Adjustment and Sensitivity Analyses of a Beta Global Rangeland Model

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G-Range

G-Range is a global model that simulates generalized changes in rangelands through time, created with support from the International Livestock Research Institute. Spatial data and a set of parameters that control plant growth and other ecological attributes in landscape units combine with computer code to represent ecological process such as soil nutrient and water dynamics, vegetation growth, fire, and wild and domestic animal offtake. The model is spatial, with areas of the world divided into square cells. Those cells that are rangelands have ecosystem dynamics simulated. A graphical user interface allows users to explore model output.

The G-Range application captures main primary production and its dynamics. It is of moderate complexity, and of a nature that a user may learn its use in a week or less. A monthly time step is used to simulate herbaceous plants, shrubs, and trees, and those plant types can change in their covers within each landscape cell through simulated time. The model represents all rangelands within a single computer process, which simplifies the logistics involved in analyses. Simulations may span a few to thousands of years. Detailed information about G-Range and the reason for its creation are described in Boone et al. (2011).

In August 2011, a beta version of G-Range was provided to collaborators. The beta version of G-Range that was distributed in a limited way included a parameter set that created draft responses from the model at 1 degree x 1 degree spatial resolution. Those draft responses were useful for demonstrating the architecture of the model, but had not been rigorously compared to observations. As part of this second effort, the values within that parameter set were edited based on information from the literature, published spatial surfaces, and our experience. Extensive sensitivity analyses were then conducted.

Baseline Simulation Methods

To guide creation of a baseline simulation we required some data that would be deemed 'truth.' These data were used to compare to output from G-Range. The intent of these comparisons was not to yield a final parameter set that would represent well all areas within 15 biomes forever after. Instead, it was to allow adjustment of parameters to change G-Range output from essentially uncontrolled to something more in agreement with reality. In-so-far as that was the goal, only cursory effort was put into determining the validity of what is here deemed 'truth;' we proceeded knowing that comparing results to published or vetted data would be helpful. That included for simulated output from the Century model. That model has been vetted many times and gridded summaries of simulations are suitable for comparison with G-Range output. In other words, given the unlimited range that G-Range output could take, it would be reassuring if output emulated results from the Century model.

We adopted a spatially explicit means of comparing global responses from G-Range to various responses. Simulations started in 1957 and continued for 50 years, to 2006. Where year-specific data were available, data from 2006 were used. For some spatial data, specific years were not available, and so recent general responses were used. In this baseline simulation, fire was not incorporated and fertilization has not been included.

We began with a list of the 100+ responses from G-Range, and then selected from those the types of responses that would be most helpful in comparisons. We then compiled from existing Century simulations or materials from web sites spatial data at 0.5 degree x 0.5 degree resolution, the resolution used in this report. Cross-tabulating those lists yielded a set of surfaces used in assessment. The 11 surfaces that were selected are show in Table 1.

Table 1. The global surface data used in comparisons with G-Range output during baseline model fitting and sensitivity analyses.

1. **Potential evapotranspiration**: The values were compiled from Century output from simulations at 0.5 degree x 0.5 degree resolution (Conant et al., in prep.).
2. **Soil surface temperature**: Soil temperature values were compiled from Century output from simulations at 0.5 degree x 0.5 degree resolution (Conant et al., in prep.).
3. **Snow-water equivalent**: Gridded snow water equivalent estimates created from satellite imagery, with values from 2006 used (Armstrong et al. 2005). These data are at 25 km x 25 km resolution, with values averaged here to yield landscape cell values.
4. **Annual evapotranspiration**: Summed from a collection of grids produced at 8 km x 8 km resolution showing continuous satellite-derived global monthly land surface evapotranspiration for 2006 (Zhang et al. 2010). The surfaces were generalized to 0.5 degree x 0.5 degree resolution by averaging pixel values. Values in mm/yr were converted to cm/yr prior to use.
5. **Plant-available soil water**: Available water was summarized from 0.5 degree x 0.5 degree resolution simulations from the Century model (Conant et al., in prep.).
6. **Decomposition coefficients**: Decomposition coefficients are corrections applied to rates of decomposition. Here, values were taken from set of modeling results from compiled 0.5 degree x 0.5 degree simulations from the Century model (Conant et al., in prep.).
7. **Soil organic carbon**: Total soil organic carbon was taken from compiled simulations at 0.5 degree x 0.5 degree in the Century model (Conant et al., in prep.).
8. **Carbon to nitrogen ratio**: From 0.5 degree x 0.5 degree estimates of carbon to nitrogen ratios within the ISRIC – World Soil Information database (Batjes 2002).
9. **Live carbon density**: These data were calculate by summing above and below ground live carbon densities from the New IPCC Tier-1 Global Biomass Carbon Map of the Year 2000 (Ruesch et al. 2008). The original map was at approximately 1 km x 1 km resolution, and values were averaged to yield the estimates used. Those estimates were converted from tons carbon per ha to g/m^2.
10. **Annual net primary production**: Summed across months for net primary productivity within a 0.5 degree x 0.5 degree suite of Century simulations compiled into global surfaces (Conant et al., in prep).
11. **Leaf area index**: Data were summed from 1998 estimates of total leaf area index at 0.5 degree x 0.5 degree resolution from the ISLSCP II FASIR-Adjusted NDVI Biophysical Parameter Fields project (Sietse 2010).

A significant product from this work is a program called FIT.AML which works in ESRIs (Redlands, CA) Arc Workstation software (listed in Appendix B). The program was critical in supporting the hundreds of simulations that have been made, each creating goodness-of-fit reports. For a given analysis, first, parameter values were edited by hand. Then FIT.AML was run, and it in turn ran the G-Range model. Then the 11 parameters listed were processed in turn. For each, an extraction tool described in Boone et al. (2011) was run which drew from the binary files produced by G-Range the data needed, for years 2004 to 2006 – 2006 was used in comparison to spatial surfaces. The extraction program created a series of layers in ESRI ASCII grid format. These were then converted to grids, the native format ArcGIS uses to store raster data, and then processed to remove values representing null values. Next, any summary statistics were done, such as averaging or summing monthly values as appropriate. Analyses on a given parameter were completed by subtracting the observed (i.e., the surfaces in Table 1) values from simulated values, yielding a deviation from observed for each pixel. Those values were then averaged for each biome. The program then created a report summarizing three types of data, the deviation from observed values, the observed values themselves, and the counts of cells used to derive the values reported. The last two entries are the same for all reports, but having them included in each report provided context.

The FIT.AML program then calls a tool that exports the facet covers for herbs, shrubs, and trees, plus bare ground cover, for the entire history of the simulation, 1957 to 2006. These are summarized every five years, from 1960 to 2005. The system then combines the results for herbs, shrubs, trees, and bare ground in a single file for each fifth year summarized. The program ends by creating a report in CSV format that summarizes changes in facet cover every five years for each of the 15 biomes assessed.

We did not make use of what is termed a 'spin-up' period when creating the baseline simulation or in sensitivity analyses, which has implications for the degree to which agreement could be reached between G-Range output and the surfaces we used in comparison, especially in regard to soil carbon and carbon to nitrogen ratio. Spin-up periods are used to allow simulation states to reach equilibrium. For example, in Century simulations, users often run the model for 2000 years to allow soil carbon pools to reach equilibrium, and save the state of the model. When using the application in analyses, analysts use the files that were generated from the model spin-up as starting points. Here, we did not want results dependent (partially) on the parameters used during a model spin-up period, and running the model for long time series in each simulation was not practical, and so a spin-up period was not used.

Baseline Simulation Results

More than 120 simulations were conducted while parameters were adjusted and the fit of the model output was improved. During that effort we began to learn about the ways in which parameters of G-Range influence model output. Most often responses were in the direction expected based on the processes the parameter informs, but sometimes the results were surprising. A subset of those surprises led to modify the G-Range code (with comments in the code tracking changes made). Ultimately, modifications seemed to be no longer improving the fit of the model, and the parameter set was judged suitable for the sensitivity analyses reported below. We stress that that parameter set is *not* intended to be a final parameter set to be released with G-Range. Rather, it brought essentially uncontrolled responses into some agreement with vetted global surfaces, and provided a baseline for the sensitivity analyses.

Table 2 shows the average responses for the 15 biomes represented in the initial G-Range application. Three sets of values are given, the deviation in the simulated results from the observed values, the observed values themselves, and a count of the number of landscape cells included in each biome that was treated as rangelands and simulated. The deviations should be interpreted in comparison to the magnitudes of the observed values. Biome 6, “Boreal evergreen forest or woodland” had insufficient rangeland cells to yield reliable results, and will not be addressed further.

Table 3 provides the average facet covers every five years (plus the initial 1957 values) for the 15 biomes. Included is bare ground cover, which is 1 minus the sum of the remaining facets. The goal for parameterizing of information in Table 3 was to generate stable facet covers through time.

Table 2. Baseline results for selected responses at the conclusion of a 50-year simulation. Three sets of values are provided, a) deviations in G-Range output from observations as recorded in spatial datasets for 2006, b) the observed values from the spatial datasets, and c) the numbers of 0.5 degree x 0.5 degree cells from which the statistics in ‘a’ and ‘b’ were calculated. Landscape unit identifiers include: 1 – Tropical evergreen forest or woodland; 2 – Tropical deciduous forest or woodland; 3 – Temperate broadleaf evergreen forest or woodland; 4 – Temperate needleleaf evergreen forest or woodland; 5 – Temperate deciduous forest or woodland; 6 – Boreal evergreen forest or woodland (which has insufficient cells in our analyses to yield reliable results); 7 – Boreal deciduous forest or woodland ; 8 – Evergreen and deciduous mixed forest or woodland; 9 – Savanna; 10 – Grassland or steppe; 11 – Dense shrubland; 12 – Open shrubland; 13 – Tundra; 14 – Desert; 15 – Polar desert, rock, or ice. Variables used include: Soil temp. – Soil temperature; ET – Annual evapotranspiration; PET – Potential evapotranspiration; Plant H_20 – Plant-available soil water; Decomp. coeff. – Decomposition coefficients; SOC – Soil organic carbon; C:N – Carbon to nitrogen ratio; Carbon dense. – Live carbon density; ANPP – Annual net primary productivity; LAI – Leaf area index.

a. Deviations from Observed

Unit	Soil temp. (˚C)	Snow H_20 (cm)	ET (cm)	PET (cm)	Plant H_2o (cm)	Decomp. coeff. (index)	SOC ($g\ m^{-2}$)	C:N (ratio)	Carbon dense. ($g\ m^{-2}$)	ANPP ($g\ m^{-2}$)	LAI (index)
1	-1.7	0	-212.5	-20.4	15.65	0.31	-102.5	3.57	-69.7	1.4	0.01
2	-4.9	-4.0	-359.5	-16.7	16.26	0.36	98.5	4.21	88.0	-9.8	-0.06
3	4.6	5.0	-5.6	-0.1	8.29	0.17	-91.9	5.46	48.7	102.4	0.17
4	4.9	60.5	-80.1	-1.5	11.05	0.20	-17.6	3.59	-55.4	240.9	-0.01
5	9.2	94.0	-141.7	17.2	14.53	0.11	566.4	3.44	-112.4	39.2	0.03
6	-	1727.1	-81.9	-	-	-	-	3.20	1671.1	-	-0.03
7	1.7	-226.1	-178.8	27.6	11.97	0.03	1808.2	2.20	296.4	-217.0	0.03
8	-1.6	200.2	-138.1	0.7	14.15	0.29	240.0	1.34	98.2	73.6	-0.14
9	-3.4	-30.9	-92.4	-22.8	11.40	0.26	-216.4	4.38	17.9	40.8	0.18
10	4.6	-7.3	-20.5	-3.1	5.39	0.09	633.9	2.51	295.7	18.2	-0.11
11	-4.5	-0.5	22.7	-15.6	7.46	0.22	15.6	3.64	145.2	130.3	0.02
12	1.2	-0.7	42.7	-12.0	1.21	0.05	78.6	2.28	288.8	-8.5	0.08
13	3.1	1014.5	-123.7	32.8	3.24	0.01	3206.7	1.24	626.4	9.7	-0.07
14	4.9	-6.3	-108.5	-13.3	0.82	0.04	-232.7	1.06	98.4	-32.5	0.04
15	-0.5	4235.2	-186.8	35.0	-2.09	-0.05	4201.1	0.45	182.6	-53.2	-0.03

(Continued)

(Table 2. Continued)

b. Observed

Unit	Soil temp. (˚C)	Snow H_20 (cm)	ET (cm)	PET (cm)	Plant H_2o (cm)	Decomp. coeff. (index)	SOC (g m^{-2})	C:N (ratio)	Carbon dense. (g m^{-2})	ANPP (g m^{-2})	LAI (index)
1	26.6	0.0	916.5	172.2	1.03	0.56	4340.2	11.81	10755.0	705.0	2.84
2	26.4	12.5	783.9	163.5	1.54	0.42	4379.6	11.64	7390.6	592.5	1.94
3	12.0	22.0	535.8	98.7	5.30	0.22	6405.5	11.33	5497.5	543.8	1.93
4	2.6	57.5	446.0	87.3	2.86	0.15	4112.3	10.81	5171.0	230.2	1.79
5	-0.4	35.8	495.6	88.8	1.48	0.24	4259.0	11.01	4134.9	347.0	1.99
6	-1.0	482.2	257.5	54.2	7.75	0.14	3448.8	13.78	1555.7	188.5	1.35
7	2.0	771.5	274.0	46.8	8.61	0.18	3508.9	12.56	1555.7	258.1	1.45
8	10.0	550.1	238.8	88.0	4.12	0.21	4485.5	13.58	1056.4	374.0	0.93
9	26.4	27.7	614.0	179.5	0.81	0.37	4038.2	11.64	4280.6	538.3	1.34
10	8.0	69.7	323.1	109.1	2.02	0.20	3168.4	10.83	1511.3	221.6	0.80
11	27.4	3.6	361.5	166.6	0.36	0.23	3036.3	11.16	2130.3	220.3	0.91
12	17.2	20.0	203.1	144.4	0.86	0.15	2969.5	11.12	1019.8	163.0	0.42
13	-3.0	333.8	216.0	24.6	6.34	0.15	2667.8	12.80	470.8	140.0	0.35
14	14.9	7.4	274.1	142.3	0.45	0.11	3005.2	10.89	161.1	113.1	0.18
15	1.0	152.9	234.1	19.1	5.92	0.14	2283.1	11.10	197.7	109.8	0.12

(Continued)

(Table 2. Continued)

c. Counts

Unit	Soil temp. (˚C)	Snow H_20 (cm)	ET (cm)	PET (cm)	Plant H_2o (cm)	Decomp. coeff. (index)	SOC ($g\ m^{-2}$)	C:N (ratio)	Carbon dense. ($g\ m^{-2}$)	ANPP ($g\ m^{-2}$)	LAI (index)
1	601	601	601	601	601	601	601	601	601	601	601
2	525	525	525	525	525	525	525	525	525	525	525
3	81	81	81	81	81	81	81	81	81	81	81
4	97	97	97	97	97	97	97	97	97	97	97
5	97	97	97	97	97	97	97	97	97	97	97
6	-	789	789	-	-	-	-	789	789	-	789
7	107	107	107	107	107	107	107	107	107	107	107
8	3558	3558	3558	3558	3558	3558	3558	3558	3558	3558	3558
9	4269	4269	4269	4269	4269	4269	4269	4269	4269	4269	4269
10	3901	3901	3901	3901	3901	3901	3901	3901	3901	3901	3901
11	1268	1268	1268	1268	1268	1268	1268	1268	1268	1268	1268
12	4215	4215	4215	4215	4215	4215	4215	4215	4215	4215	4215
13	4267	4267	4267	4267	4267	4267	4267	4267	4267	4267	4267
14	5453	5453	5453	5453	5453	5453	5453	5453	5453	5453	5453
15	472	472	472	472	472	472	472	472	472	472	472

Table 3. Baseline results for facet cover over a 50-year simulation, with covers reported in five year increments. Landscape unit identifiers include: 1 – Tropical evergreen forest or woodland; 2 – Tropical deciduous forest or woodland; 3 – Temperate broadleaf evergreen forest or woodland; 4 – Temperate needleleaf evergreen forest or woodland; 5 – Temperate deciduous forest or woodland; 6 – Boreal evergreen forest or woodland; 7 – Boreal deciduous forest or woodland ; 8 – Evergreen and deciduous mixed forest or woodland; 9 – Savanna; 10 – Grassland or steppe; 11 – Dense shrubland; 12 – Open shrubland; 13 – Tundra; 14 – Desert; 15 – Polar desert, rock, or ice.

		Landscape Unit Identifier														
Year	**Facet**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1957	Herbs	0.305	0.274	0.408	0.356	0.313	0.328	0.342	0.397	0.330	0.371	0.218	0.136	0.447	0.020	0.038
1960	Herbs	0.167	0.333	0.331	0.307	0.272	0.267	0.281	0.489	0.166	0.530	0.450	0.082	0.345	0.013	0.016
1965	Herbs	0.193	0.380	0.349	0.357	0.281	0.296	0.304	0.483	0.257	0.464	0.338	0.120	0.439	0.014	0.017
1970	Herbs	0.195	0.392	0.226	0.313	0.294	0.281	0.329	0.468	0.279	0.453	0.283	0.153	0.476	0.020	0.021
1975	Herbs	0.183	0.374	0.156	0.287	0.296	0.258	0.321	0.457	0.273	0.438	0.214	0.153	0.489	0.028	0.023
1980	Herbs	0.196	0.349	0.146	0.278	0.305	0.250	0.349	0.440	0.275	0.431	0.206	0.139	0.510	0.033	0.026
1985	Herbs	0.216	0.325	0.160	0.283	0.292	0.246	0.402	0.428	0.271	0.435	0.182	0.130	0.515	0.040	0.028
1990	Herbs	0.249	0.296	0.172	0.293	0.291	0.252	0.365	0.428	0.278	0.428	0.205	0.141	0.527	0.048	0.033
1995	Herbs	0.276	0.277	0.203	0.299	0.299	0.258	0.338	0.431	0.290	0.424	0.218	0.141	0.528	0.056	0.032
2000	Herbs	0.303	0.264	0.271	0.326	0.305	0.260	0.364	0.428	0.318	0.417	0.207	0.142	0.527	0.060	0.035
2005	Herbs	0.331	0.250	0.346	0.352	0.305	0.273	0.370	0.423	0.334	0.411	0.205	0.148	0.511	0.064	0.038
1957	Shrubs	0.286	0.271	0.272	0.226	0.277	0.307	0.291	0.338	0.329	0.155	0.279	0.147	0.081	0.006	0.014
1960	Shrubs	0.479	0.324	0.439	0.335	0.332	0.397	0.346	0.373	0.477	0.211	0.380	0.160	0.108	0.013	0.014
1965	Shrubs	0.448	0.311	0.400	0.305	0.328	0.379	0.330	0.387	0.435	0.215	0.340	0.180	0.133	0.025	0.018
1970	Shrubs	0.418	0.307	0.365	0.276	0.321	0.357	0.317	0.377	0.404	0.209	0.315	0.188	0.141	0.028	0.023
1975	Shrubs	0.389	0.308	0.335	0.271	0.316	0.339	0.303	0.365	0.374	0.202	0.296	0.187	0.139	0.029	0.028
1980	Shrubs	0.364	0.311	0.306	0.265	0.310	0.324	0.307	0.354	0.346	0.195	0.290	0.187	0.137	0.029	0.032
1985	Shrubs	0.341	0.313	0.281	0.253	0.309	0.308	0.299	0.345	0.328	0.196	0.285	0.187	0.132	0.029	0.037
1990	Shrubs	0.321	0.315	0.259	0.239	0.307	0.296	0.289	0.336	0.312	0.194	0.278	0.193	0.128	0.029	0.040
1995	Shrubs	0.301	0.316	0.245	0.239	0.303	0.284	0.282	0.327	0.297	0.190	0.273	0.193	0.122	0.029	0.044
2000	Shrubs	0.282	0.318	0.233	0.233	0.301	0.277	0.268	0.317	0.278	0.185	0.264	0.188	0.117	0.029	0.048
2005	Shrubs	0.263	0.319	0.216	0.223	0.301	0.266	0.255	0.310	0.273	0.186	0.267	0.193	0.115	0.029	0.051

(Continued)

(Table 3. Continued)

		Landscape Unit Identifier														
Year	**Facet**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
1957	Trees	0.222	0.319	0.108	0.265	0.331	0.269	0.215	0.089	0.189	0.056	0.083	0.009	0.021	0.000	0.001
1960	Trees	0.351	0.341	0.228	0.357	0.395	0.334	0.252	0.103	0.356	0.091	0.132	0.010	0.030	0.002	0.002
1965	Trees	0.332	0.308	0.204	0.322	0.389	0.321	0.241	0.114	0.305	0.088	0.107	0.011	0.037	0.002	0.003
1970	Trees	0.314	0.294	0.181	0.290	0.384	0.303	0.233	0.119	0.269	0.083	0.092	0.012	0.039	0.002	0.004
1975	Trees	0.297	0.288	0.161	0.280	0.380	0.288	0.222	0.115	0.236	0.079	0.084	0.013	0.040	0.002	0.005
1980	Trees	0.281	0.286	0.143	0.269	0.374	0.276	0.227	0.111	0.206	0.074	0.076	0.014	0.040	0.002	0.006
1985	Trees	0.266	0.284	0.127	0.256	0.375	0.263	0.222	0.107	0.188	0.073	0.074	0.015	0.039	0.002	0.006
1990	Trees	0.253	0.283	0.112	0.238	0.373	0.252	0.216	0.105	0.173	0.073	0.069	0.016	0.038	0.002	0.007
1995	Trees	0.240	0.281	0.100	0.235	0.370	0.243	0.215	0.101	0.160	0.070	0.064	0.016	0.036	0.002	0.008
2000	Trees	0.227	0.281	0.089	0.232	0.369	0.236	0.206	0.096	0.144	0.068	0.059	0.016	0.035	0.002	0.008
2005	Trees	0.215	0.280	0.079	0.220	0.369	0.227	0.196	0.094	0.141	0.068	0.060	0.017	0.035	0.002	0.008
1957	Bare	0.186	0.135	0.209	0.151	0.077	0.093	0.151	0.174	0.150	0.416	0.417	0.707	0.449	0.972	0.945
1960	Bare	0.001	0.000	0.000	0.000	0.000	0.000	0.119	0.034	0.000	0.166	0.036	0.746	0.516	0.971	0.966
1965	Bare	0.025	0.000	0.046	0.014	0.000	0.003	0.123	0.014	0.002	0.232	0.213	0.687	0.389	0.957	0.960
1970	Bare	0.071	0.005	0.226	0.118	0.000	0.057	0.119	0.034	0.046	0.252	0.308	0.646	0.342	0.947	0.951
1975	Bare	0.129	0.028	0.346	0.160	0.006	0.112	0.152	0.061	0.114	0.279	0.404	0.644	0.330	0.938	0.943
1980	Bare	0.157	0.052	0.403	0.187	0.009	0.149	0.115	0.093	0.172	0.298	0.427	0.659	0.312	0.934	0.934
1985	Bare	0.175	0.076	0.430	0.206	0.021	0.182	0.076	0.118	0.210	0.294	0.457	0.666	0.313	0.926	0.927
1990	Bare	0.176	0.104	0.455	0.227	0.027	0.199	0.128	0.129	0.236	0.302	0.447	0.648	0.306	0.918	0.918
1995	Bare	0.181	0.123	0.450	0.226	0.026	0.214	0.164	0.140	0.251	0.314	0.444	0.647	0.311	0.911	0.914
2000	Bare	0.186	0.135	0.405	0.207	0.023	0.224	0.160	0.157	0.259	0.328	0.468	0.652	0.319	0.906	0.907
2005	Bare	0.189	0.148	0.357	0.203	0.024	0.233	0.176	0.172	0.250	0.332	0.466	0.641	0.337	0.902	0.901

Deviations shown in Table 2a are instructive on several levels. Two of the metrics we compared to we had suspected were not influenced by G-Range parameters (confirmed during sensitivity analyses), snow water-equivalent and potential evapotranspiration. The deviations in those metrics seen in Table 2a could never be influenced by changes made to parameters. The differences seen in those metrics are due to some combination of errors in the observed surfaces, incomplete descriptions of the processes, coding errors, or generalizations and errors in the input surfaces. Coding these processes is straightforward and their mathematical descriptions are well established. We suspect that the majority of deviations from the observed values are due to the generalized nature of CRU data (CRU 2008). Potential evapotranspiration was generally underestimated by perhaps 10%, except in polar biomes, where potential evapotranspiration was overestimated. Snow water-equivalent estimates were variable. Again, polar biomes were poorly estimated, and (for several metrics) were poorly estimated for biome 7, boreal deciduous forest or woodland.

Other metrics were influenced by changes in G-Range parameters in-so-far as vegetation cover or litter altered their values, such as soil temperature, annual evapotranspiration, plant-available soil water, and decomposition coefficients. Annual evapotranspiration was underestimated, and plant-available water was greatly overestimated, sufficient to require a review of the coding of G-Range. Decomposition coefficients were overestimated.

