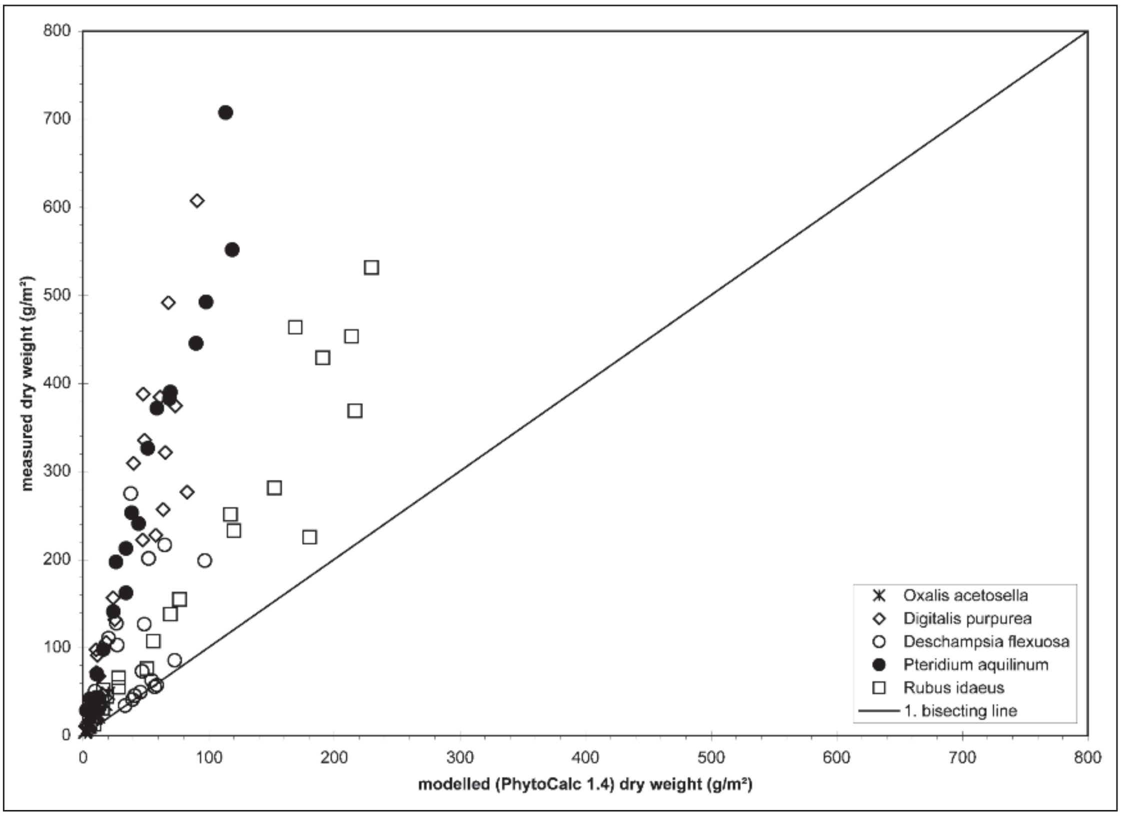

Fig. 1

Measured and modelled dry weights with PhytoCalc 1.4.

Mit PhytoCalc 1.4 gemessene und modellierte Trockengewichte.

Tab. 3

Coefficients of determination out of the variance of measured and new modelled data pairs around the first bisecting line. DW = dry weight.

Bestimmtheitsmaße aus den Streuungen von gemessenen und modellierten Datenpaaren um die Winkelhalbierende. DW = Trockengewicht.

Species	DW	C	N	K	Ca	Mg	P	S
Oxalis acetosella	0,94	0,94	0,91	0,87	0,89	0,90	0,85	0,91
Digitalis purpurea	0,79	0,79	0,71	0,66	0,74	0,72	0,60	0,75
Deschampsia flexuosa	0,59	0,59	0,17	0,17	0,73	0,72	0,12	0,24
Pteridium aquilinum	0,97	0,97	0,92	0,85	0,96	0,87	0,76	0,96
Rubus idaeus	0,94	0,94	0,91	0,91	0,89	0,90	0,89	0,90
Picea abies	0,93	0,95	0,97	0,93	0,94	0,92	0,94	0,97

4. DISCUSSION AND CONCLUSIONS

Neither PhytoCalc 1.3 nor PhytoCalc 1.4 was able to appropriately model the measured dry weights and elemental stocks of the 5 species for one species respective element throughout. The transferability of PhytoCalc beyond the stands, thus seems to be limited for clear-cut conditions in the central German highlands, were even-aged *Picea abies* stands are interspersed with small clear-cuts. Until now, only N and S stocks were expected to not be ensured in regions outside the North-eastern German lowlands or South-western German highlands, due to possibly different deposition rates across Germany (BOLTE et al., 2002).