More parameters were available to control the values of soil organic carbon, carbon to nitrogen ratio, live carbon density, net primary productivity, and leaf area index. Live carbon density, annual net primary productivity, and leaf area indices were represented reasonably, but with some biomes represented less well. Soil organic carbon was sometimes represented quite well, but in polar biomes and in boreal deciduous forest or woodland estimates were too high, sometimes greatly overestimated.

Facet covers (Table 3) were relatively stable, as desired. Controls on plant establishment and whole plant death were sufficient to allow facet covers to be adjusted well. The lack of a spin-up period is evident, in that some facet covers vary from their base values in initial years prior to reaching some equilibrium.

Sensitivity Analysis Methods

We conducted what is termed a local sensitivity analysis, where the influence of changing a single parameter was assessed, all else being unchanged. This contrasts with a global sensitivity analysis, where the sensitivity of a simulation to ambiguity in many inputs is assessed simultaneously. Such an analysis is helpful, but beyond the scope of this effort. Another simplification that was made was to not conduct sensitivity analyses on the 11 parameters that influence fire (plus fire would have had to have been parameterized), or the five parameters that allow fertilization (plus its parameterization).

G-Range outputs may be reported directly in sensitivity analyses (i.e., the equivalent of Tables 2 and 3 for every simulation), but the deviations seen in outputs versus the observed surfaces would make that confusing. Instead, the baseline simulation (Tables 2, 3) was the datum to which sensitivity results from G-Range simulations were compared. Deviations from the values in those tables were of interest. Seven sensitivity values were tested for each parameter, with one of those values typically being that used in the baseline simulation. The range of values tested was suggested by variability in values between biomes, by practical limits, or by our knowledge of reasonable ranges for parameters.

A version of the FIT.AML was modified to support sensitivity analyses, and a brief program was prepared to run the seven simulations in sequence. A main change made was to reporting, in that G-Range output included the subtraction of results from the baseline simulation. A suite of seven parameter files was edited by hand to represent a single sensitivity analysis. Each set of seven simulations required about 8 hours to complete, and 94 such analyses were used to characterize the sensitivity of 56 variables. The difference in counts is due to their being families of values given for some parameters. For example, *leaf_death_rate* provides three values, one for herbs, one for shrubs, and one for trees. Each was assessed separately. Results from two variables are not available due to technical difficulties.

To constrain the length of this report, we limited the summary for each sensitivity analysis to one page. Three graphs are provided, often one of a selected facet cover and two chosen from the 11 candidate physical or biochemical responses assessed. No spatial responses are presented, as these assessments are at the biome scale; averages of rangeland cells within biomes were what was assessed. In each page, the purpose of the parameter was described. The means that were used to assign baseline values was cited. The values used in sensitivity analyses were reported. In that table and in the figures, for simplicity, the simulations are referred to by the numbers 1 through 7. Readers may refer to the table of sensitivity analyses to see the values referred to by the numbers. Results are interpreted, and then brief conclusions are drawn.

Sensitivity Analysis Results

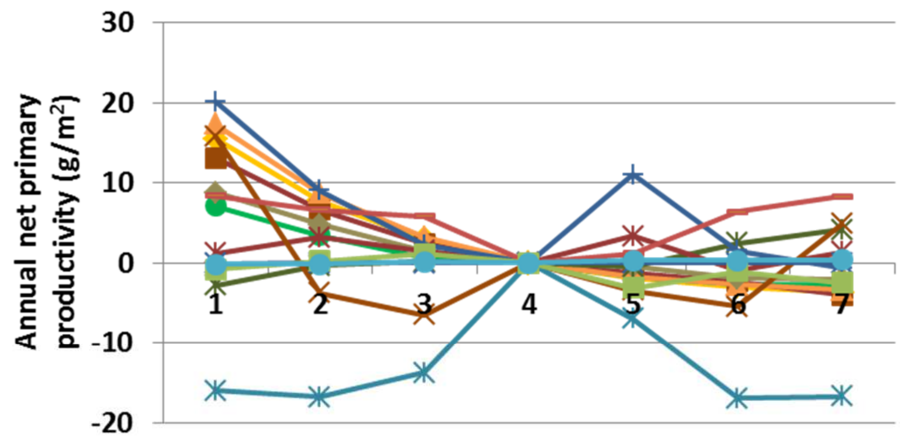
1. Precipitation threshold

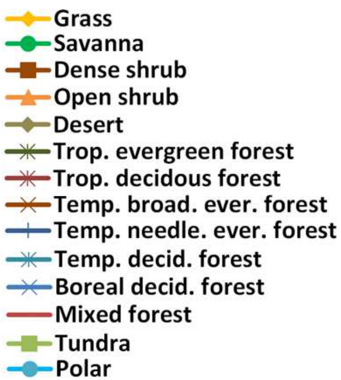
Purpose: The variable prcp_threshold describes the amount of precipitation, in cm, that is required for their to be runoff. Runoff is lost to the system and stored as an accumulate which is output.

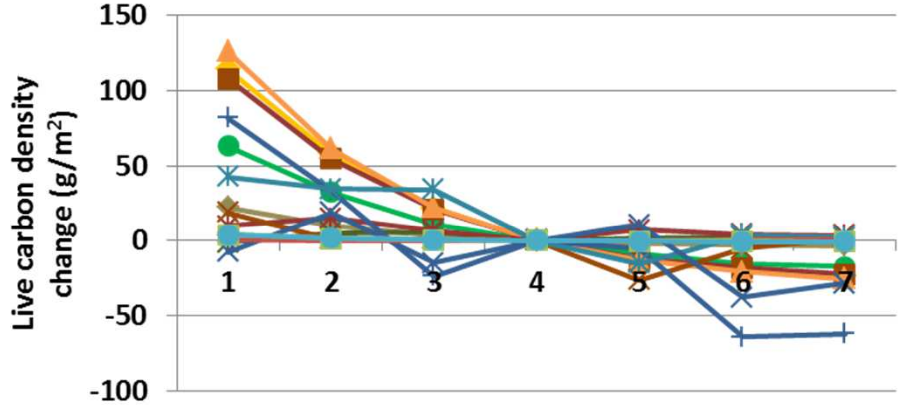
Basis for assignment: The variable is PRECRO in Century 4.5, and the value for landscape units was assigned based on the example files released with that software.

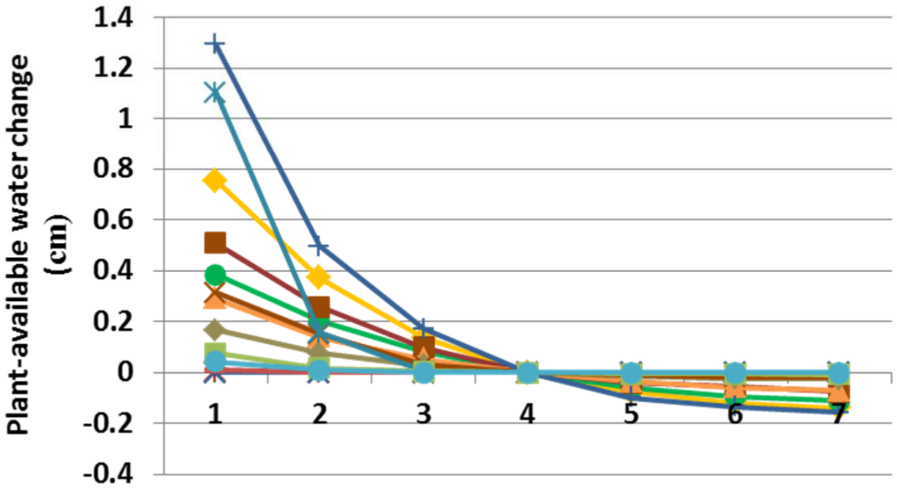
Baseline values:
8.00 cm (for all landscape units)

Sensitivity values:
1 – 2.00
2 – 4.00
3 – 6.00
4 – 8.00
5 – 10.00
6 – 12.00
7 – 14.00









Interpretation: Snow water equivalent and potential evapotranspiration did not change. Soil temperature changed a fraction of degree. Actual evaporation increased up to 15 cm in some landscape units with precipitation threshold at 2.00c cm. Soil organic carbon increased to up to 170 g m^{-2} in tropical deciduous forest, but otherwise changed less than 100 g m^{-2}. Net primary productivity changed up to 20 g m^{-2} (top) and live carbon density up to 125 g m^{-2} (above). Cover of herbs, shrubs, and trees changed 2% or less (left).

Conclusion: The parameter captures an important process and has mostly moderate influences on assessed outcomes. The parameter should be retained.

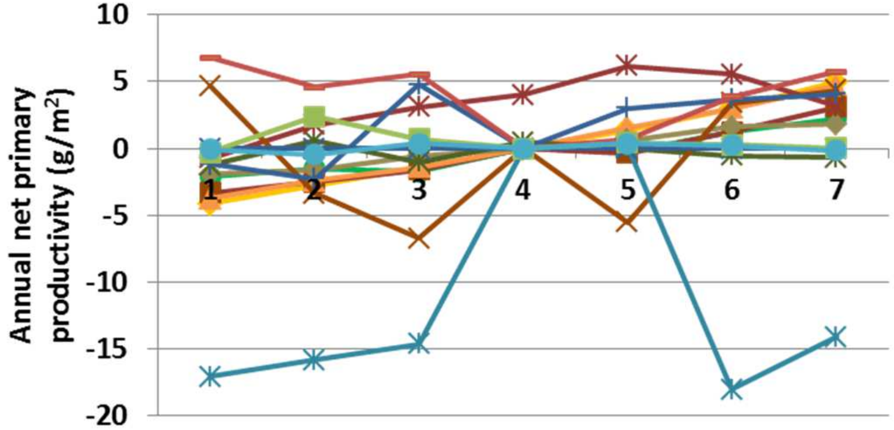
2. Precipitation threshold fraction

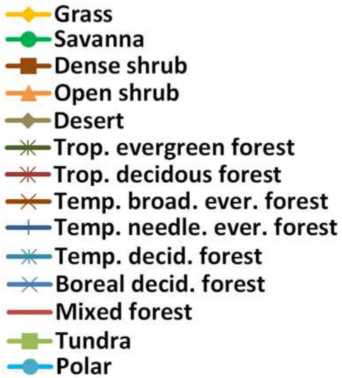
Purpose: The variable prcp_threshold_fraction describes the amount of precipitation in each month that is lost to runoff. Precipitation on the soil is reduced by the precipitation threshold, then multiplied by this fraction to determine runoff.

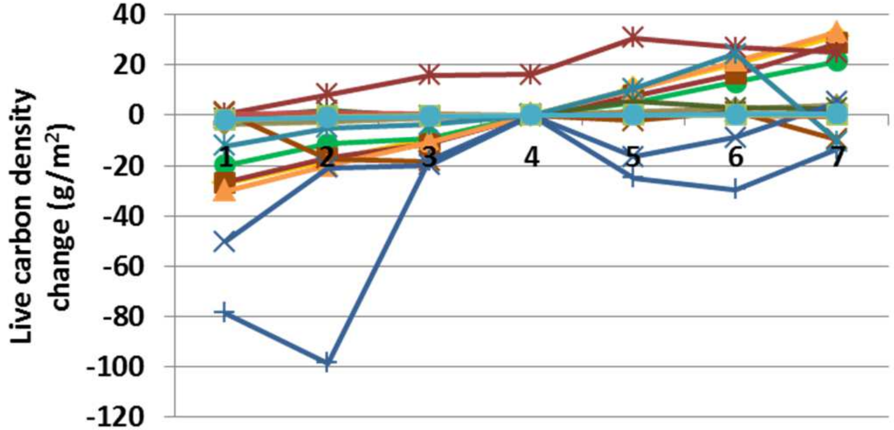
Basis for assignment: The variable is FRACRO in Century 4.5, and the value for landscape units was assigned based on the example files released with that software. Two entries were reduced in fitting.

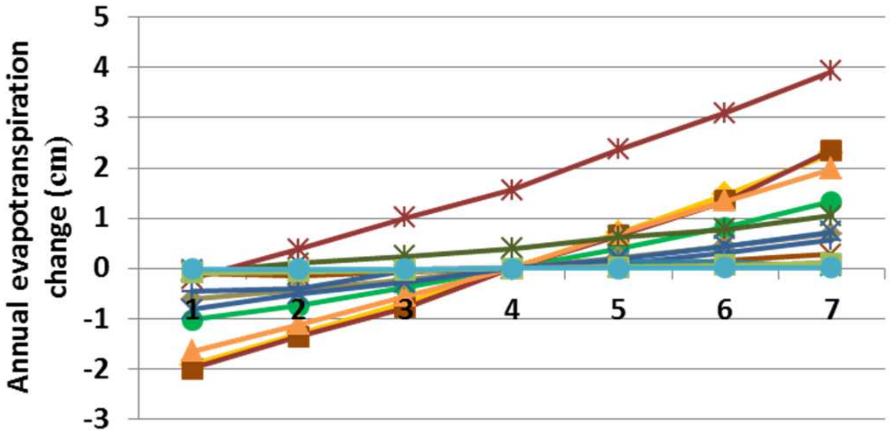
Baseline values:
0.02 (for units 1-2), 0.15 (for units 3-15)

Sensitivity values:
1 – 0.00
2 – 0.05
3 – 0.10
4 – 0.15
5 – 0.20
6 – 0.25
7 – 0.30









Interpretation: Snow water equivalent and potential evapotranspiration did not change. Soil temperature changed a fraction of degree. Actual evaporation increased up to 4 cm in some landscape units (left). Soil organic carbon decreased to up to 140 g/m^2 in, but some units increased less than 100 g/m^2. Live carbon density (above) and net primary production (top) changed modestly. Cover of herbs, shrubs, and trees changed by 2% or less in simulations, except for a 6.5% decline in herbaceous cover and increase in bare ground for tropical broadleaf evergreen forest.

Conclusion: The parameter captures an important process and has mostly moderate influences on assessed outcomes.

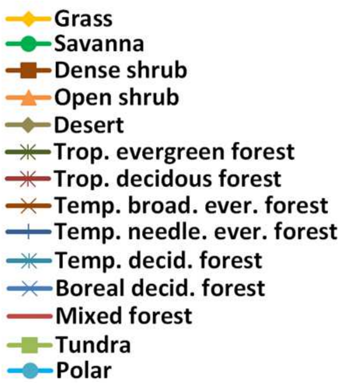
3. Base flow fraction

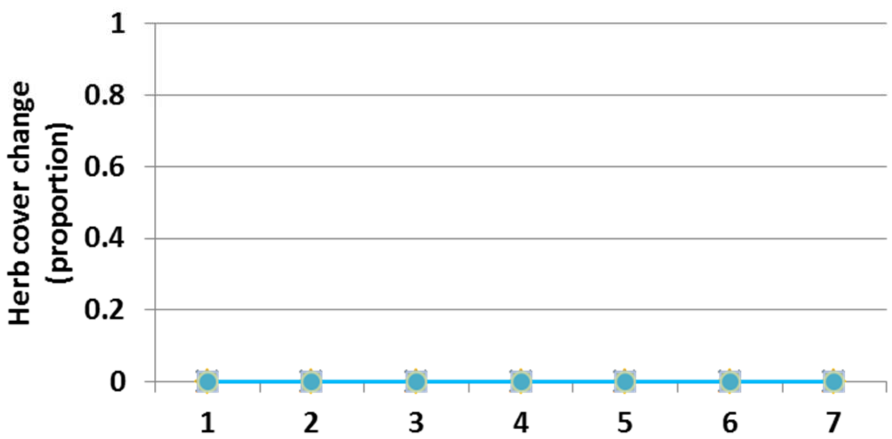
Purpose: The variable base_flow captures the fraction of soil water in the last layer of soil that is lost to base flow. The parameter influences mineral leaching from soils.

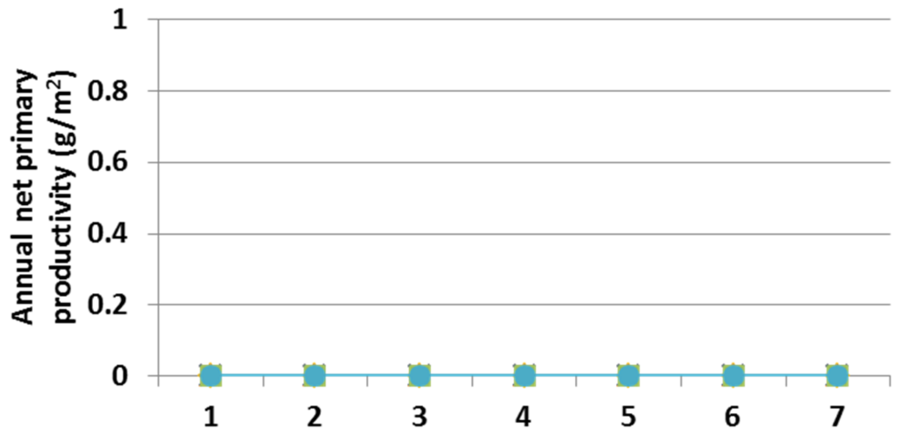
Basis for assignment: The variable is BASEF in Century 4.5, and the value for landscape units was assigned based on the example files released with that software. Examples released with that model were matched with landscape units.

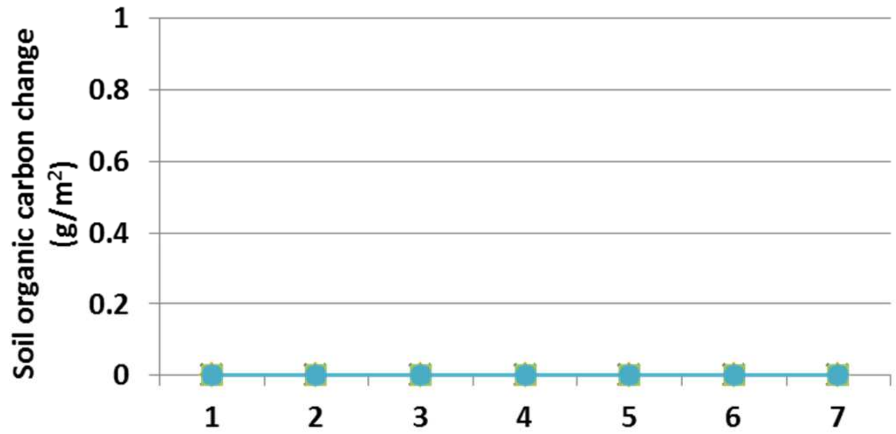
Baseline values:
0.20 (for units 1-2, 10, 11)
0.30 (for units 3-9, 12)
0.00 (for units 13-15)

Sensitivity values:
1 – 0.000
2 – 0.075
3 – 0.150
4 – 0.225
5 – 0.300
6 – 0.375
7 – 0.450









Interpretation: Over the range of values used in sensitivity analyses, base flow fraction had no effect on any output metric summarized. This is the case for biogeochemical and production responses, and changes in facet covers as well.

Conclusion: A thorough review of the G-Range computer code is called for to ensure that the parameter is captured as appropriate. If shown to be correct, the parameter may be considered for removal.

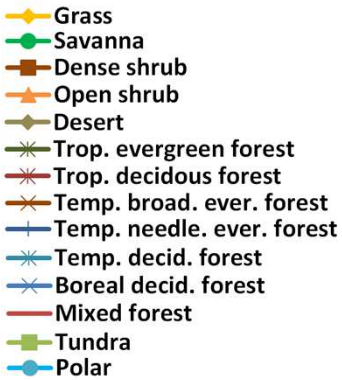
4. Soil transpiration fraction

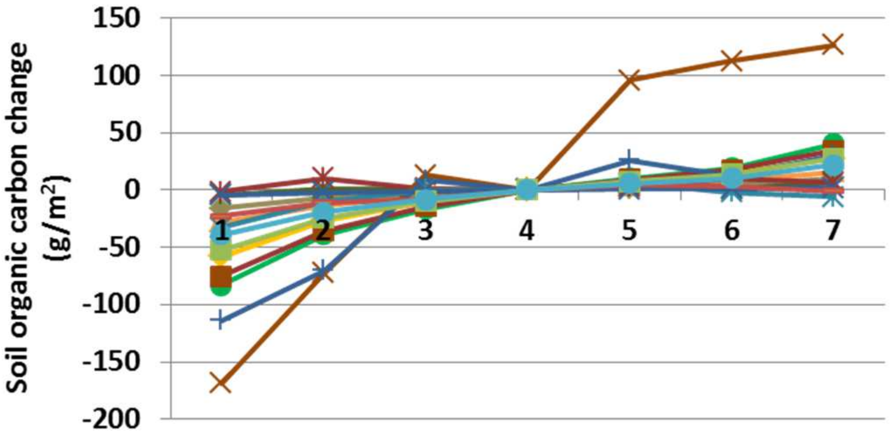
Purpose: The variable soil_transpiration_fraction describes the maximum fraction of water that may be transpired from each of the four soil layers. The value provides a cap on transpiration from a given layer.

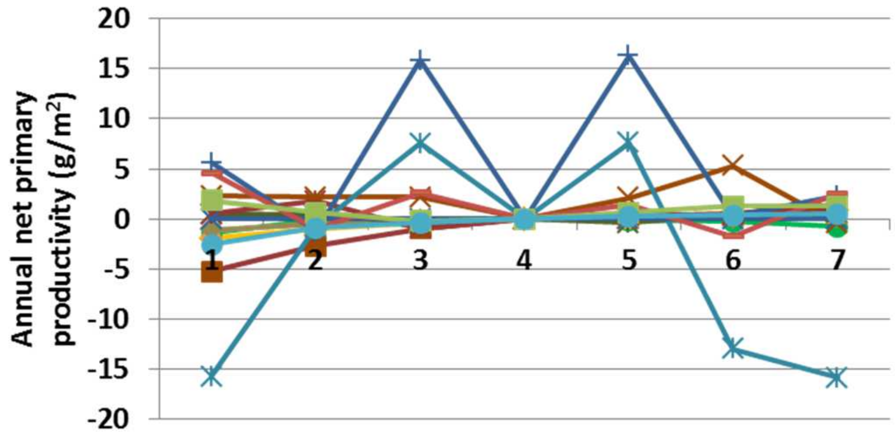
Basis for assignment: The variable is AWTL in Century 4.5, and the value for landscape units was assigned based on the example files released with that software. Values were assigned the same for all landscape units based on those examples.

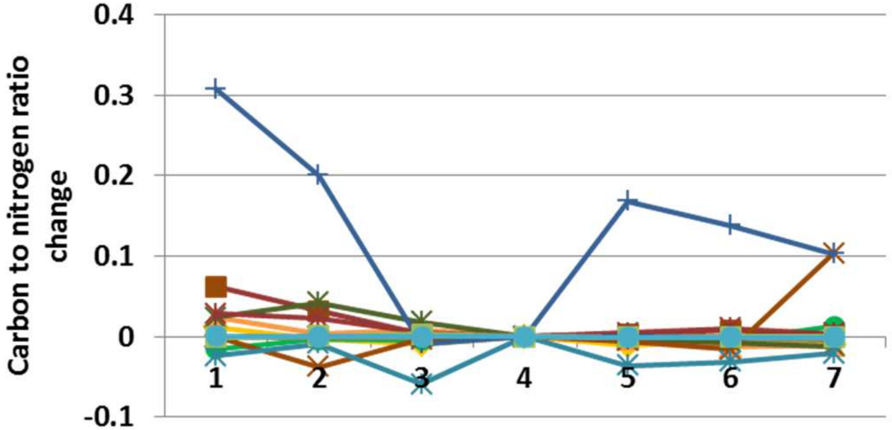
Baseline values:
0.8, 0.6, 0.4, 0.2

Sensitivity values:
1 – 0.50, 0.30, 0.10, 0.05
2 – 0.60, 0.40, 0.20, 0.10
3 – 0.70, 0.50, 0.30, 0.15
4 – 0.80, 0.60, 0.40, 0.20
5 – 0.90, 0.70, 0.50, 0.25
6 – 0.99, 0.80, 0.60, 0.30
7 – 0.99, 0.90, 0.70, 0.35









Interpretation: Changes associated with soil transpiration fraction values were modest. Potential evapotranspiration and snow water equivalent did not change. Actual evapotranspiration changed < 2 cm, and soil temperature varied < 0.02 degrees. Soil organic matter changed up to 170 g m^{-2} (left), and carbon to nitrogen ratio by 0.31. Trivial changes in facet cover occurred in the sensitivity analysis, with only tropical broadleaf evergreen forest showing a decline of 3%, and the rest < 2% in herbaceous cover.

Conclusion: The limit on soil transpiration fraction appears helpful, but does not alter outputs a great deal in the current application. The parameter may be retained for flexibility.

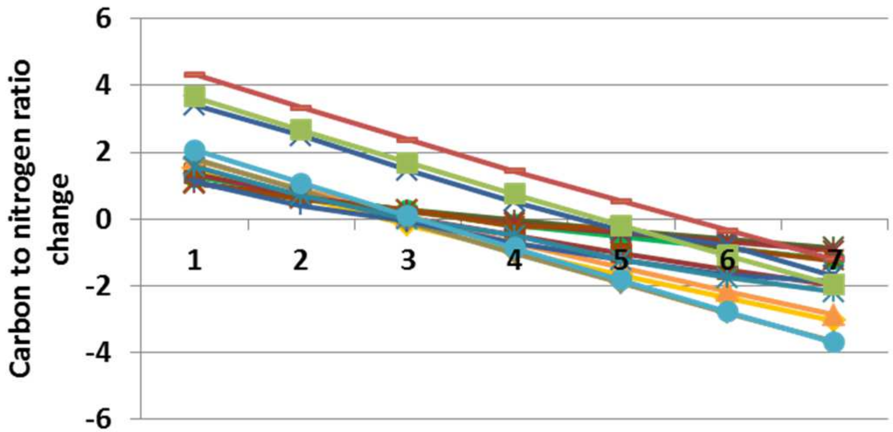
5. Initial soil carbon to nitrogen ratio

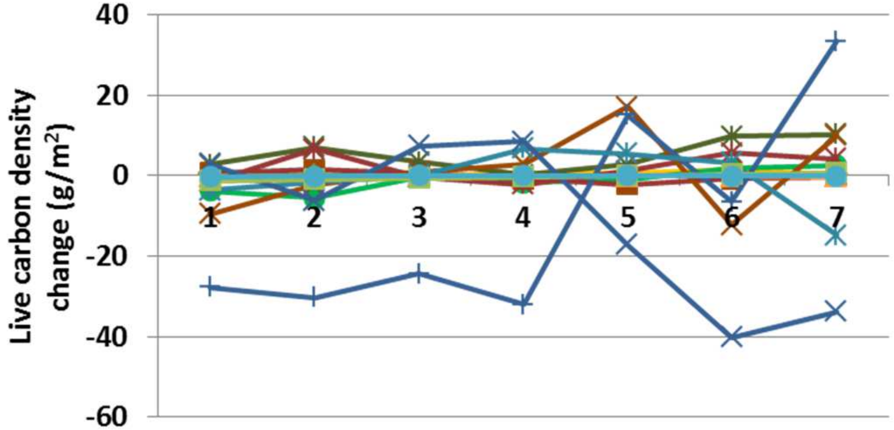
Purpose: The variable init_soil_c_n_ratio describes the soil carbon to nitrogen ratio that is used in initializing the model. The value initializes both a surface and subsoil layer, and nitrogen in intermediate and passive pools.

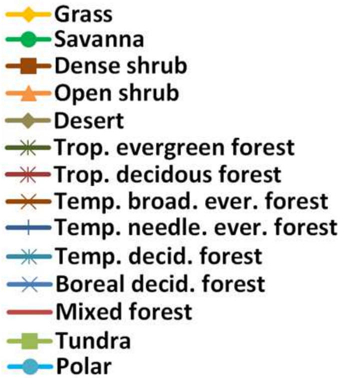
Basis for assignment: The variables for landscape units were initialized based on a published values in Potter et al. (Tellus 49B, 1-17; 1997).

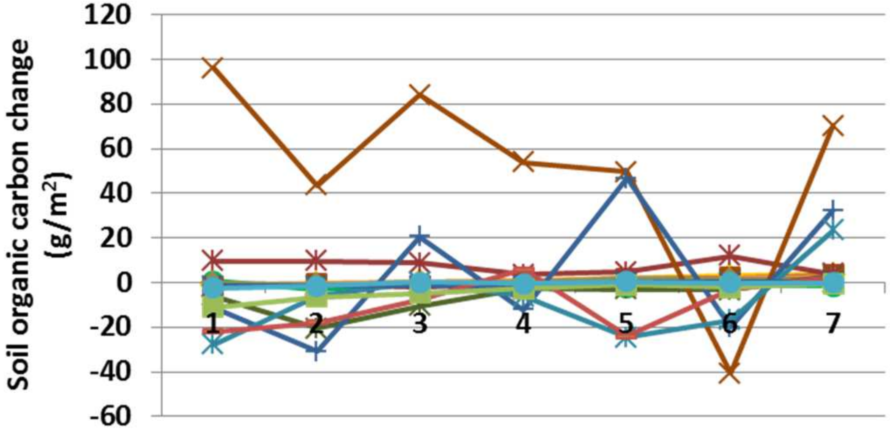
Baseline values:
Various values for the 15 landscape units, from 10.9 to 13.8

Sensitivity values:
1 – 9.0
2 – 10.0
3 – 11.0
4 – 12.0
5 – 13.0
6 – 14.0
7 – 15.0









Interpretation: Decomposition coefficients (in addition to snow water equivalent and potential evapotranspiration) did not change. Initial soil carbon to nitrogen ratios appear to persist after 50 years of simulation (above). Annual net primary production changed < 25 g m^{-2}. Live carbon density (above) changed up to 40 g m^{-2}. Soil organic carbon changed up to 97 g m^{-2} (left). Shrub and tree facets changes less than 1% in analyses. The herb facet increased up to 3.5%, and decreased < 2%, except for tropical broadleaf evergreen forest, which declined 5% in high C to N ratios.

Conclusion: Estimates for the parameter are readily available and capture an important trait. The parameter should be retained.

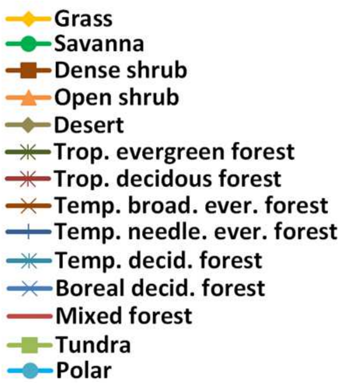
6. Initial lignin nitrogen ratio

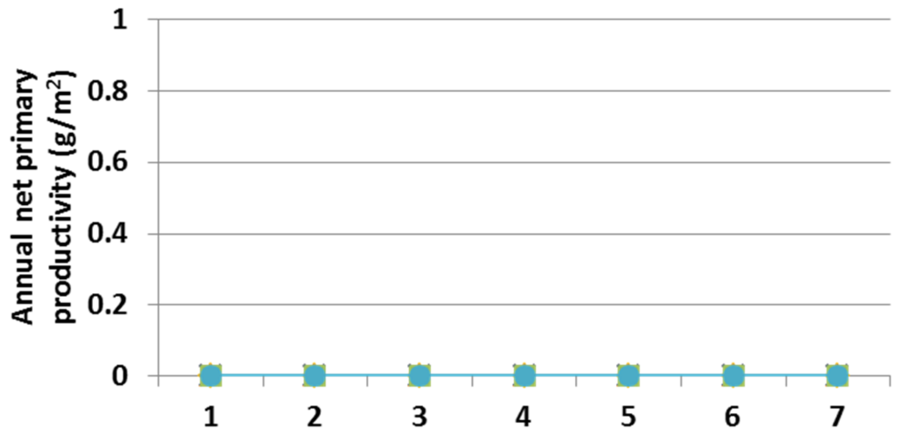
Purpose: The variable init_lignin_n_ratio describes the lignin to nitrogen ratio used to initialize the model.

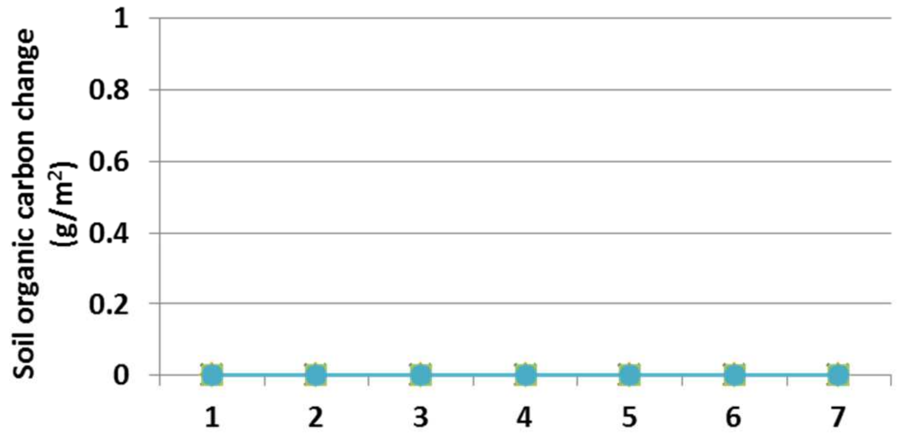
Basis for assignment: The variables for landscape units were initialized based on a published values in Potter et al. (Tellus 49B, 1-17; 1997).

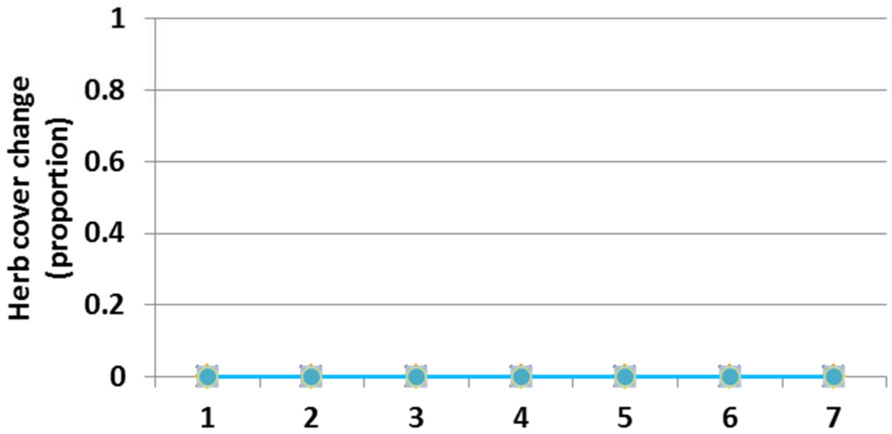
Baseline values:
Various values for the 15 landscape units, from 145 to 1100, but excluding types 14 and 15 (tundra and polar), the values are below 300.

Sensitivity values:
1 – 100
2 – 150
3 – 200
4 – 250
5 – 300
6 – 350
7 – 400









Interpretation: No changes in biogeochemistry, plant production, or facet cover were observed in sensitivity analyses. Initial lignin nitrogen ratio is used to calculate a fraction of metabolizable materials, but it not used in further calculations.

Conclusion: A review of G-Range computer code is called for, but the parameter appears to be used to calculate a fraction of metabolizable material, but not used thereafter. The code requires correction or the parameter may be removed.

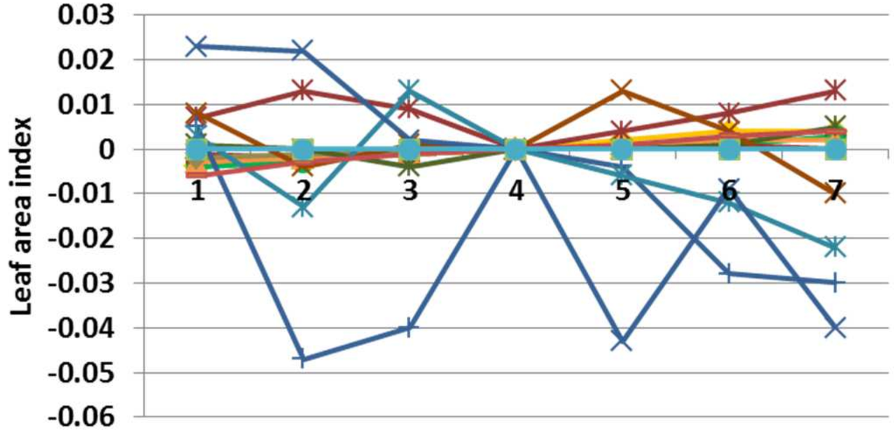
7a. Initial tree carbon, live parts

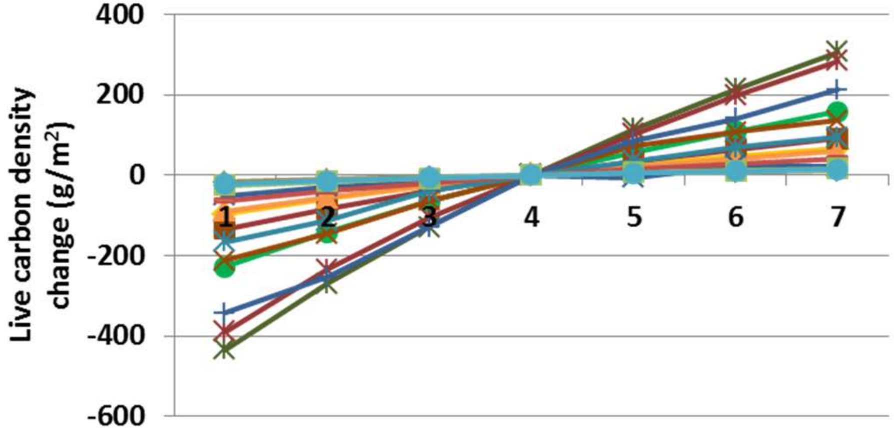
Purpose: The variable tree_carbon includes a live and dead set of values for leaves, fine roots, fine branches, coarse branches, and coarse roots. The values initialize carbon densities (g m^{-2}) in the live plant parts.

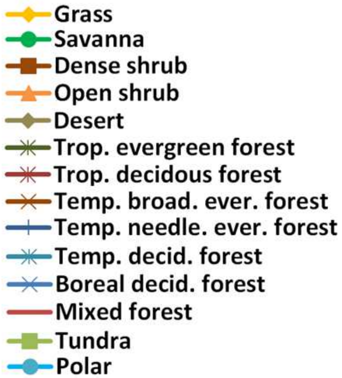
Basis for assignment: The parameters were based on RLVCIS, RLWCIS, etc. in Century 4.5. These were similar across example land cover types, and set to a single suite of values in G-Range landscape units.

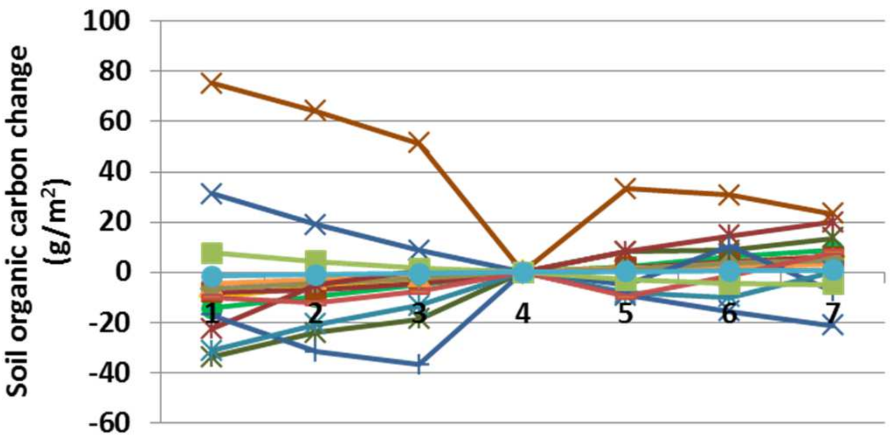
Baseline values:
1200, 500, 800, 3500, 1200 (for all units)

Sensitivity values:
1 – 900, 200, 500, 3200, 900
2 – 1000, 300, 600, 3300, 1000
3 – 1100, 400, 700, 3400, 1100
4 – 1200, 500, 800, 3500, 1200
5 – 1300, 600, 900, 3600, 1300
6 – 1400, 700, 1000, 3700, 1400
7 – 1500, 800, 1100, 3800, 1500









Interpretation: Initial carbon densities in live tree parts led to differences in carbon concentrations. Live carbon density changed up to 500 g m^{-2} in each direction (above). Carbon to nitrogen ratio changed less than 0.5 for plant types, most less than 0.1. Leaf area index changed up to 0.048 (top). Changes not shown tended to be minor (e.g., < 0.1 degree change in soil temperature). Herb facet cover changed 3% or less under different carbon concentrations in trees, with the values highest at lower C values.

Conclusion: An ability to initialize carbon density in tree parts is helpful, and has modest effects on simulation outcomes. The parameter group should be retained.

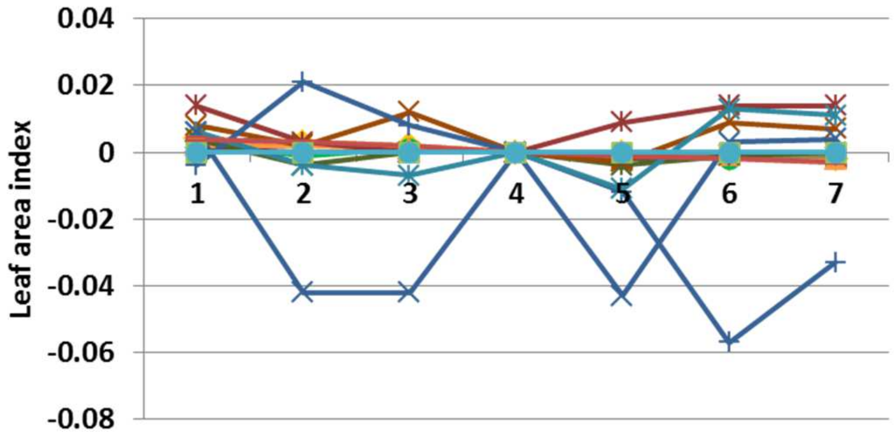
7b. Initial tree carbon, dead parts

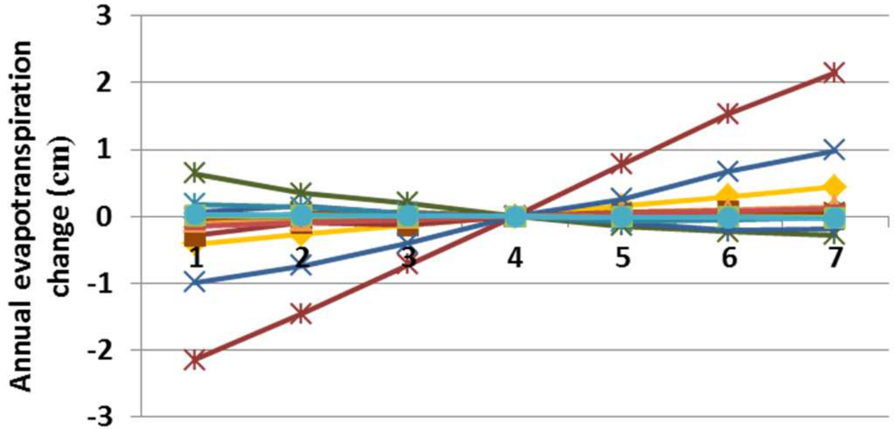
Purpose: The variable tree_carbon includes a live and dead set of values for leaves, fine roots, fine branches, coarse branches, and coarse roots. The values initialize carbon densities (g m^{-2}) in the dead plant parts.

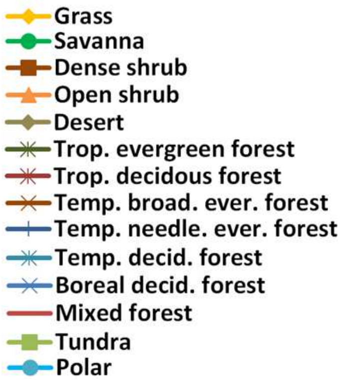
Basis for assignment: The parameters were based on RLVCIS, RLWCIS, etc. in Century 4.5. These were similar across example land cover types, and set to a single suite of values in G-Range landscape units.

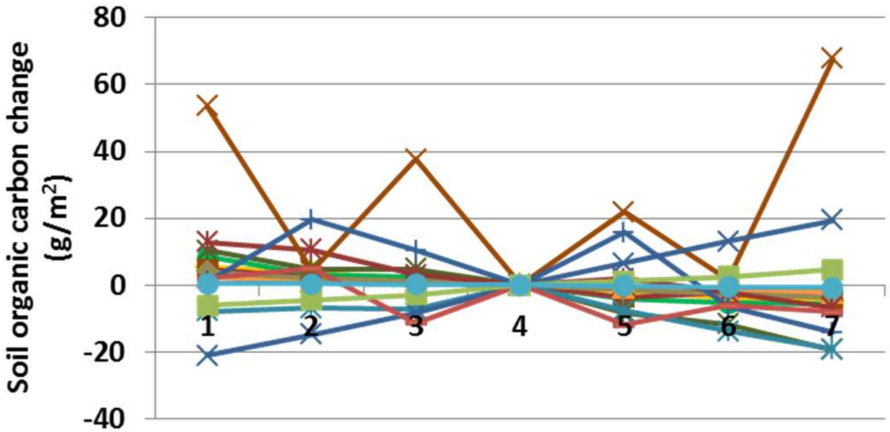
Baseline values:
100, 100, 300, 200, 300 (for all units)

Sensitivity values:
1 – 55, 55, 255, 155, 255
2 – 70, 70, 270, 170, 270
3 – 85, 85, 285, 185, 285
4 – 100, 100, 300, 200, 300
5 – 115, 115, 315, 215, 315
6 – 130, 130, 330, 230, 330
7 – 145, 145, 345, 245, 345









Interpretation: Initial carbon densities in dead tree parts affect carbon concentrations after 50 years of simulation. Leaf area index showed small changes (top). Decomposition coefficients, soil temperature, and C to N ratio changed little. Live carbon density increased by 250 g m^{-2} at the lowest dead plant parts carbon densities, to -200 g m^{-2} at the highest dead plant part carbon densities. Herb facet cover changed 3% or less under different carbon concentrations, with the values highest at lower C values.

Conclusion: An ability to initialize carbon density in tree parts is helpful, and has modest effects on simulation outcomes. The parameter group should be retained.

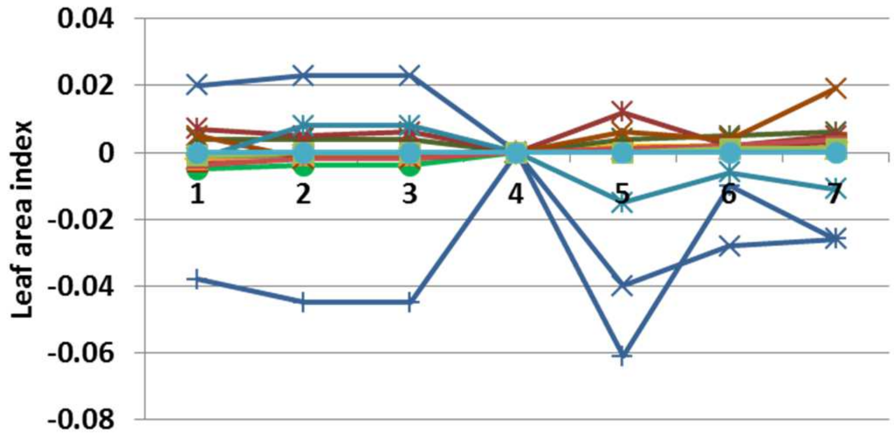
8a. Initial shrub carbon, live parts

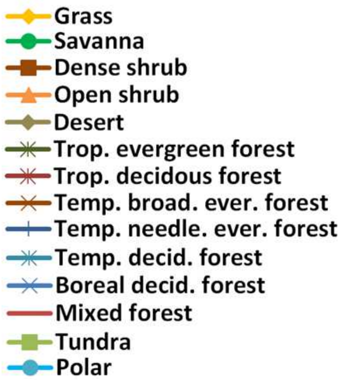
Purpose: The variable shrub_carbon includes a live and dead set of values for leaves, fine roots, fine branches, coarse branches, and coarse roots. The values initialize carbon densities (g m^{-2}) in the live plant parts.

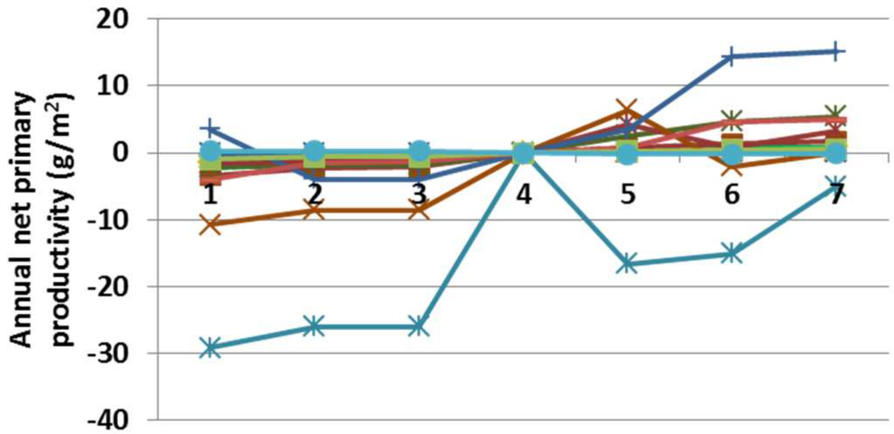
Basis for assignment: The parameters were based on RLVCIS, RLWCIS, etc. in Century 4.5. These were similar across example land cover types, and set to a single suite of values in G-Range landscape units.