Generally, the existing and new functions of PhytoCalc have to be resilient because of possible disturbances like e. g. user bias, sample preparation or sample analysis. Despite that, several studies (e. g. MROTZEK, 1998; SCHMIDT et al., 1998) proved the high quality of the allometric relations that the dry weights model is based upon. Looking at *Pteridium aquilinum* or *Rubus idaeus* for e. g., it is nevertheless obvious, that 2 significantly different functions can emanate from the same data, depending on how the functions are iteratively determined (BOLTE, 2006). This way, because of the multiplicative connection to the elemental model, the elemental stocks can be affected stronger than by differences in the elemental contents itself. In the future, the dry weight model of PhytoCalc should be checked as much as possible for yet to be validated stand sites. For extreme conditions like clear-cuts, fast-growing plantations or perhaps even agricultural areas, additional calibration efforts have to be effected.

Contrary to the visually estimated ground coverages that can be digitally objectified, mean shoot length is not always a prestigious value. Some species show great discrepancies between flowering/taller and non-flowering/smaller shoots, e. g. *Digitalis purpurea* and the arithmetic means then does not represent the real proportion, each of them contributes to the dry weight and elemental stocks. Similar problems can occur, when there are only less number species to be measured per plot, potentially causing statistical bolters. Both cases are dangerous especially while integrating new species-specific functions into PhytoCalc. For a start, the best corrective for such species like *Digitalis purpurea* will be to measure all shoots, neglecting their condition and plots subsections. Measuring "middle" shoots in favour may be another alternative, just like weighting, a significant correlation between shoot length and proportion to dry weight and elemental stocks assumed.

In order to advance the assessment of dry weights and elementals stocks of understorey phytomass it is better to work on reclaiming species-specific functionalities, because grouping always entails a loss of information. Since ground coverage and mean shoot length have to be determined somehow, PhytoCalc 1.4 seems to be only a waypoint en route to a version, where all species are considered apart, perhaps even for different site characteristics. *Tab. 3* validates the allometric approach to be pursued in the future. Aiming at regionalisation, the efforts in integrating new functions in PhytoCalc or calibrating it, should focus on ground coverages < 50% with consequently adapted categories for most of the species, because only less species are able to cover plots > 100 m^2 completely.

Besides these general aspects and their influences, there are special reasons for every species surveyed accounting for the differences between measured and modelled dry weights: *Oxalis acetosella* was harvested in July, not April to May. Besides phenological aspects, the parameter shoot length might have been overestimated slightly in PhytoCalc 1.4 while using arithmetic means, neglecting the fact that flowering shoots does not contribute considerably to the dry weight. *Digitalis purpurea* shoots showed lignifying tendencies due to the favourable light and nutrient conditions. Furthermore, they were harvested at the highest peak within their biennial cycle. *Deschampsia flexuosa* had slightly overestimated ground coverages. The corresponding dry weights of about 1 t/ha are nevertheless reliable (NYKVIST, 1997; PALVAINEN et al., 2005). *Pteridium aquilinum* is prone of shoots to be harvested, hanging over the edges of the frame and accounting for high dry weights. *Rubus idaeus* finally can feature species internal differences (HÖHNE and FIEDLER, 1963). Furthermore, the fact that some shoots of the last year were also harvested can not be neglected.

Comparing the elemental contents to the references (BOLTE, 1999; HÖHNE, 1962, 1963), *Deschampsia flexuosa* and *Pteridium aquilinum* were not as rich in K as *Rubus idaeus*. Correspondingly, *Pteridium aquilinum* was richer in Ca and Mg than *Deschampsia flexuosa*, but poorer than *Oxalis acetosella*, *Digitalis purpurea* and *Rubus idaeus*. Furthermore, *Oxalis acetosella* was richer in P than the other species. This classification was found to be overlaid by leaching and retranslocation effects related to N, K, P and S due to differences in the harvesting time (HÖHNE and FIEDLER, 1963) and liming effects for Ca and Mg, last one subsumable in different site characteristics (FOGGO, 1989).

The integration of a new species-specific function for juvenile, up to 1 m high *Picea abies* was a success. Thus, PhytoCalc seems to be applicable for wooden species of low height too. Although the new function is comparably qualitative, the differences in the elemental contents between branches and needles indicate that a differentiation of age-groups is probably necessary. Contrary to BOLTE (2006), the coniferous species should therefore only be integrated up to average heights of at most 0,5 m for a start.

5. SUMMARY

This study's objective was to check the applicability of the phytomass and elemental stock model "PhytoCalc" under clear-cut conditions. Two model versions were consulted, focussing upon 4 widespread and biomass-rich species at small clear-cuts within even-aged *Picea abies* stands in central German highlands and 1 appropriate species within them: *Oxalis acetosella* L., *Digitalis purpurea* L., *Deschampsia flexuosa* (L.) Drejer, *Pteridium aquilinum* (L.) Kuhn and *Rubus idaeus* L. Both PhytoCalc versions failed at clear-cut sites for now, because the balances of energy, matter and water, influencing the understorey phytomass here, are significantly different compared to the forest stand. Liming effects, deviations in harvesting time and user bias were found to be possible sources of error as well as the determination of the 2 simple model parameters ground coverage and mean shoot length can be challenging in some special cases.