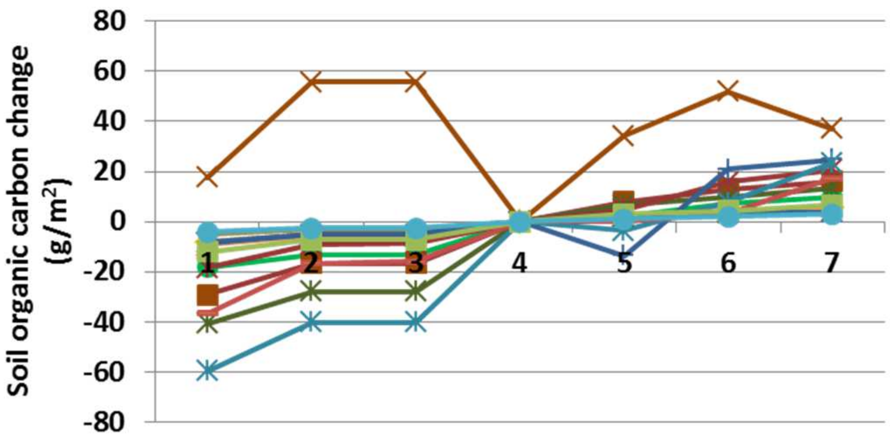
Baseline values:
300, 150, 200, 800, 300 (for all units)

Sensitivity values:
1 – 180, 30, 80, 680, 180
2 – 220, 70, 120, 720, 220
3 – 260, 110, 160, 760, 260
4 – 300, 150, 200, 800, 300
5 – 340, 190, 240, 840, 340
6 – 380, 230, 280, 880, 380
7 – 420, 270, 320, 920, 420









Interpretation: Initial carbon densities in live shrub parts led to differences in carbon concentrations after 50 years of simulation. Leaf area index changed a small amount (top), as did soil carbon (left). Live carbon density declined up to 800 g m^{-2} in forest units, 400 g m^{-2} in savanna, when carbon densities were low. When carbon densities were high, live carbon density increased up to 500 g m^{-2}. Shrub and tree facets changed less than 0.5%, and the herb facet changes 3.5% or less, with non-forest types changing 1.5% or less.

Conclusion: An ability to initialize carbon density in shrub parts is helpful, and has modest effects on simulation outcomes. The parameter group should be retained.

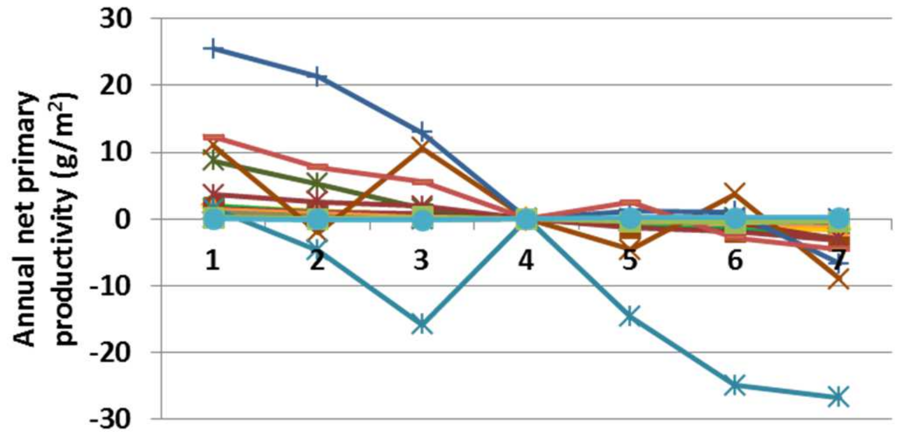
8b. Initial shrub carbon, dead parts

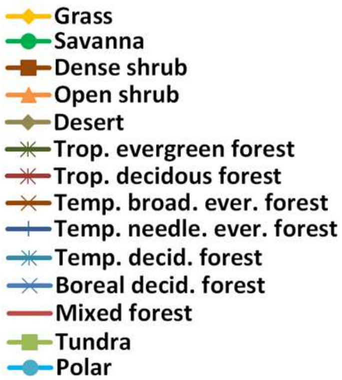
Purpose: The variable shrub_carbon includes a live and dead set of values for leaves, fine roots, fine branches, coarse branches, and coarse roots. The values initialize carbon densities (g m^{-2}) in the dead plant parts.

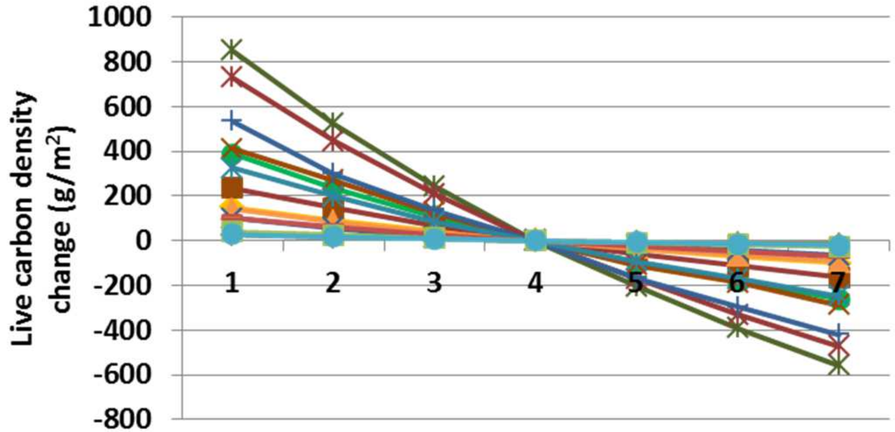
Basis for assignment: The parameters were based on RLVCIS, RLWCIS, etc. in Century 4.5. These were similar across example land cover types, and set to a single suite of values in G-Range landscape units.

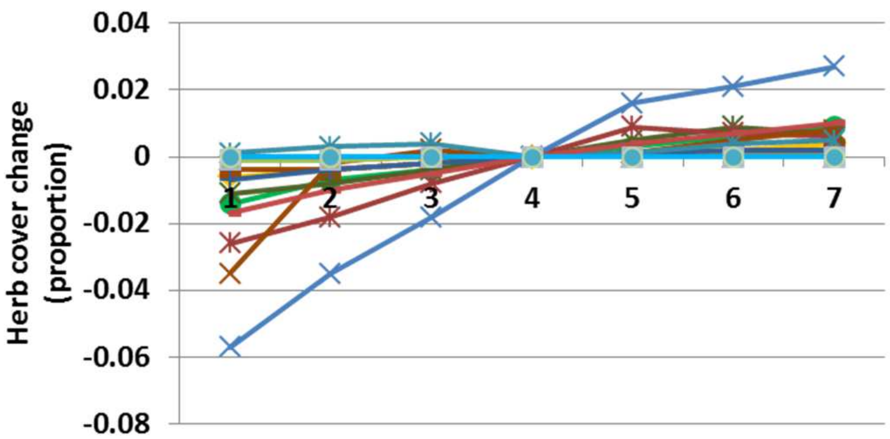
Baseline values:
40, 40, 80, 60, 80 (for all units)

Sensitivity values:
1 – 10, 10, 50, 30, 50
2 – 20, 20, 60, 40, 60
3 – 30, 30, 70, 50, 70
4 – 40, 40, 80, 60, 80
5 – 50, 50, 90, 70, 90
6 – 60, 60, 100, 80, 100
7 – 70, 70, 110, 90, 110









Interpretation: Initial carbon densities in dead shrub parts do influence carbon densities later in simulations (above). Annual evapotranspiration changed by up to 1.3 cm for deciduous forest landscape units. Soil temperature changed by up to 0.04 degrees C. Plant-available water changed < 0.04 cm, with the grassland type showing the largest change. Soil organic carbon changed up to 40 g m-2, except for boreal deciduous forest. Shrub and tree facet covers essentially did not change. Herb cover changed up to 6% (left).

Conclusion: An ability to initialize carbon density in shrub parts is helpful, and has modest effects on simulation outcomes. The parameter group should be retained.

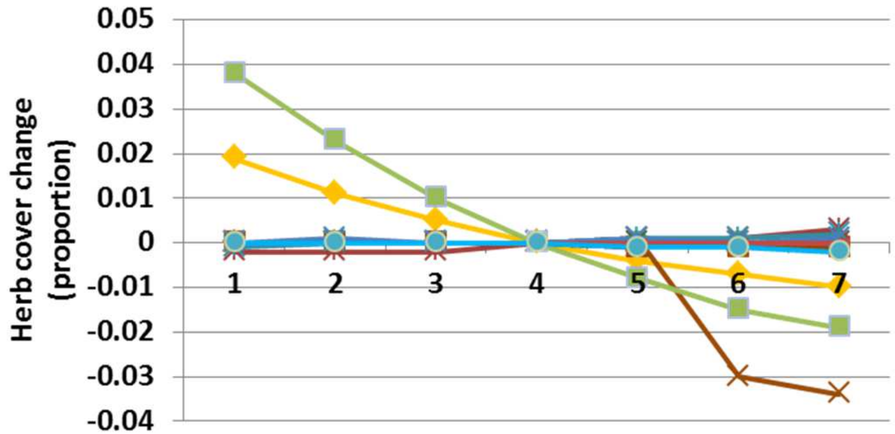
9. Plant dimension

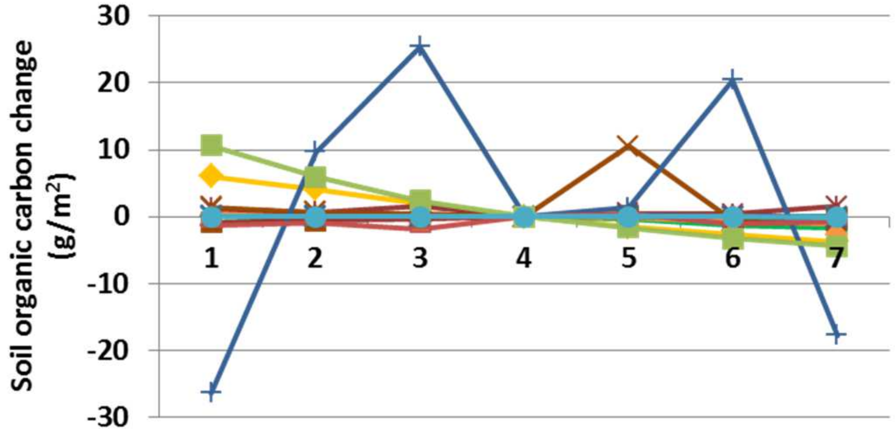
Purpose: The variable plant_dimension describes a single dimension of the area occupied by a plant root base. Three values are provided, one each for herbs, shrubs, and trees. Values are in meters.

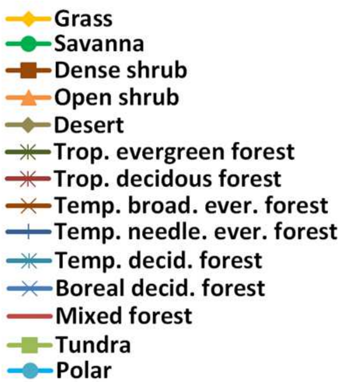
Basis for assignment: These values were inferred.

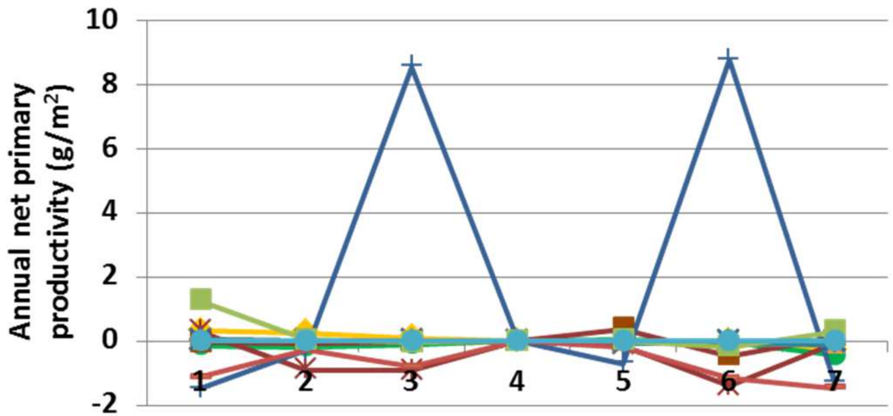
Baseline values:
0.5, 2.0, 8.0 (for all units)

Sensitivity values:
1 – 0.2, 1.4, 5.0
2 – 0.3, 1.6, 6.0
3 – 0.4, 1.8, 7.0
4 – 0.5, 2.0, 8.0
5 – 0.6, 2.2, 9.0
6 – 0.7, 2.4, 10.0
7 – 0.8, 2.6, 11.0









Interpretation: Herbaceous facet cover changed up to 4%. The logic of G-Range suggests that this is due to rounding error, in the sense that plant packing within the simulated 1 km² area was more complete when plants were small. Shrub and tree covers did not change. All biogeochemical and plant production responses were either no changes, or small responses associated with the changes in herbaceous facet cover. For example, soil organic carbon (above) changed less than 30 g m-2.

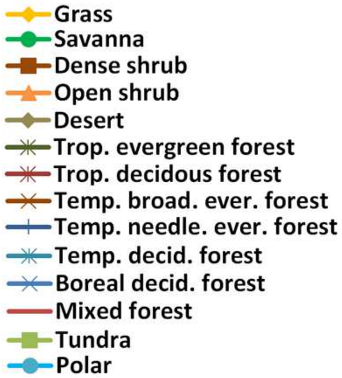
Conclusion: These values may be entered into G-Range directly (i.e., hard wired) and removed from the parameter set.

10a. Temperature production - Temperatures

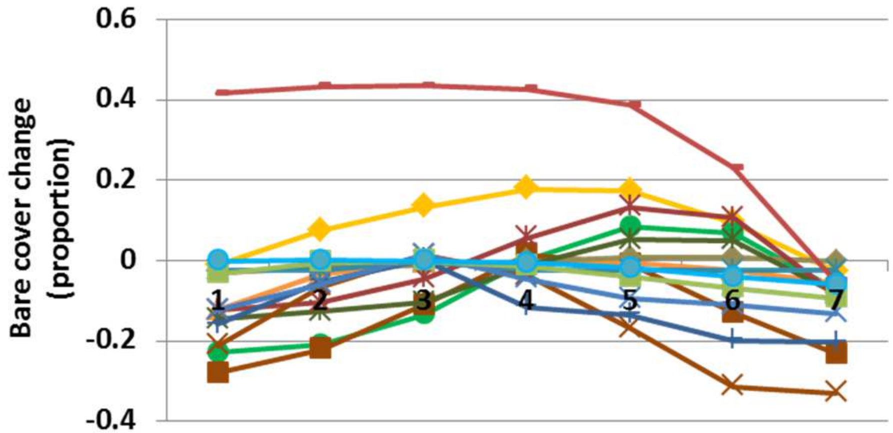
Purpose: The variable temperature_production describes the effect of temperature on plant production. There are two pieces, two parameters providing optimum and maximum temperatures, and two parameters describing the shape of the response curve. Here only temperature values are adjusted.

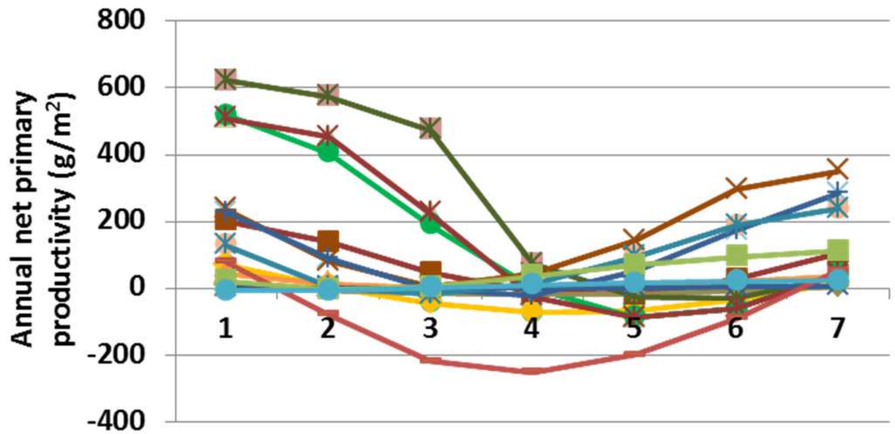
Basis for assignment: These values are variable PPDF in Century. Values distributed with that model for example biomes were used to initialize G-Range biomes.

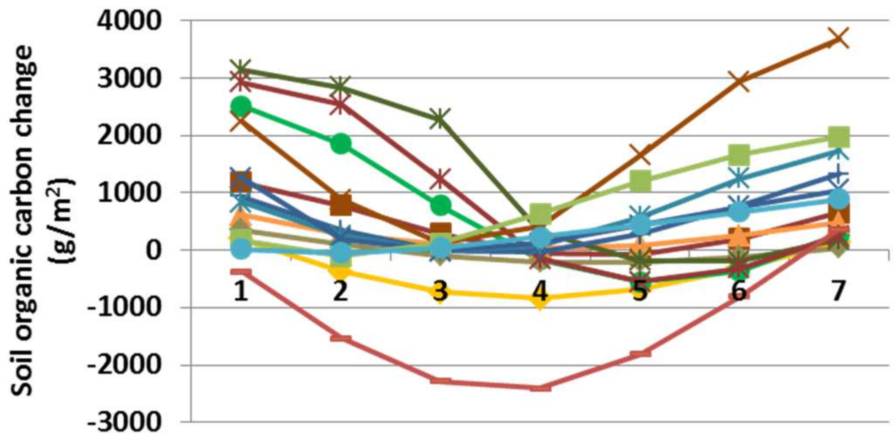
Baseline values:
30., 45., 1.0, 2.5 (units 1-2, 8-10, 14)
15., 32., 1.0, 3.5 (3-5, 7, 15)
19., 35., 1.0, 3.5 (6), 18., 35., 1.2, 3.0 (11, 12)



Sensitivity values:
1 – 8., 24.
2 – 12., 28.
3 – 16., 32.
4 – 20., 36.
5 – 24., 40.
6 – 28., 44.
7 – 32., 48.







Interpretation: Changes in the temperatures associated with optimum and maximum production led to very large changes in outputs. Soil temperature declined up to 9 degrees C under low temperatures. Plant-available water declined more than 3 cm. Decomposition coefficients declined by 0.2. Soil organic carbon changed markedly (above). In general, these changes are associated with large changes in production (top). Facet covers all changed markedly as well, leading to change in bare ground (left).

Conclusion: These parameters are important in describing the process-based responses of plants, and apparently must be defined well to yield reasonable outputs. The parameters should be retained.

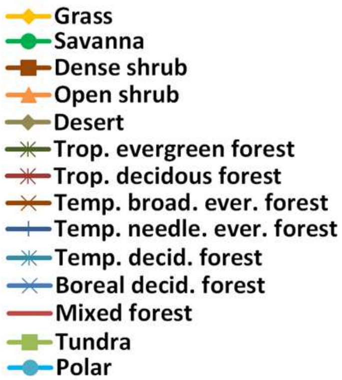
10b. Temperature production – Curve shapes

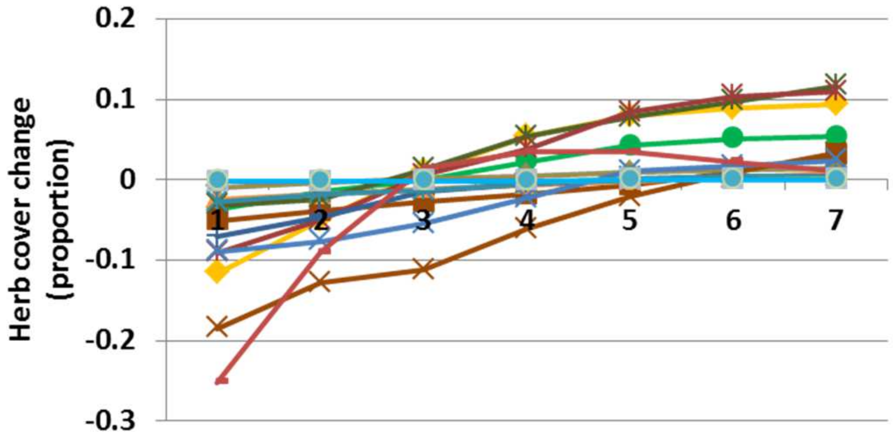
Purpose: The variable temperature_production describes the effect of temperature on plant production. There are two pieces, two parameters providing optimum and maximum temperatures, and two parameters describing the shape of the response curve.   Here only curve shapes are adjusted.

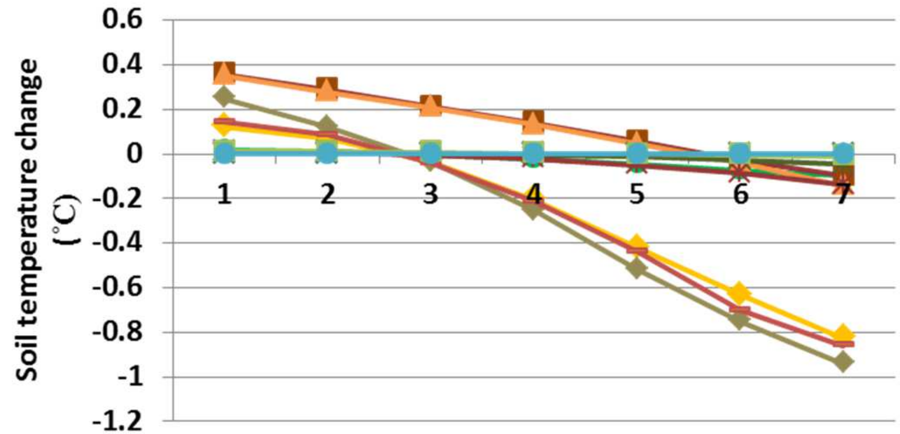
Basis for assignment: These values are variable PPDF in Century. Values distributed with that model for example biomes were used to initialize G-Range biomes.

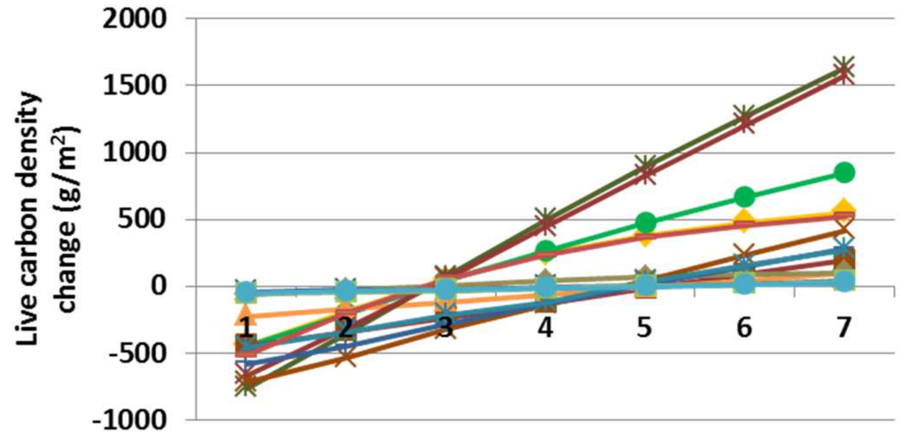
Baseline values:
30., 45., 1.0, 2.5 (units 1-2, 8-10, 14)
15., 32., 1.0, 3.5 (3-5, 7, 15)
19., 35., 1.0, 3.5 (6), 18., 35., 1.2, 3.0 (11, 12)

Sensitivity values:
1 – 0.7, 2.25
2 – 0.8, 2.50
3 – 0.9, 2.75
4 – 1.0, 3.00
5 – 1.1, 3.25
6 – 1.2, 3.50
7 – 1.3, 3.75









Interpretation: Changes in the curves defining production responses to different temperatures led to very large changes in some outputs. Plant-available water declined more than 2 cm. Decomposition coefficients and C:N ratio showed modest responses (e.g., 0.7 change in C:N ratio).   Carbon density changed markedly, up to 1600 g m-2 increases in tropical forest types for sensitivity test 7 (above). Primary production did not change a great deal, up to 150 g m-2. Herbaceous facet cover changed (left), but less so for other facets

Conclusion: These parameters are important in describing the process-based responses of plants, and apparently must be defined well to yield reasonable outputs. The parameters should be retained.

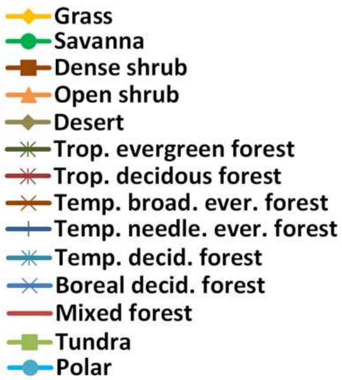
11. Standing dead production halved

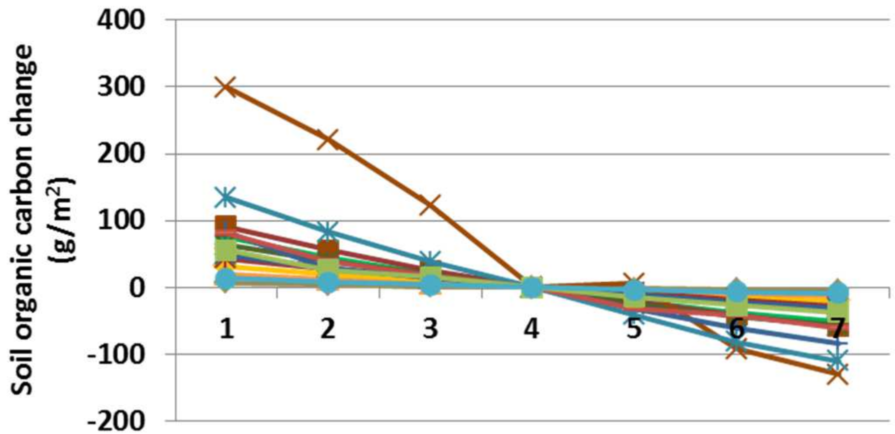
Purpose: The variable standing_dead_production_halved captures a reduction in production based on structural material that causes physical obstruction. The value is in g C m^{-2}.

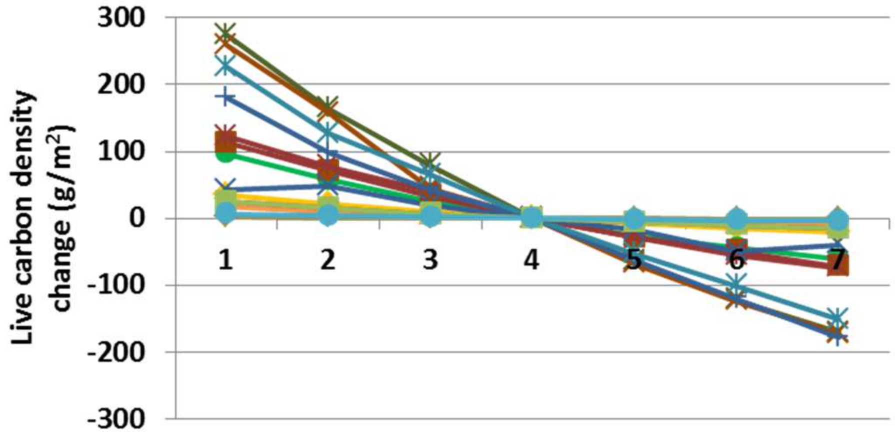
Basis for assignment: These values are variable BIOK5 in Century. The value was similar across biome types in the example files, and a single value was used here.

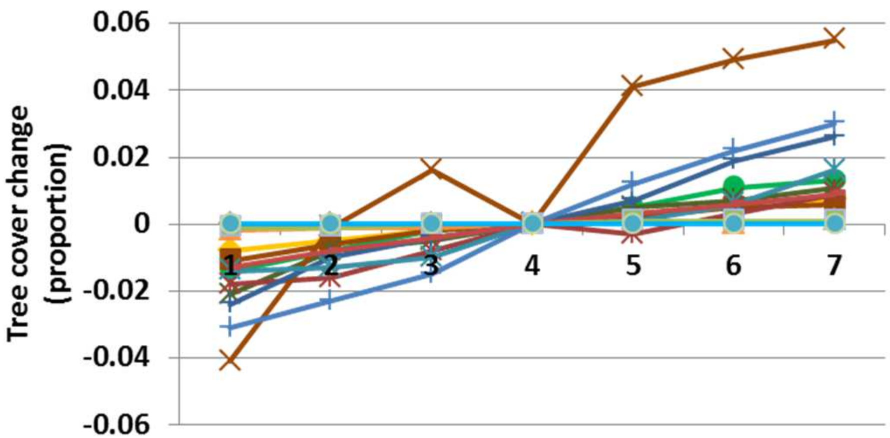
Baseline values:
999.0 (for all units)

Sensitivity values:
1 – 699.0
2 – 799.0
3 – 899.0
4 – 999.0
5 – 1099.0
6 – 1199.0
7 – 1299.0









Interpretation: The parameter is directed toward forested land cover types, and changes in responses reflect that. Forests yield structural dead material sufficient to halve production, and other types do not. Annual evapotranspiration changed up to 5.5 cm. Temperate forests changed plant-available water by 0.2 cm. Soil organic carbon increased up to 300 g m^{-2} (top). Live carbon density changed up to 280 g m^{-2} (above). Herbaceous cover changed up to 5% in forested biomes. Other changes in facet cover were modest (left).

Conclusion: This parameter improves model fit in Century, and influences outputs in G-Range. Forested landscapes are not a focus of G-Range, but the parameter may be retained.

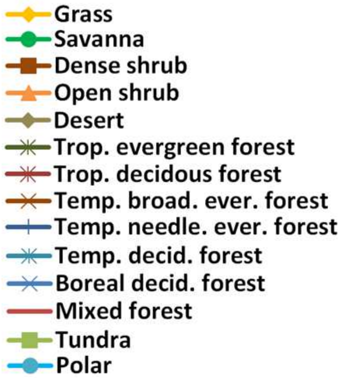
12. Radiation production coefficient

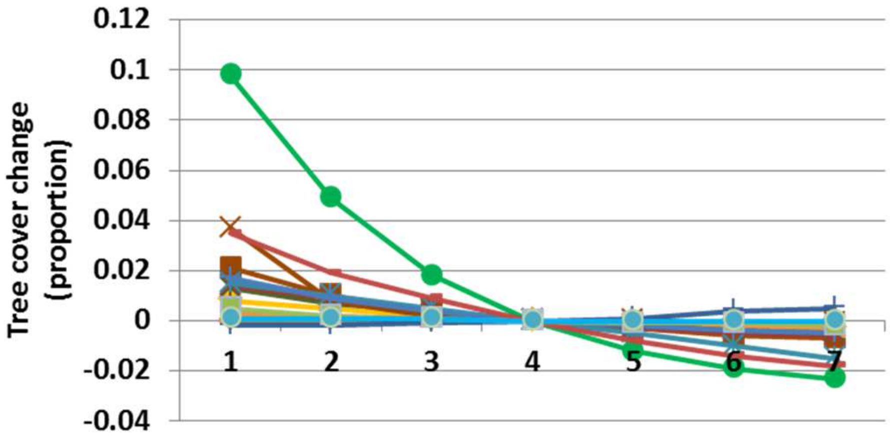
Purpose: The variable radiation_production_coefficient relates the solar radiation outside the atmosphere to monthly aboveground vegetation production. The coefficient is unitless.

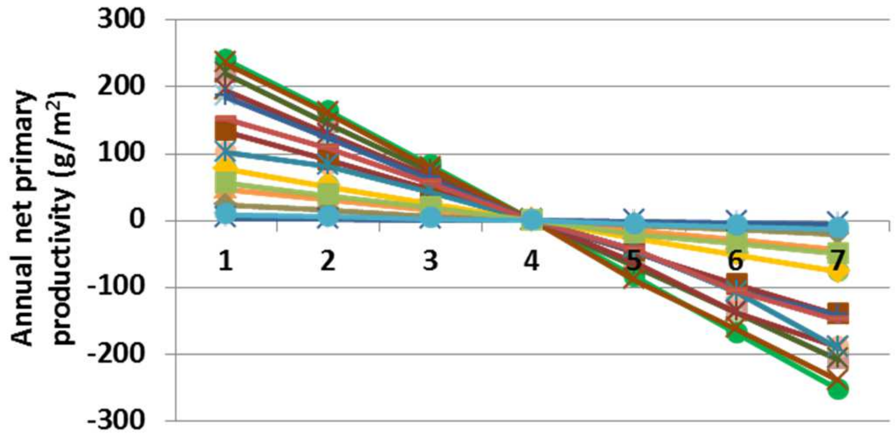
Basis for assignment: These values are variable PRDX in Century 4.5. Example files for biomes from that model suggested the value was the same across biomes.

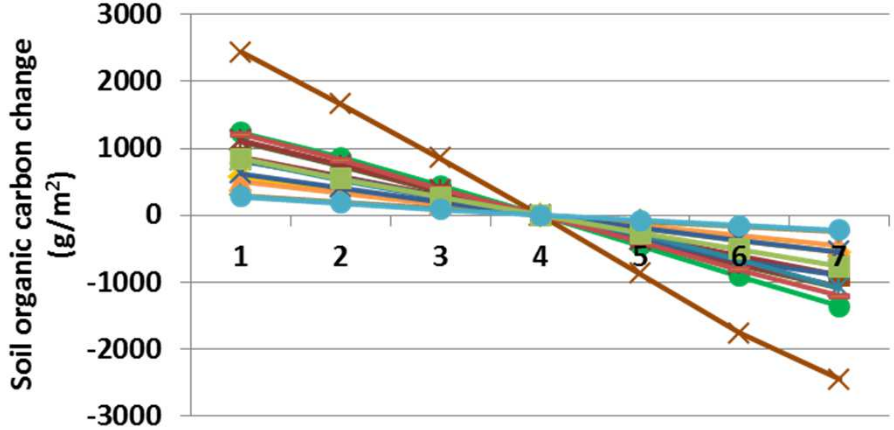
Baseline values:
0.40 (for all units)

Sensitivity values:
1 – 0.25
2 – 0.30
3 – 0.35
4 – 0.40
5 – 0.45
6 – 0.50
7 – 0.55









Interpretation: Differences in radiation production coefficients cause large-scale changes in G-Range output. Annual net primary productivity (top) and other metrics often changed in lock-step with the coefficient. C:N ratio varied by almost 1 unit. The decomposition coefficient was 0.04 less with low coefficients. Herbaceous cover changed up to 20%, and trees a 10% increase in the savanna biome under a low coefficient (left).

Conclusion: This parameter is an important control on vegetation productivity. The value is appropriate to retain in G-Range, and must be set carefully given its sensitivity. The same value for all biomes is likely insufficient.

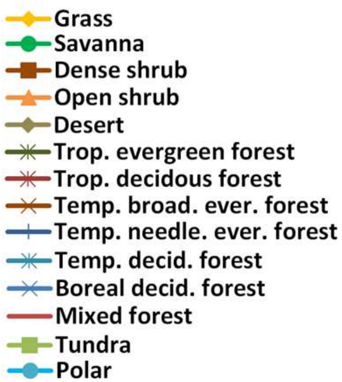
13. Fraction carbon to roots

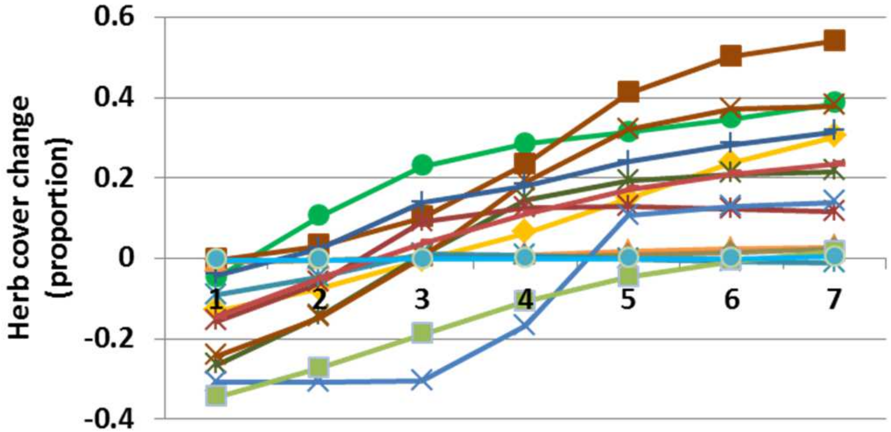
Purpose: As one may guess, the variable fraction_carbon_to_roots is the fraction of carbon assimilated that it put to roots versus aboveground plant parts.

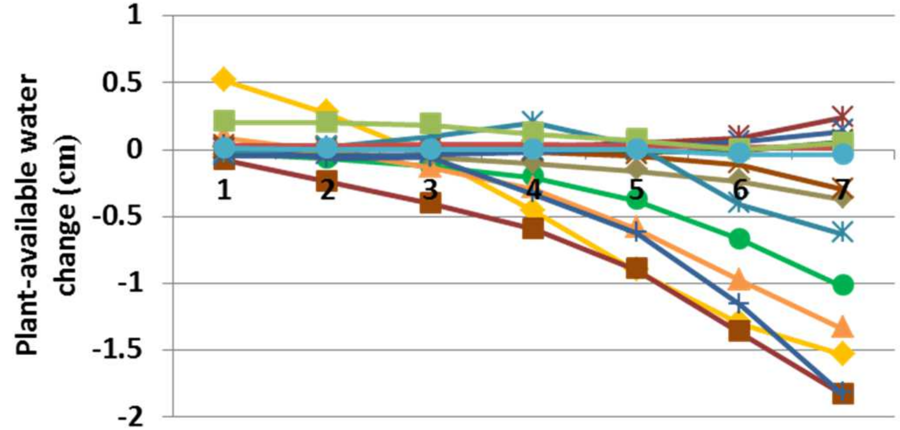
Basis for assignment: These values are variable FRTC in Century. Initial values were drawn from files distributed with Century. Numerous changes were made while adjusting the model.

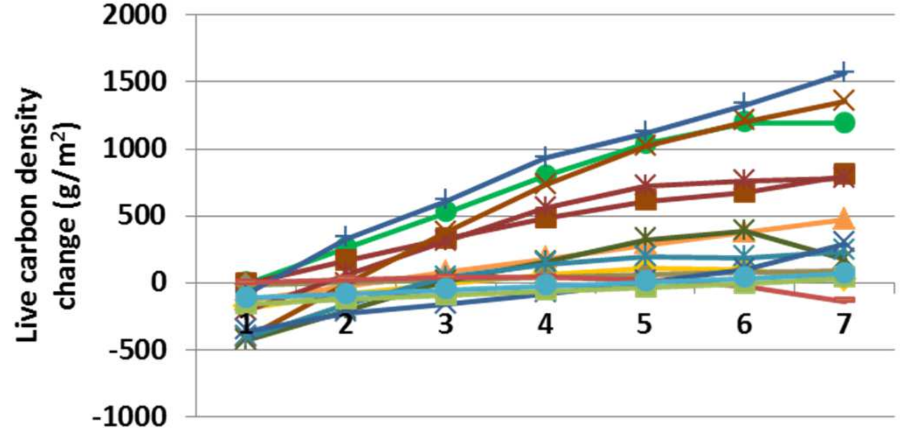
Baseline values:
0.63, 0.63, 0.63 (unit 1)
0.63, 0.56, 0.56 (unit 2)
...
0.64, 0.50, 0.50 (unit 14)
0.75, 0.75, 0.75 (unit 15)

Sensitivity values:
1 – 0.500, 0.500, 0.500
2 – 0.567, 0.567, 0.567
3 – 0.633, 0.633, 0.633
4 – 0.700, 0.700, 0.700
5 – 0.767, 0.767, 0.767
6 – 0.833, 0.833, 0.833
7 – 0.900, 0.900, 0.900









Interpretation: As one may predict, the fraction of carbon assimilated that goes to roots has profound effects on the outcome of G-Range, especially over the broad range of values studied. Annual net primary production did not change greatly (< 70 g m^{-2}), but live carbon density increased up to 1600 g m^{-2} (above). C:N ratio declined by up to two units. Soil carbon responses were more variable, increasing 500 g m^{-2} and decreasing 1700 g m^{-2} in sensitivity test 7. Tree and shrub facets each changed up to 7%. Large changes in herbaceous facet cover were observed (left).

Conclusion: The parameter is important in this process-based model, and must be set carefully. The parameter should be retained.

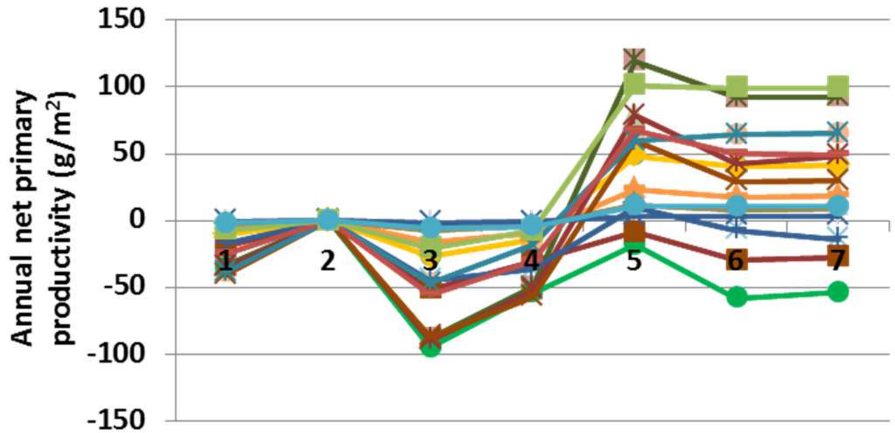
14. Grazing effect

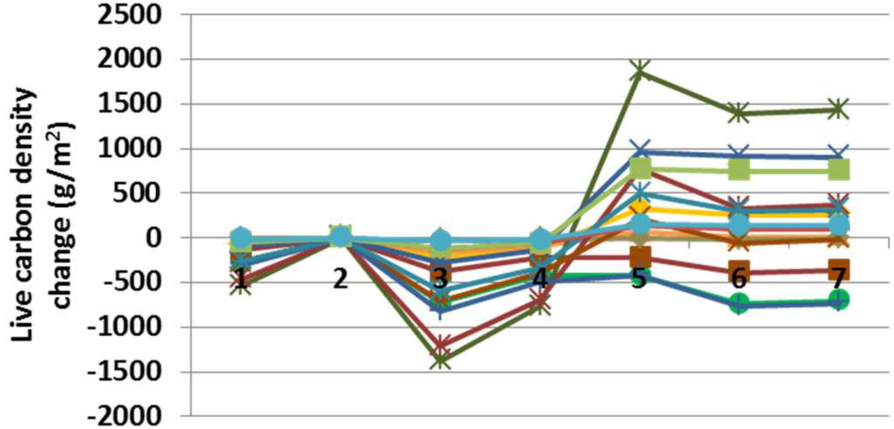
Purpose: The variable grazing_effect is unlike most in G-Range, it is a categorical variable. Grazing effect, from 0 to 6, signifies which of seven functional responses to use to model grazing effects on production. See page 54 of Boone et al. (2011) for their definitions.

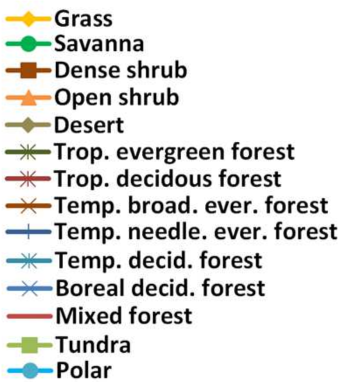
Basis for assignment: These values are variable GRZEFF in Century. A linear (type 1) response is used in most example biomes, and was used throughout here.

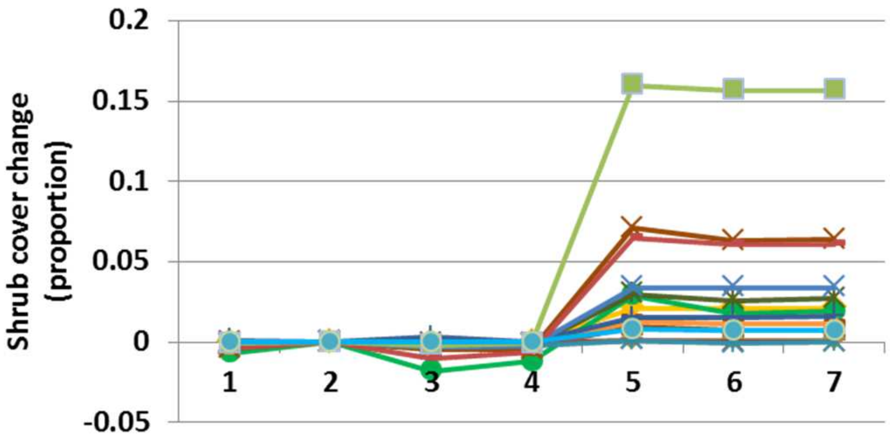
Baseline values:
1 (all units)

Sensitivity values:
1 – 0
2 – 1
3 – 2
4 – 3
5 – 4
6 – 5
7 – 6









Interpretation: The grazing functional response has important effects on the outputs from G-Range. Functional responses 0 through 3 led to relatively small changes in outputs, but 4-6 caused large changes. Effects on root to shoot ratios presumably led to those changes. Annual net primary productivity changed up to 120 g m^{-2} (top). Leaf area index declined up to 0.3, and carbon to nitrogen ratio changed < 1 unit. Herb cover declined by as much as 22% in some landscape units under responses 5 and 6. Shrubs expanded in response (left), especially in tundra, and trees expanded as well.

Conclusion: The parameter provides flexibility in G-Range modeling. The parameter should be retained.

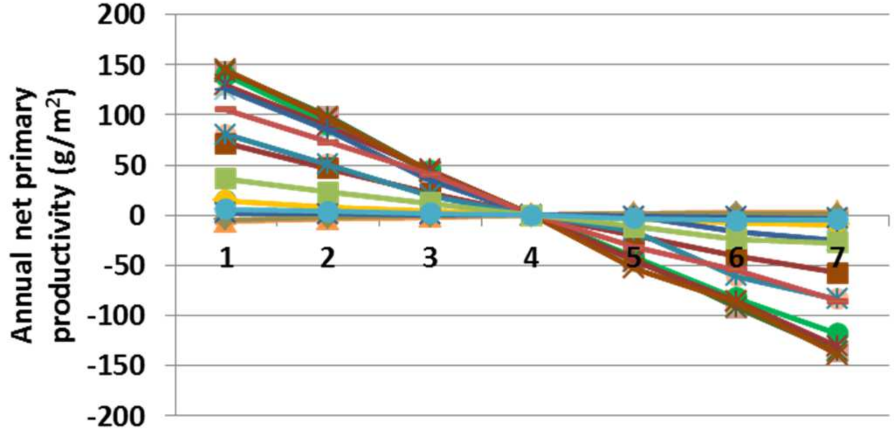
15. Effect of CO_2 on production

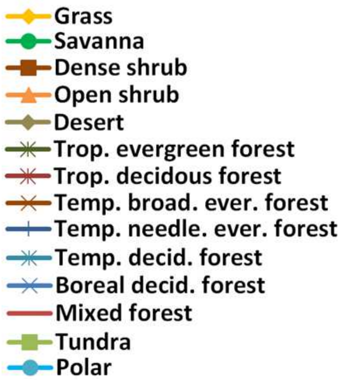
Purpose: The variable effect_of_co2_on_production is a unitless value that reflects the effect CO_2 has on the transpiration rates of plants. Under increased carbon dioxide, plants may close stomata and reduce transpiration rates.

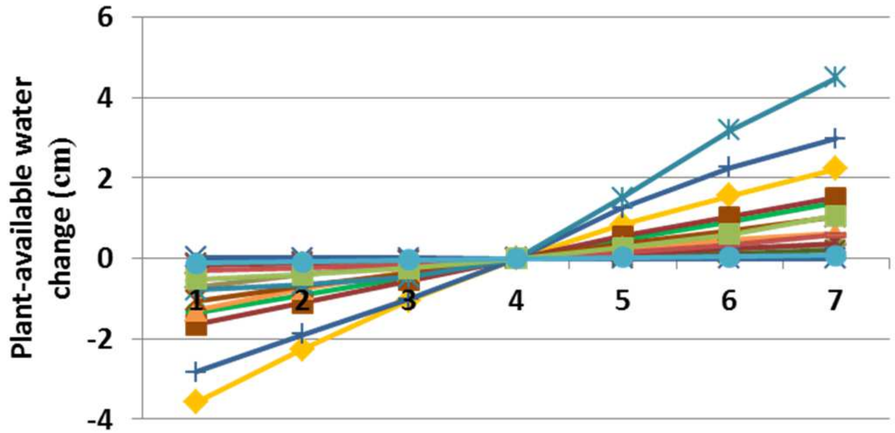
Basis for assignment: The value is variable CO2ITR in Century. The typical value used in example files is 0.8. That is taken as the base response.

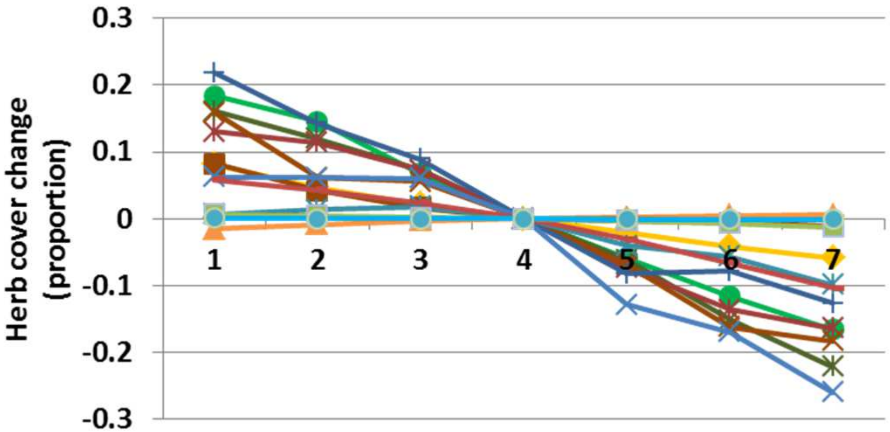
Baseline values:
0.800 (all units)

Sensitivity values:
1 – 0.600
2 – 0.667
3 – 0.733
4 – 0.800
5 – 0.867
6 – 0.933
7 – 1.000









Interpretation: The effect of CO_2 on production has large effects on model output. Net primary productivity changed up to 150 g m^{-2} (top), and plant-available soil water changed in the opposite pattern (above). Annual evapotranspiration changed in the same nature as primary productivity, up to 90 cm for tropical forests. Soil organic carbon had the similar pattern of change, with changes up to 850 g m^{-2}, except for temperate boreal forests which changed up to 1750 g m^{-2}. Herb cover changed markedly, up to 25% (left). Shrubs and trees changed less than 5%.