Nevertheless, PhytoCalc was found to be an easy, cheap and fast approach that should be chased further one to obtain dry weight and elemental stocks of understorey phytomass. So e. g. the model seems to be applicable for wooden species of low height too, as shown with juvenile, up to 1 m high *Picea abies*. The calibrations efforts should now first focus on reliable functions for dry weight even under extreme conditions like clear-cuts for as much species as possible.

6. Zusammenfassung

Titel des Beitrages: *Anwendung des Phytomasse- und Elementvorratsmodells „PhytoCalc" unter Kahlschlagbedingungen*

Ziel dieser Untersuchung war es, die Anwendbarkeit des Phytomasse- und Elementvorratsmodells „PhytoCalc" unter Kahlschlagbedingungen zu testen. Dazu wurden 2 verschiedene Modellversionen und 4 weit verbreitete und biomassereiche Arten herangezogen: *Digitalis purpurea* L., *Deschampsia flexuosa* (L.) Drejer, *Pteridium aquilinum* (L.) Kuhn and *Rubus idaeus* L. Zur Kontrolle und als typische Art für einen gleichaltrigen *Picea abies* Bestand wurde *Oxalis acetosella* L. ausgewählt.

Beide PhytoCalc-Versionen hatten Probleme, die gemessenen Werte hinreichend genau zu modellieren bzw. mussten dafür erst angepasst werden. Die Gründe dafür liegen vor allem in einem unterschiedlichen Energie-, Stoff- und Wasserhaushalt der Freiflächen im Vergleich zum Bestand, der die Bodenvegetation signifikant beeinflusst. Auch die Ermittlung der beiden Modellparameter Deckungsgrad und mittlere Sprosslänge kann in speziellen Fällen problembehaftet sein. Mögliche weitere Fehlerquellen sind Kalkungseffekte, der Zeitpunkt der Beerntung, Bearbeitereffekte (Subjektivität) und standörtliche Verschiedenheiten.

Abseits der extremen Rahmenbedingungen auf einem Kahlschlag bleibt PhytoCalc weiterhin ein wertvoller, da kostengünstiger, simpler und schneller Ansatz zur Quantifizierung von Trockengewichten und Elementvorräten der Bodenvegetation. Dass die grundlegende Idee sinnvoll und auch für verholzende Arten adaptierbar scheint, wurde am Beispiel von bis zu 1 m hoher Fichten-Naturverjüngung deutlich. Durch die Integration neuer, bisher noch nicht berücksichtigter Arten und weitere Feinkalibrierung können die Anwendungsgebiete des Modells noch erweitert werden.

7. Résumé

Titre de l’article: *Pertinence du modèle «PhytoCalc», relatif à la phytomasse et aux réserves en éléments de base, dans le cas de coupes rases.*

L’objectif de cette étude était de vérifier l’applicabilité du modèle «PhytoCalc», relatif à la phytomasse et aux réserves en éléments de base, dans le cas de coupes rases. Deux versions du modèle ont été consultées à propos de 4 espèces largement répandues et riches en biomasse, dans des petites coupes rases faites dans des peuplements équiennes de *Picea abies* des collines du Centre de l’Allemagne et 1 espèce judicieusement choisie parmi elles: *Oxalis acetosella* L., *Digitalis purpurea* L., *Deschampsia flexuosa* (L.) Drejer, *Pteridium aquilinum* (L.) Kuhn et *Rubus idaeus* L. Les deux versions PhytoCalc n’ont pas bien fonctionné jusqu’à maintenant dans le cas des coupes rases, parce que les équilibres d’énergie, de matière et d’eau, qui y exercent de l’influence sur la biomasse en sous-étage, sont significativement différentes de ceux qui règnent dans un peuplement forestier. Des effets de chaulage, des dérives dans les dates de récolte et des biais dus aux utilisateurs peuvent être des sources d’erreur possibles; on peut aussi penser que la détermination des 2 paramètres simples du modèle, couverture au sol et longueur moyenne de pousse, peut être une gageure dans certains cas particuliers.

Il n’en reste pas moins que l’on a trouvé que PhytoCalc était un moyen facile, peu coûteux et rapide d’aborder le problème que l’on devrait continuer à utiliser pour apprécier la masse sèche et les réserves en éléments de base de la phytomasse en sous-étage. Ainsi par exemple le modèle semble être applicable aussi aux espèces ligneuses dont la hauteur est encore faible, comme on l’a constaté dans le cas de *Picea abies*, au stade juvénile, jusqu’à 1 m de hauteur. Les efforts de calibration devraient maintenant se focaliser en premier lieu sur des fonctions fiables en ce qui concerne la masse sèche, même dans des conditions extrêmes comme les coupes rases, pour le plus grand nombre possible d’espèces. R.K.

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