Conclusion: The parameter provides an opportunity for response to CO_2, and should be retained.

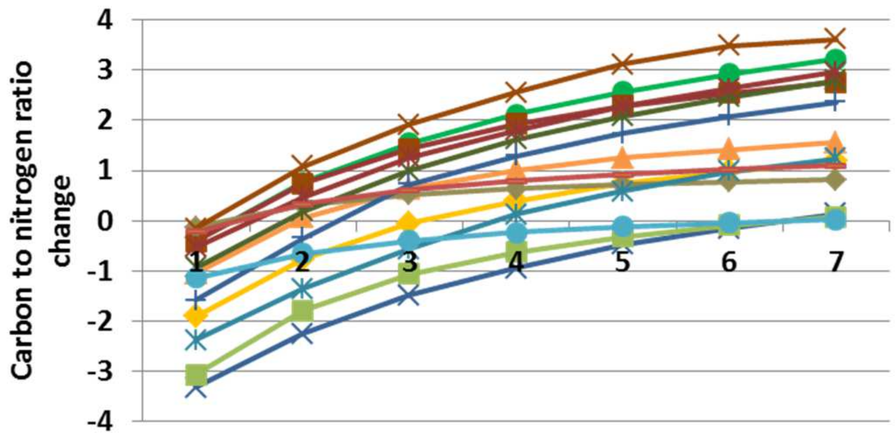
16. Decomposition rate of structure litter by inverts

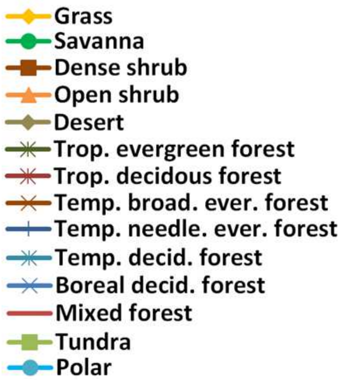
Purpose: The variable decomp_rate_structural_litter_inverts controls the rate of decomposition by invertebrates. The rates apply to the litter on the surface of the soil and below the surface, and so two values are supplied.

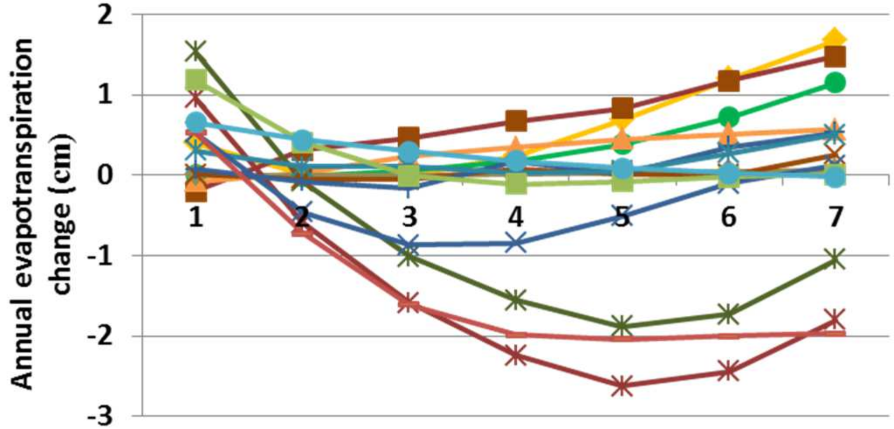
Basis for assignment: The value is variable DECINV in the Savanna model. The typical value used in applications was used here, but adjusted as the model was fit to observed data.

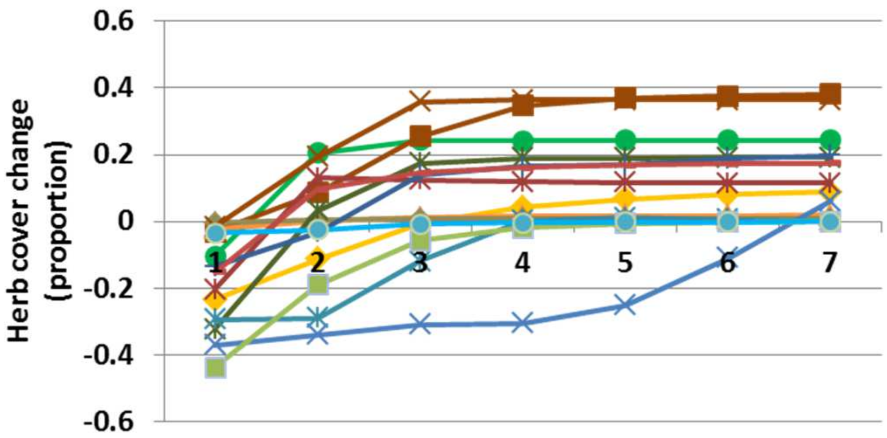
Baseline values:
Various, from 1.1 to 6.5 for the first value, and 1.1 to 6.5 for the second value

Sensitivity values:
1 – 1.0, 1.0
2 – 2.0, 2.0
3 – 3.0, 3.0
4 – 4.0, 4.0
5 – 5.0, 5.0
6 – 6.0, 6.0
7 – 7.0, 7.0









Interpretation: Annual net primary productivity changed by up to 15 g m^{-2}. Leaf area index changed little. Carbon to nitrogen ratio changed in a regular fashion (top). Annual evapotranspiration changed up to 3 cm (above). Soil temperature changed less than 0.5 degrees C. Shrub and tree cover did not change markedly, but herbaceous cover changed a great deal, 40% in either direction (left), with bare ground making up the difference.

Conclusion: The parameter yielded surprising changes to G-Range output, captures an important process, and should be retained.

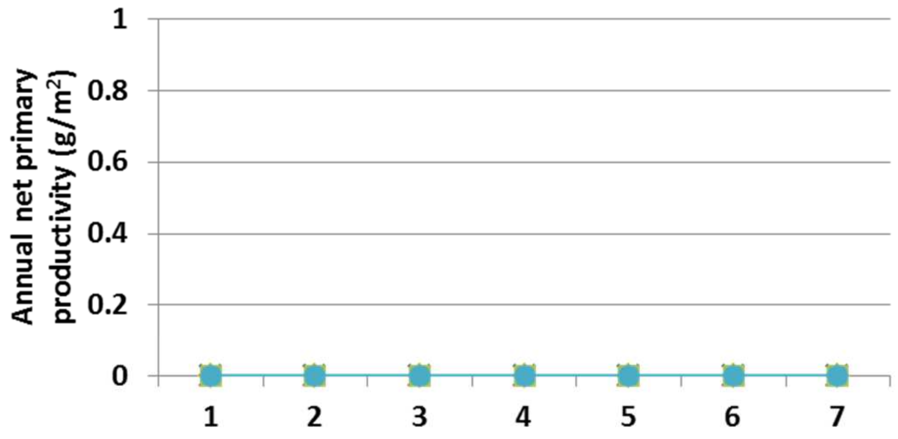
17. Feces lignin

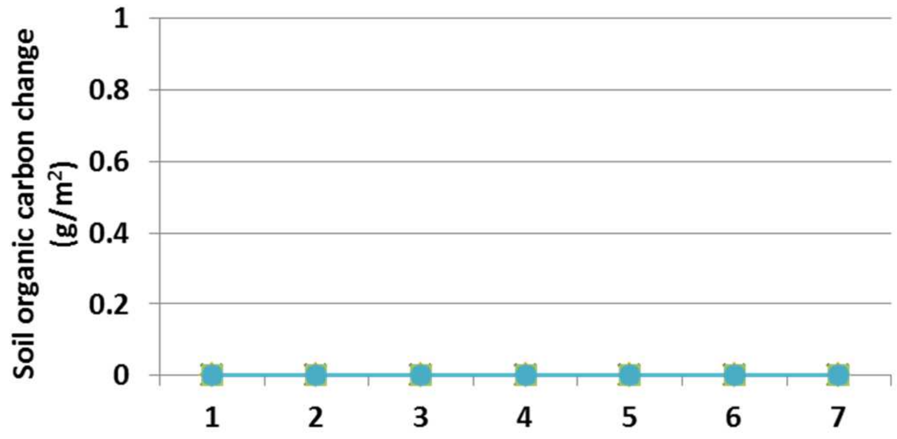
Purpose: The variable feces_lignin describes the proportion of feces that are lignin. The intent is to allow partitioning of lignin.

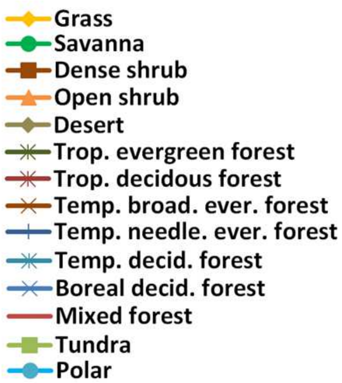
Basis for assignment: The value is variable FECLIG in the Century model. The typical value used in examples released with that software was used.

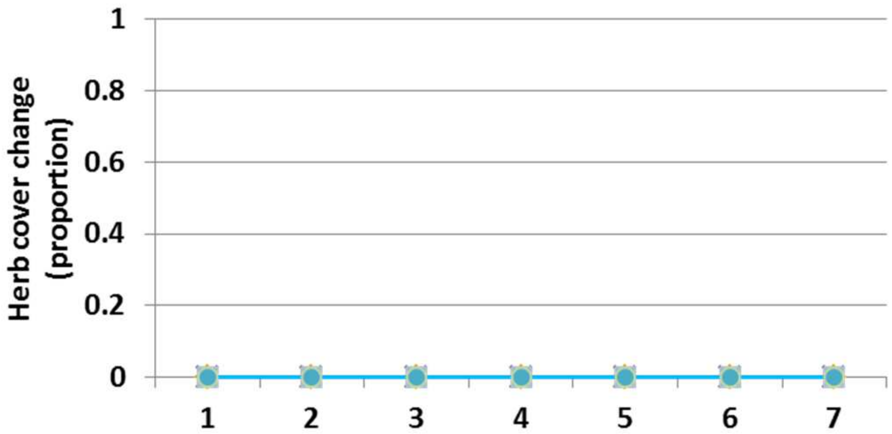
Baseline values:
0.25

Sensitivity values:
1 – 0.19
2 – 0.21
3 – 0.23
4 – 0.25
5 – 0.27
6 – 0.29
7 – 0.31









Interpretation: Feces lignin is being read into G-Range and echoed to a file, but is not being used in any way in the model.

Conclusion: Lignin in feces should be tracked. The oversight will be corrected in the released version of G-Range.

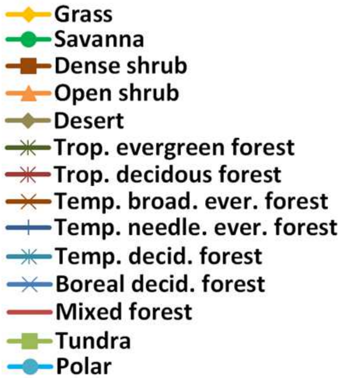
18. Lignin content fraction and precipitation

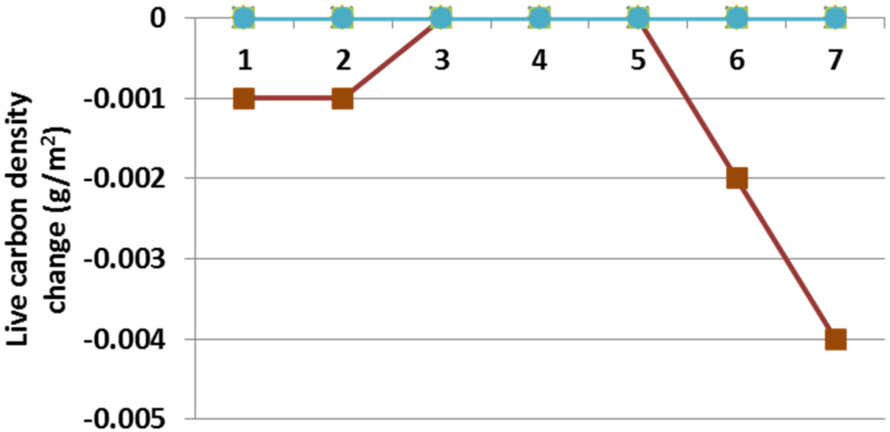
Purpose: The variable lignin-content_fraction_and_precip relates precipitation to the lignin content in materials, using two regression equations, one for aboveground and one for belowground.

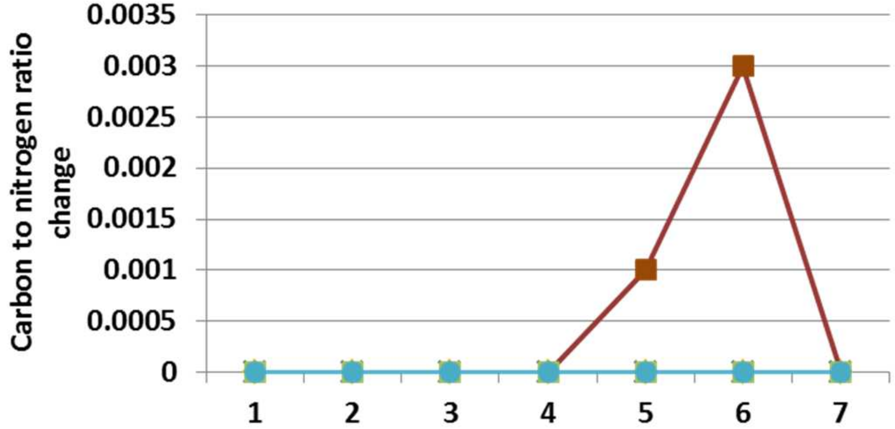
Basis for assignment: The value is variable FLIGN in the Century model. The typical value used in examples released with that software was used.

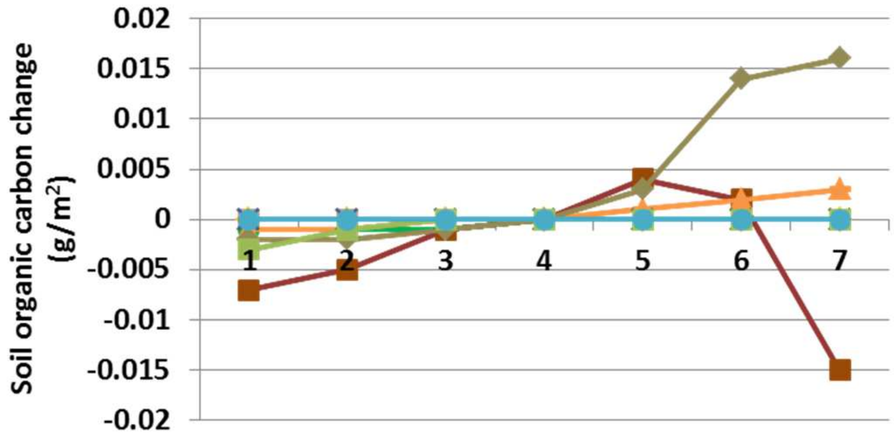
Baseline values:
0.0200, 0.0012, 0.2600, -0.0015 in all units

Sensitivity values:
(for brevity, only slopes were adjusted)
1 – 0.0200, 0.0006, 0.2600, -0.0009
2 – 0.0200, 0.0008, 0.2600, -0.0011
3 – 0.0200, 0.0010, 0.2600, -0.0013
4 – 0.0200, 0.0012, 0.2600, -0.0015
5 – 0.0200, 0.0014, 0.2600, -0.0017
6 – 0.0200, 0.0016, 0.2600, -0.0019
7 – 0.0200, 0.0018, 0.2600, -0.0021









Interpretation: Extremely small changes in G-Range output were associated with changes in the slope of lignin content given precipitation. No changes occurred in facet covers.

Conclusion: The relationship appears correctly programmed within G-Range. The sensitivity values may vary too little, and the units in the code should be checked. But in general the parameter appears to change output in a minor way.

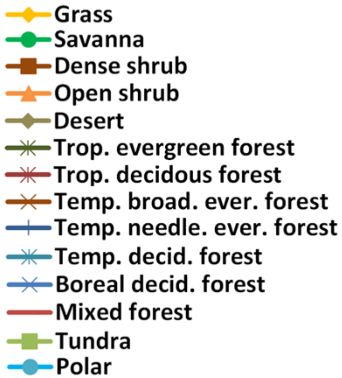
19. Fraction urine volatized

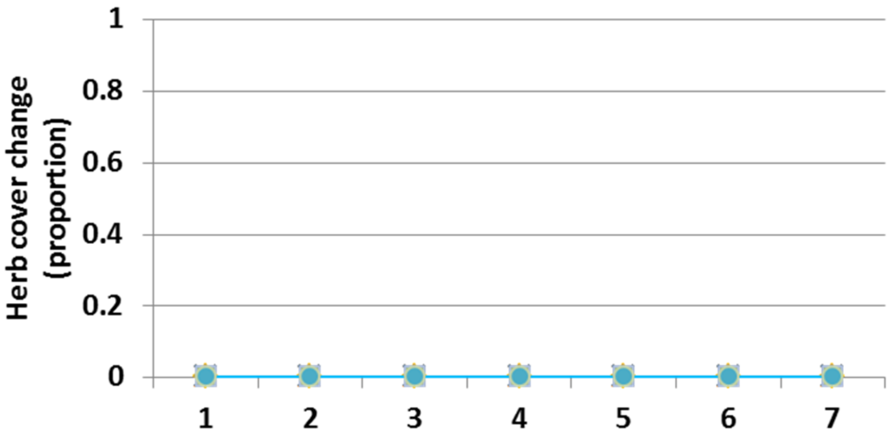
Purpose: The variable fraction_urine_volatized describes the fraction of urine nitrogen deposited that is volatilized. The variable captures the idea that all nitrogen in urine is not entering the soil.

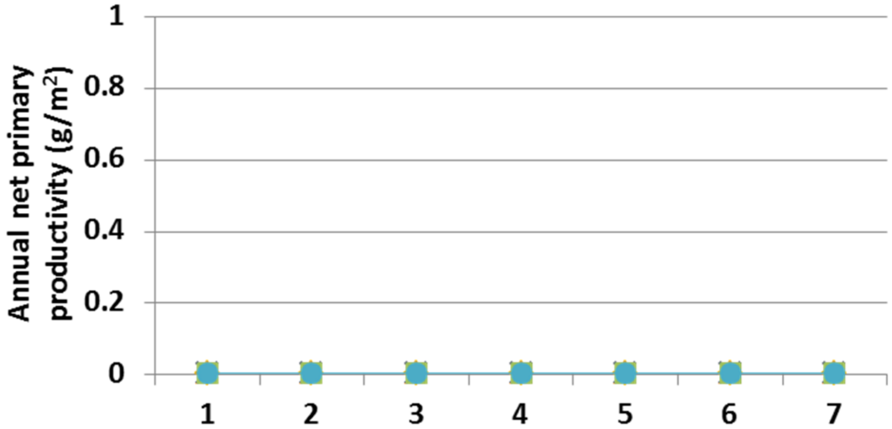
Basis for assignment: The value is variable URINEVOL in the Savanna model. The typical value used in applications was used here.

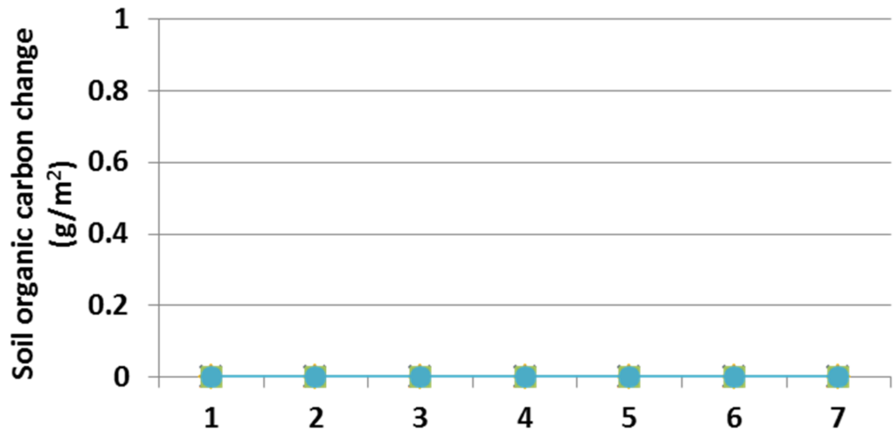
Baseline values:
0.20 in all units

Sensitivity values:
1 – 0.11
2 – 0.14
3 – 0.17
4 – 0.20
5 – 0.23
6 – 0.26
7 – 0.29









Interpretation: No changes in the biogeochemistry, productivity, or facet covers were associated with changes in the fraction of urine nitrogen that was volatized.

Conclusion: The relationship appears correctly programmed within G-Range. The quantity of urine deposited and other logic should be checked. In general the parameter is appropriate to include in G-Range and should be explored more fully.

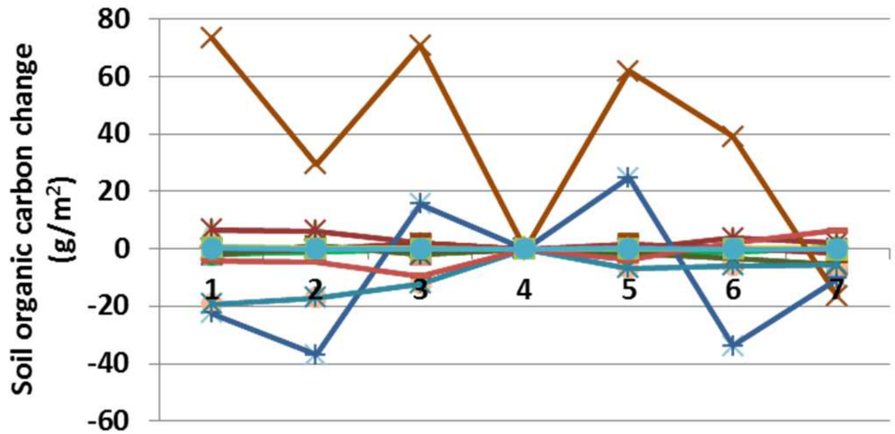
20. Precipitation nitrogen deposition

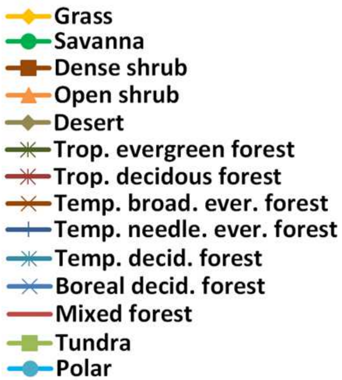
Purpose: The variable set precip_n_deposition defines a line that describes the rate of nitrogen deposition as it relates to precipitation.

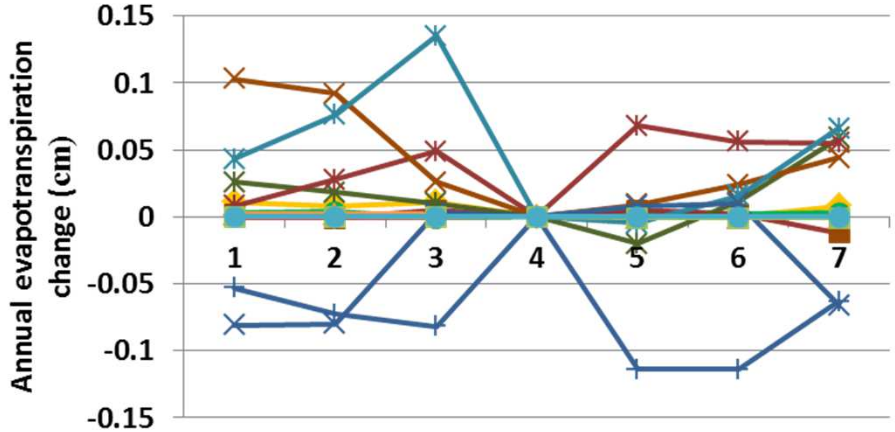
Basis for assignment: The value is variable EPNFA in the Century model. The typical values used in example files distributed with that model are used here.

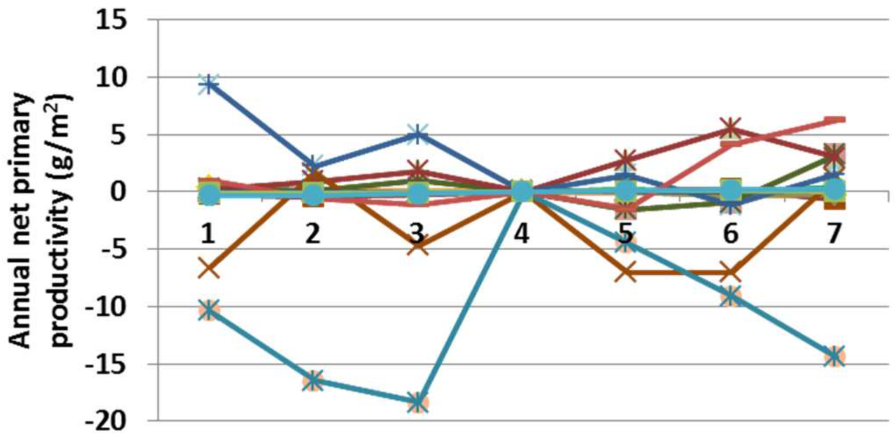
Baseline values:
0.05, 0.007in all units

Sensitivity values:
(only the slope was changed, for brevity)
1 – 0.05, 0.001
2 – 0.05, 0.003
3 – 0.05, 0.005
4 – 0.05, 0.007
5 – 0.05, 0.009
6 – 0.05, 0.011
7 – 0.05, 0.013









Interpretation: Changes in the slope associating nitrogen deposition with precipitation let to modest changes in the results of G-Range. Soil temperature a fraction of a degree, and soil water changed little as well. Carbon to nitrogen ratio changed less than 0.2. Productivity changed up to 20 g m^{-2} (left), and soil carbon changed a small amount (top). Herbs decreased up to 4% in tropical broadleaf evergreen forest. Other facets showed small changes as well.

Conclusion: The code within G-Range is incomplete. The parameters are not being used as the components of a line. The parameters will be retained and the code corrected prior to release of G-Range.

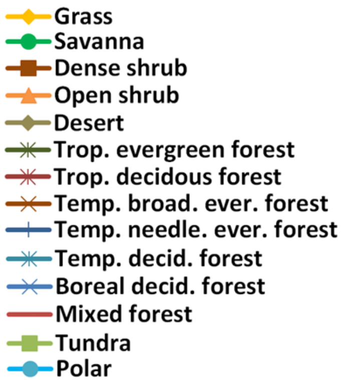
21. Precipitation nitrogen symbiotic

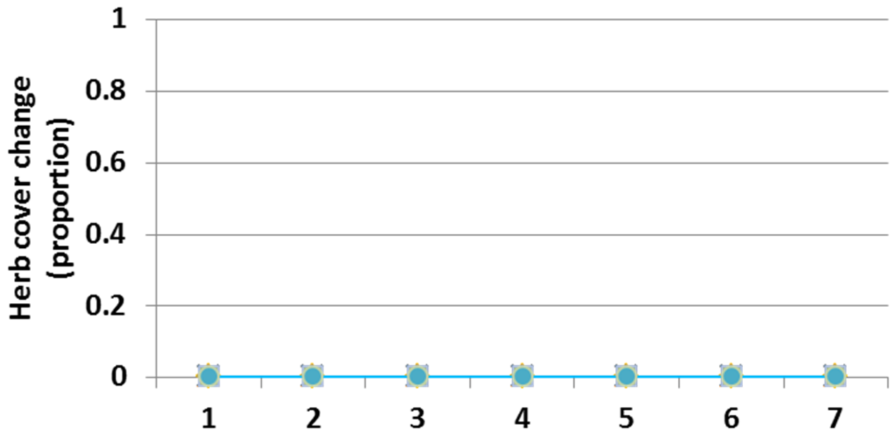
Purpose: The variable set precip_n_symbiotic defines a line that describes the rate of symbiotic nitrogen fixation as it relates to precipitation.

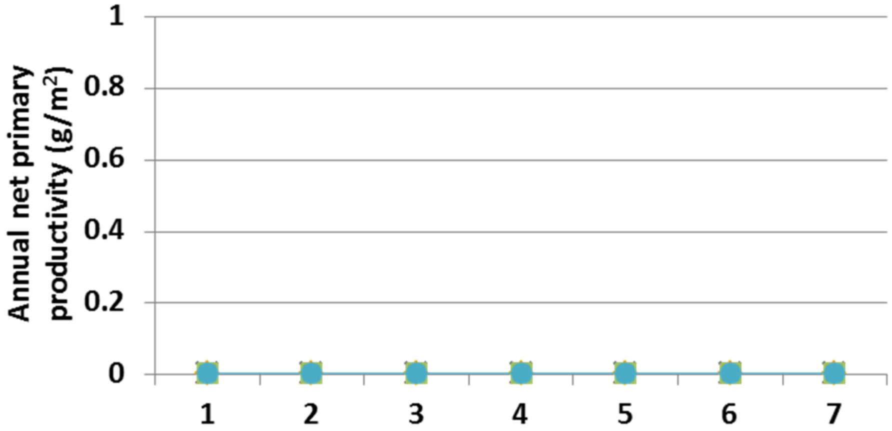
Basis for assignment: The value is variable EPNFS in the Century model. The typical values used in example files distributed with that model are used here.

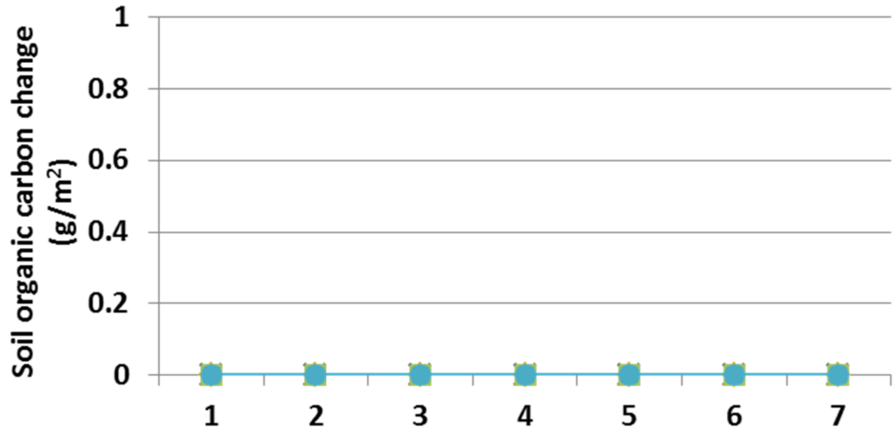
Baseline values
30.00, 0.0100 in all units

Sensitivity values:
(only the slope was changed, for brevity)
1 – 30.00, 0.040
2 – 30.00, 0.060
3 – 30.00, 0.080
4 – 30.00, 0.010
5 – 30.00, 0.012
6 – 30.00, 0.014
7 – 30.00, 0.016









Interpretation: The parameter values relating precipitation to nitrogen symbiosis are read into the software and printed to an echo file, but is not used otherwise.

Conclusion: The code within G-Range is incomplete. The parameters are not being used as the components of a line. The parameters will be retained and the code corrected prior to release of G-Range.

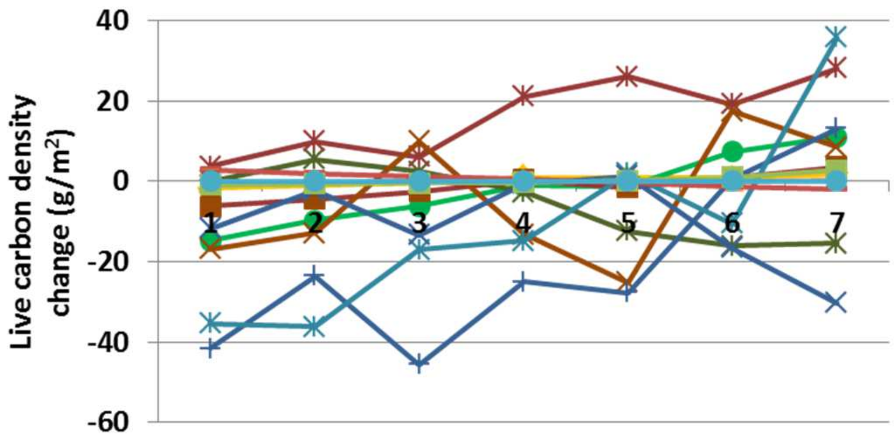
22. Decomposition litter mixing between facets

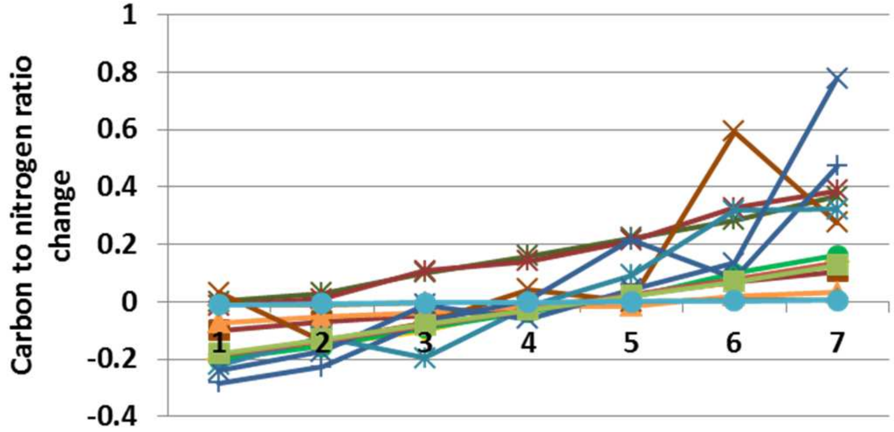
Purpose: The variable set decomp_litter_mix_facets describes the degree to which litter mixes between facets within a given landscape cell. As little falls, it may fall in neighboring facets. The value is a proportion.

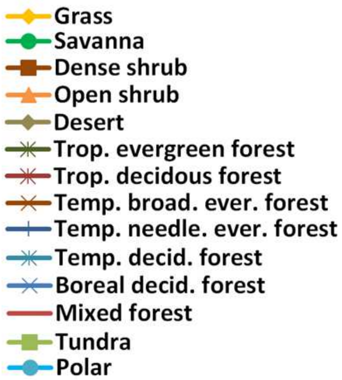
Basis for assignment: The value is variable FLITRMIX in the Savanna model. The base values used in Savanna applications were used to initialize the model, and were then modified while fitting observed values..

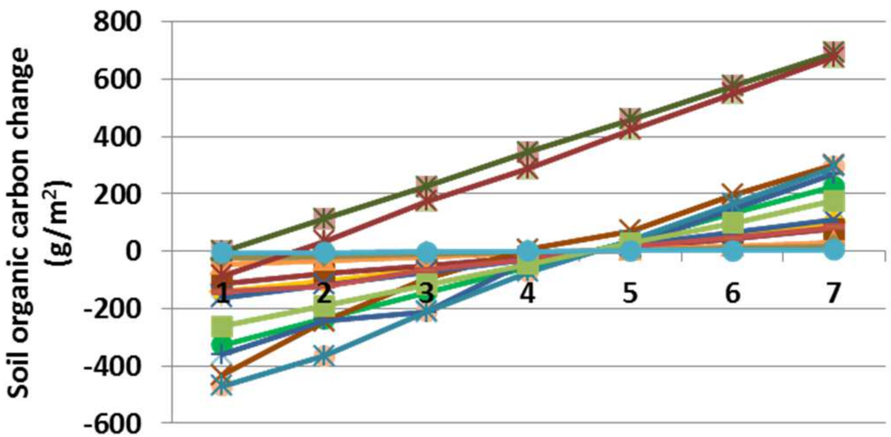
Baseline values
30.00, 0.0100 in all units

Sensitivity values:
(only the slope was changed, for brevity)
1 – 30.00, 0.040
2 – 30.00, 0.060
3 – 30.00, 0.080
4 – 30.00, 0.010
5 – 30.00, 0.012
6 – 30.00, 0.014
7 – 30.00, 0.016









Interpretation: Changes in soil carbon (left) and life carbon density were modest (top). Soil temperature was a fraction of degree higher in dense shrub in sensitivity runs 1-3. Decomposition coefficients were essentially constant. Leaf area index changed less than 0.07. A change of up to 4.5% cover in the herb facet occurred, mirrors by changes in bare ground. Tree and shrub cover changed little.

Conclusion: Mixing of litter captures a process that influences outputs from G-Range. The parameter should be retained.

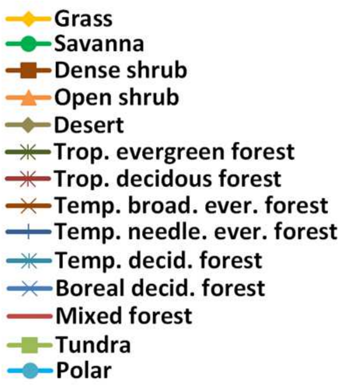
23a. Degree days phenology - Herbs

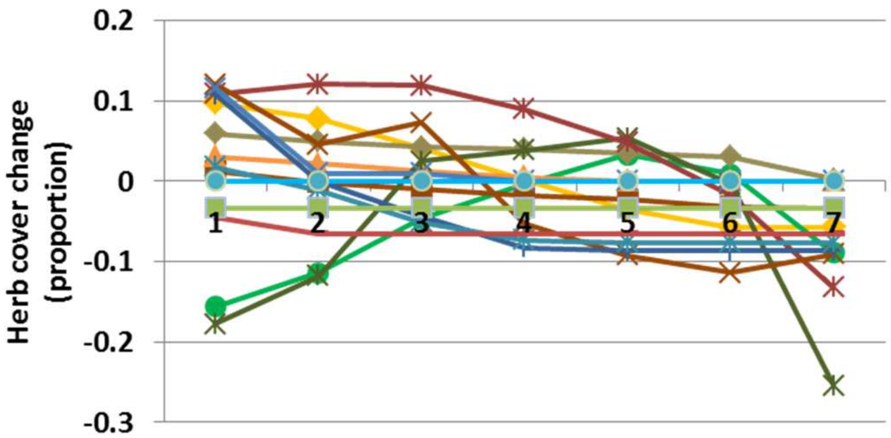
Purpose: The variable set degree_days_phen describes the relationship between heat accumulation (or degree days) and the phenology of herbs, shrubs, and trees. Three sets of values are given, four values comprising each set. These correspond with the four levels of phenology represented in G-Range.

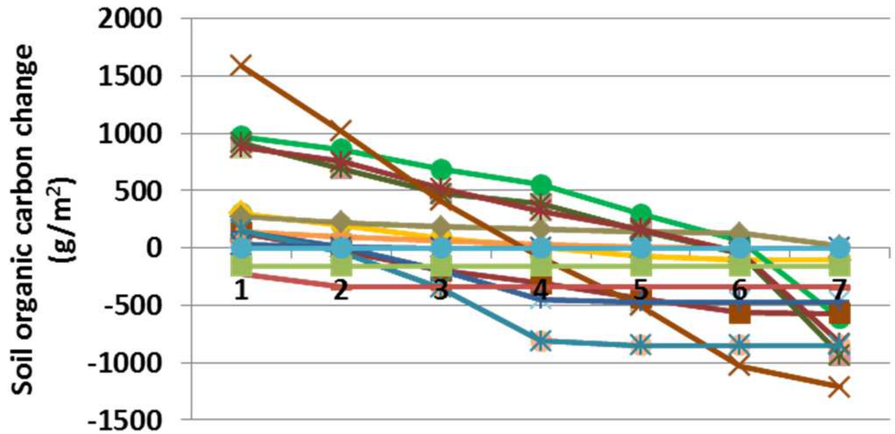
Basis for assignment: The values were set initially based on a spatial heat accumulation surface from the Oak Ridge National Laboratory Spatial Data Access Tool. The values were then adjusted to improve fit with observed data.

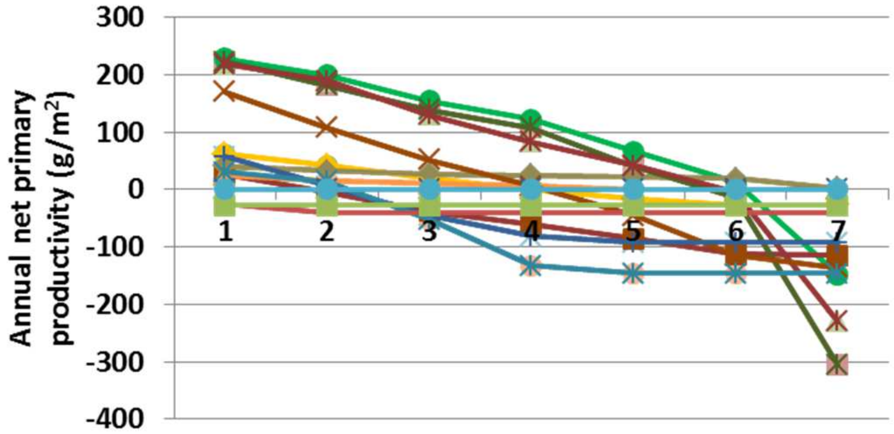
Baseline values
Unique values were used for each unit.

Sensitivity values:
(herb values changed)
1 – 50, 100, 300, 600
2 – 150, 300, 600, 1000
3 – 250, 500, 1000, 1500
4 – 500, 800, 1200, 2000
5 – 750, 1000, 1500, 2500
6 – 1000, 1500, 2250, 3000
7 – 1500, 2500, 4000, 6000









Interpretation: Degree days have the most important implications for the final phenology stage of herbs in G-Range. Herbs enter senescence based on the final value assigned. Because of that, changes in G-Range output were large. Annual evapotranspiration changed by up to 17%, and plant available soil water by 1.1 cm. Soil carbon (top) and net primary productivity changed markedly (above). Change in herbaceous cover was up to 26% (left). Trees and shrubs showed changes on par with those of herbs. Bare ground changed up to 30%.

Conclusion: The final value in phenology is most important at this point in G-Range, but phenology may play a larger role in the future.

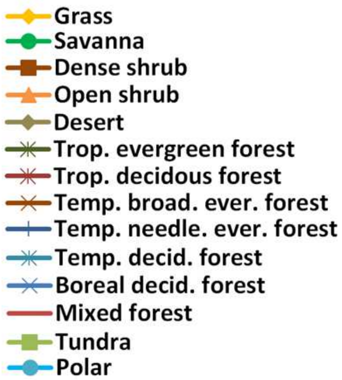
23b. Degree days phenology - Shrubs

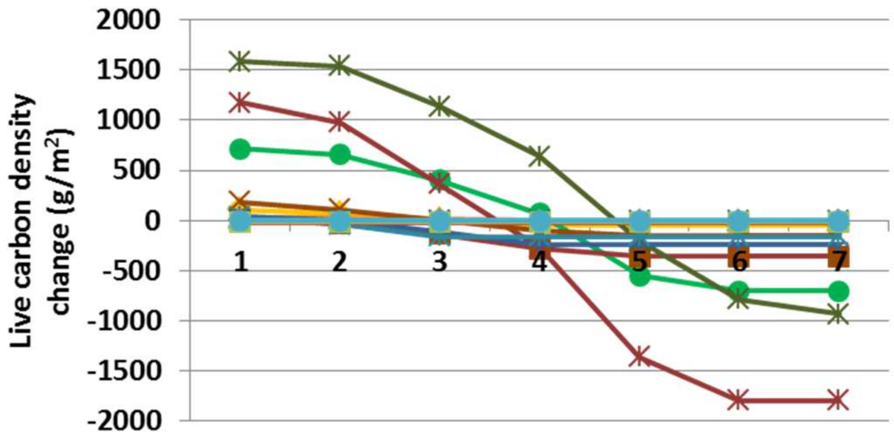
Purpose: The variable set degree_days_phen describes the relationship between heat accumulation (or degree days) and the phenology of herbs, shrubs, and trees. Three sets of values are given, four values comprising each set. These correspond with the four levels of phenology represented in G-Range.

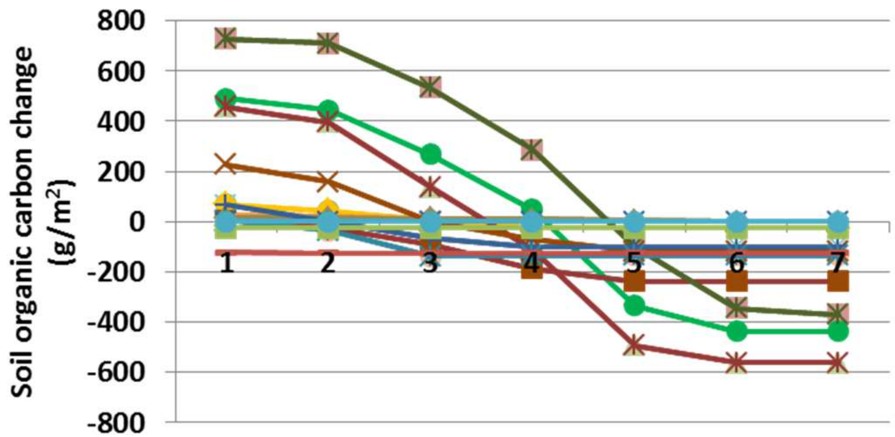
Basis for assignment: The values were set initially based on a spatial heat accumulation surface from the Oak Ridge National Laboratory Spatial Data Access Tool. The values were then adjusted to improve fit with observed data.

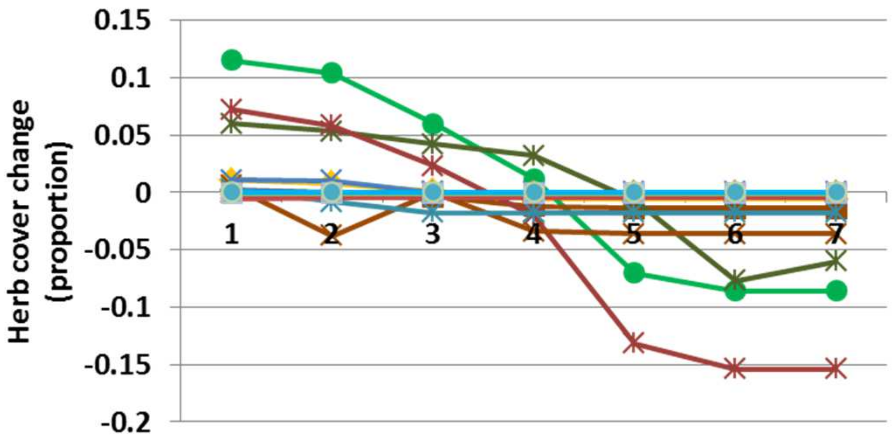
Baseline values
Unique values were used for each unit.

Sensitivity values:
(shrubs only changed)
1 – 50, 100, 400, 800
2 – 150, 300, 700, 1200
3 – 250, 500, 1200, 2000
4 – 500, 800, 1500, 3000
5 – 750, 1500, 3000, 5000
6 – 1000, 1800, 3500, 7000
7 – 1500, 2500, 4000, 8000









Interpretation: Modest changes occurred throughout G-Range associated with changes in shrub phenology as it relates to degree day accumulation. Evapotranspiration changed less than 1 cm, and soil temperature changed less than half a degree. Annual net primary productivity changed up to 150 g m^{-2}, in a pattern much like those above for live carbon density (top) and soil organic carbon (above). Herbaceous cover changed up to 15% in both directions (left), with those changes compensated by changes in bare ground.

Conclusion: Phenology may play a larger role in the future, but for now, it is a helpful trait to include in this process-based model.

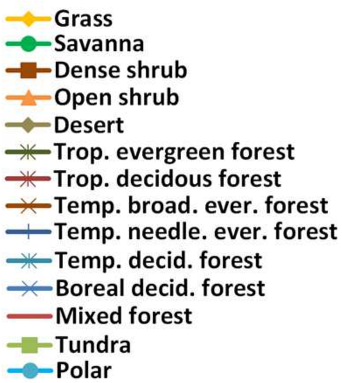
23c. Degree days phenology - Trees

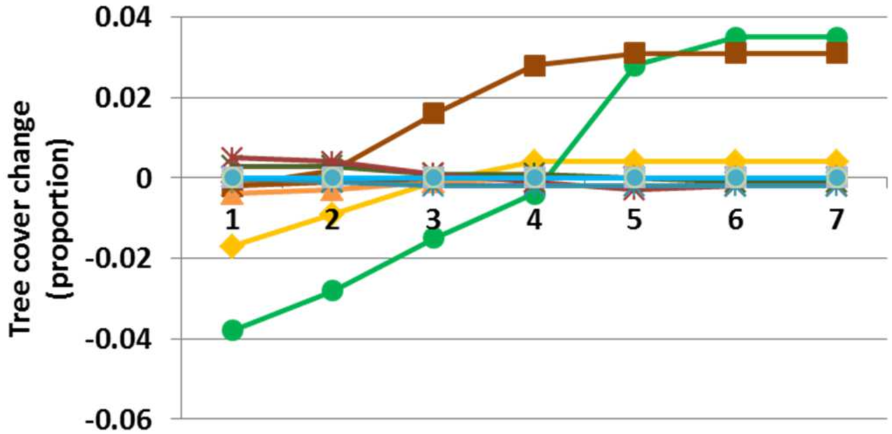
Purpose: The variable set degree_days_phen describes the relationship between heat accumulation (or degree days) and the phenology of herbs, shrubs, and trees. Three sets of values are given, four values comprising each set. These correspond with the four levels of phenology represented in G-Range.

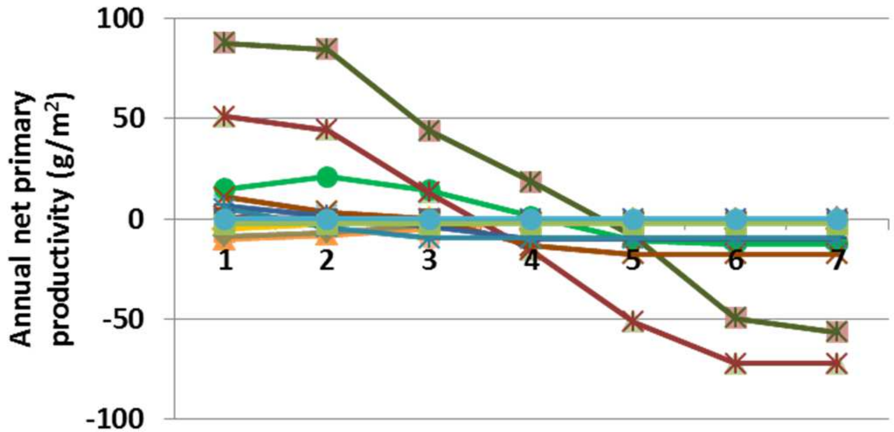
Basis for assignment: The values were set initially based on a spatial heat accumulation surface from the Oak Ridge National Laboratory Spatial Data Access Tool. The values were then adjusted to improve fit with observed data.

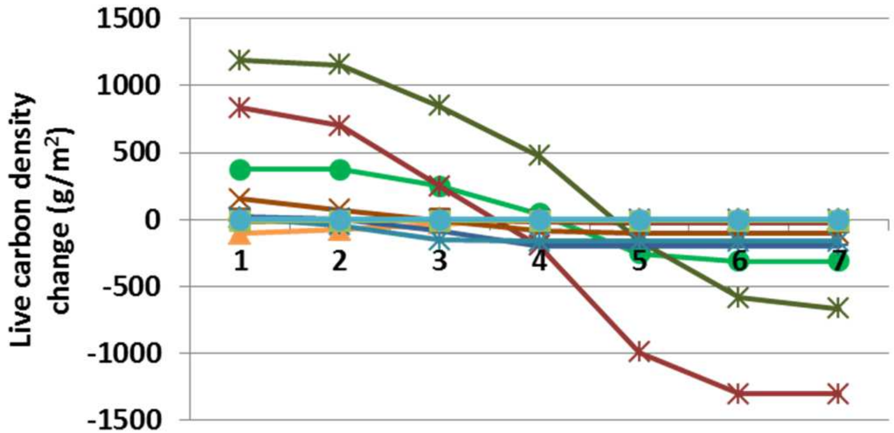
Baseline values
Unique values were used for each unit.

Sensitivity values:
(trees only changed)
1 – 50, 100, 400, 800
2 – 150, 300, 700, 1200
3 – 250, 500, 1200, 2000
4 – 500, 800, 1500, 3000
5 – 750, 1500, 3000, 5000
6 – 1000, 1800, 3500, 7000
7 – 1500, 2500, 4000, 8000









Interpretation: Some changes occurred throughout G-Range associated with changes in tree phenology as it relates to degree day accumulation. Evapotranspiration changed by more than 50 cm, and soil temperature changed up to 1 degree. Annual net primary productivity (top) and live carbon density (above) changed markedly. The tree facet cover changed up to 4% (left), as did the shrub facet cover. Herbs changed up to 25% in the savanna land cover type, and bare ground changed up to 13%.

Conclusion: Phenology may play a larger role in the future, but for now, it is a helpful trait to include in this process-based model.

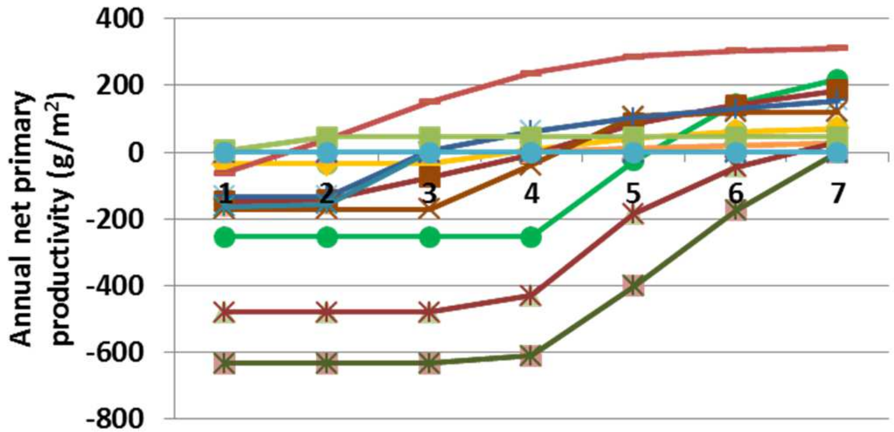
24. Degree days reset

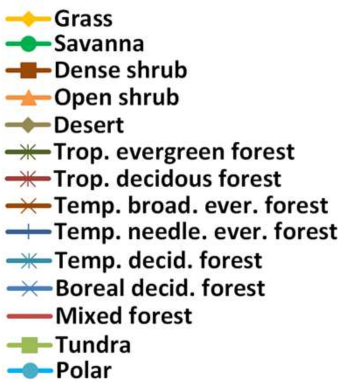
Purpose: The variable set degree_days_reset, when exceeded in a cell, changes the phenology stage of a plant type from the final value of 4 (senescence) to 0. That is, plants are reset to an early phenological stage.

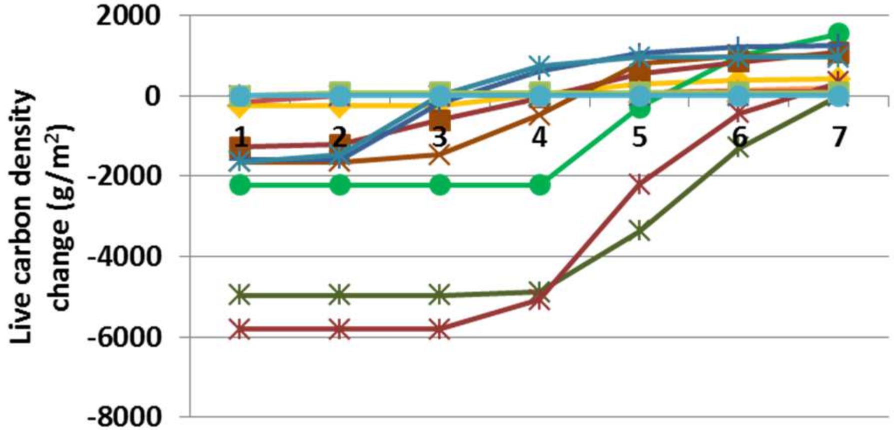
Basis for assignment: The values were set initially based on a spatial heat accumulation surface from the Oak Ridge National Laboratory Spatial Data Access Tool. The values were then adjusted to improve fit with observed data.

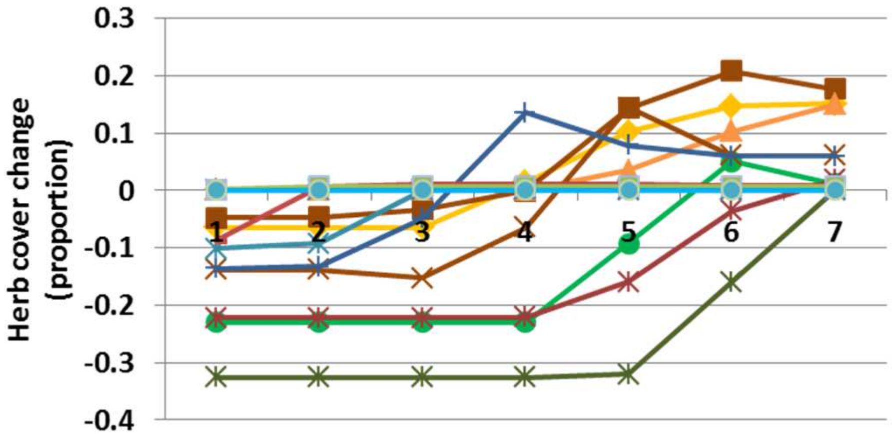
Baseline values
Various, from 350, 350, 350 to 7000, 8000, 8000

Sensitivity values:
1 – 350, 350, 350
2 – 1000, 1000, 1000
3 – 2000, 2000, 2000
4 – 3000, 3000, 3000
5 – 4500, 4500, 4500
6 – 6000, 6000, 6000
7 – 7500, 7500, 7500









Interpretation: Phenology reset is a difficult variable on which to do sensitivity analyses given the framework used here. But changes in output were large. Annual evapotranspiration declined by up to 62 cm, soil organic carbon changed up to 2250 g m-2. Live carbon density changed markedly (above), as did annual net primary productivity (top). Herbaceous cover decreased by up to 33% (left), and at the highest values used here, shrubs and trees increased in cover by up to 12%. Bare ground increased as herbaceous cover declined.

Conclusion: An ability to reset phenology is important in G-Range, and the variable set should be retained.

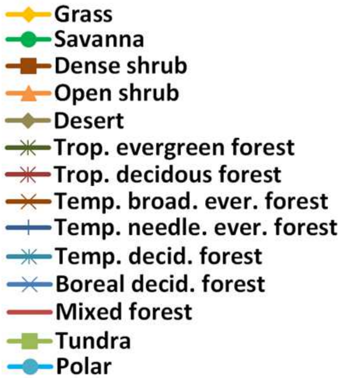
25. Tree site potential

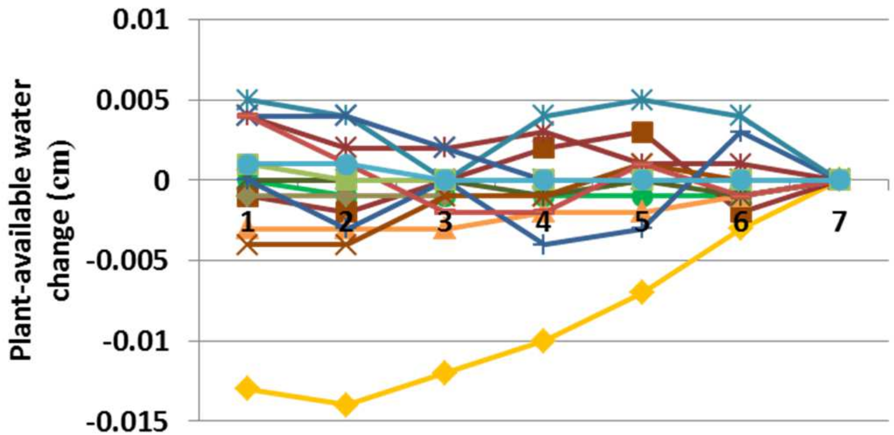
Purpose: The variable tree_site_potential is from Century, and is used to describe the site potential of an area if trees are absent, and serves as a multiplier of that potential.

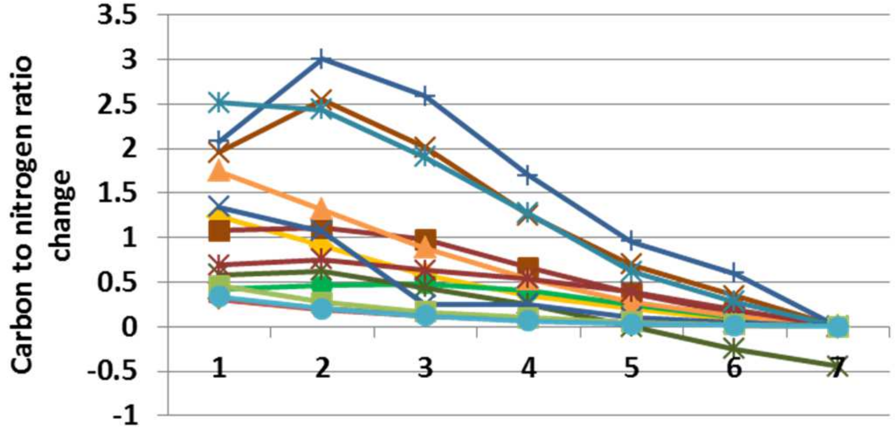
Basis for assignment: The values were set based on SITPOT-M from the Century example files, and were initialized to 1.0. During adjustment of the model the value for one landscape unit was changed..

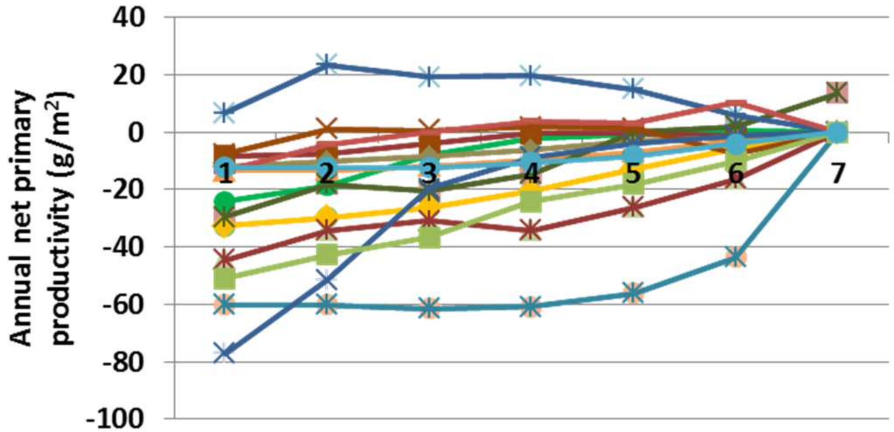
Baseline values
0.8 for unit 1
1.0 for units 2-15

Sensitivity values:
1 – 0.4
2 – 0.5
3 – 0.6
4 – 0.7
5 – 0.8
6 – 0.9
7 – 1.0









Interpretation: Annual evapotranspiration changed by up to 0.8 cm, and soil temperature and decomposition coefficients by only fractions. Soil organic carbon changed by up to 270 g m-2. Plant available soil water (left) and net primary productivity (above) changed modestly, whereas carbon to nitrogen ratios changed significantly (top). Herbaceous cover increased up to 11% in tropical deciduous forest under low tree site potentials, and decreased by 8% at high potential for tropical evergreen forest. Shrub and tree cover changed little.

Conclusion: Tree site potential may be removed for brevity, if changes in herbaceous cover are sufficient using other parameters.

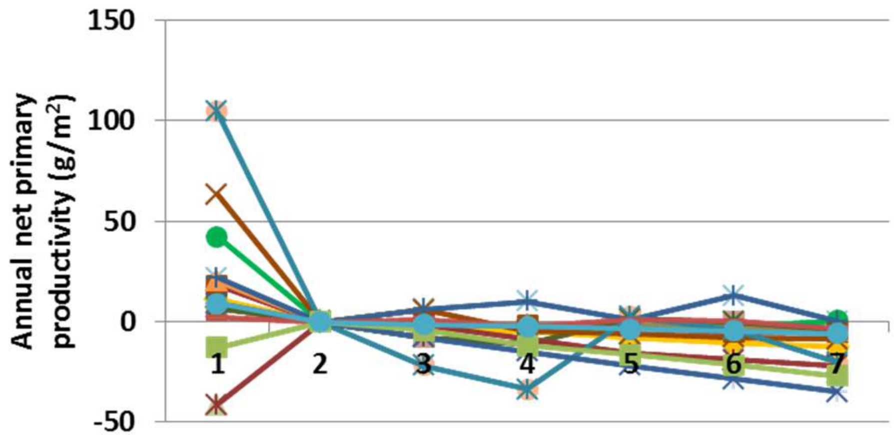
26. Maximum symbiotic N fixation ratio

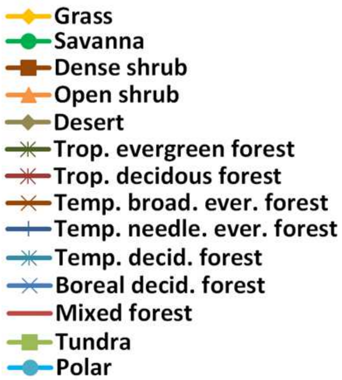
Purpose: The variable max_symbiotic_n_fixation_ratio describes the maximum nitrogen that is fixed through symbiotic relationships. The value is a ratio, but may be thought of as being in grams nitrogen for grams carbon of new growth.

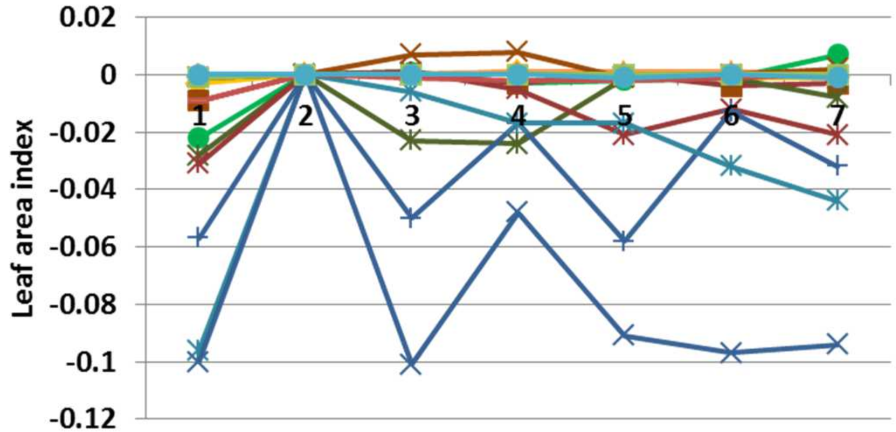
Basis for assignment: The values were set based on SNFXMX from the Century example files, and were initialized to the value used in those examples.

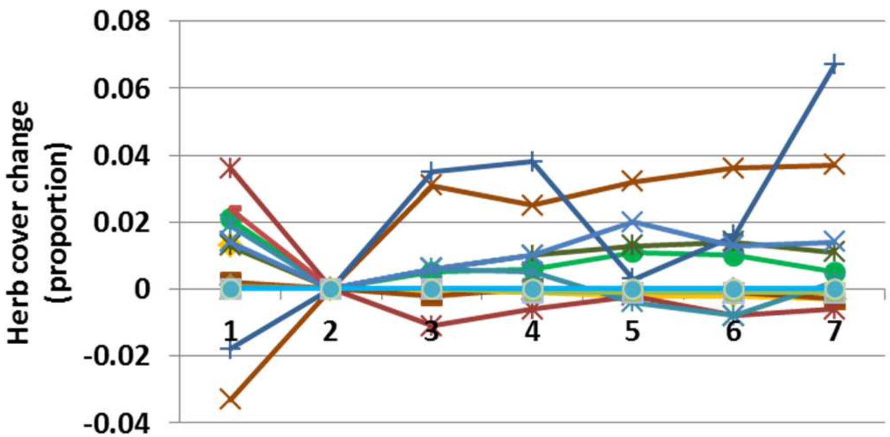
Baseline values
0.001 for all units

Sensitivity values:
1 – 0.000
2 – 0.001
3 – 0.002
4 – 0.003
5 – 0.004
6 – 0.005
7 – 0.006









Interpretation: Changes in response to varying the maximum symbiotic nitrogen fixation ratio were modest. Evapotranspiration changed up to 0.3 cm, and soil temperature a quarter of a degree. Soil organic carbon increased 117 g m-2 in temperate broadleaf evergreen forests. Carbon to nitrogen ratio mostly increased, up to 0.37 units. Live carbon density mostly declined, as did leaf area index (above). Herbaceous cover changed by up to 7% (left), and shrub and tree cover changed less than 1%.

Conclusion: The parameter captures a known process in ecosystems, and may retained, although the values assessed let to modest differences in G-Range output.

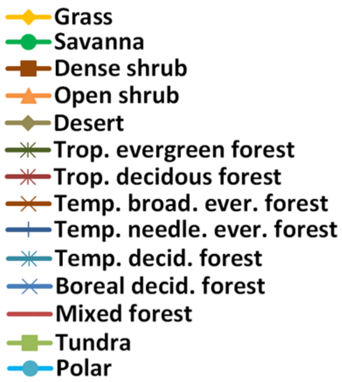
27a. Minimum C to N ratio - Herbs

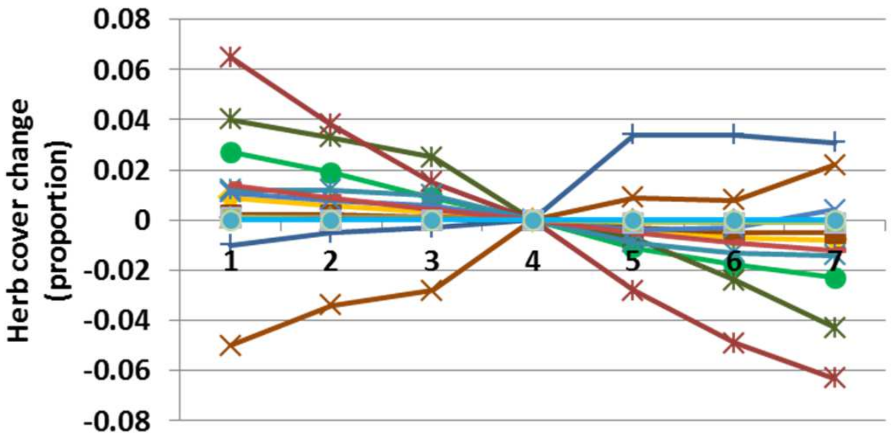
Purpose: The variable set minimum_c_n_ratio describes the minimum carbon to nitrogen ratio that may occur in simulated plant parts. Three groups of five values are used, one set for each facet, and the five values represent leaves, fine roots, fine branches, coarse branches, and coarse roots.

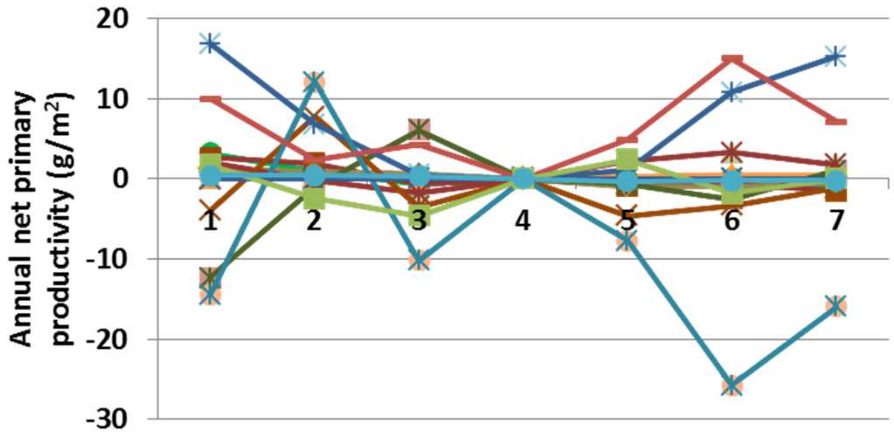
Basis for assignment: The values were set based on AGLCIS and AGLIVE in the Century example files.

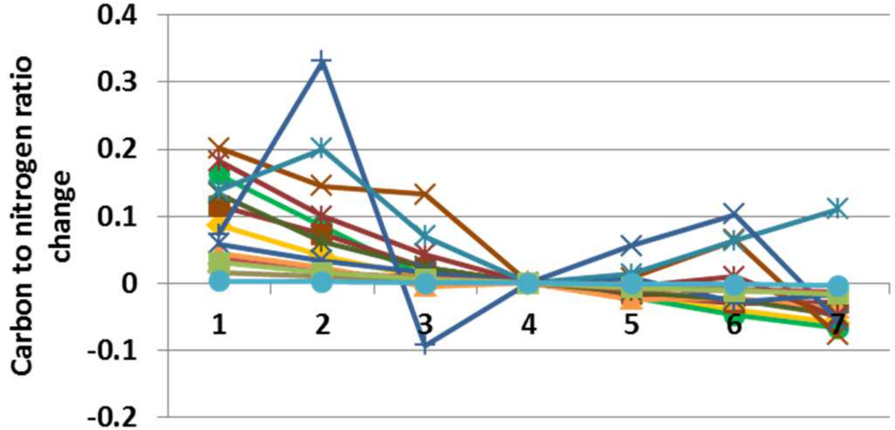
Baseline values
10., 13., 0., 0., 0., 13., 20., 30., 50., 60., 15., 21., 32., 52., 52 for all units

Sensitivity values:
(herbs only adjusted, last 3 values not used)
1 – 7, 10, 0, 0, 0
2 – 8, 11, 0, 0, 0
3 – 9, 12, 0, 0, 0
4 – 10, 13, 0, 0, 0
5 – 11, 14, 0, 0, 0
6 – 12, 15, 0, 0, 0
7 – 13, 16, 0, 0, 0









Interpretation: Responses from the model suggest that the carbon to nitrogen ratio in G-Range is rarely trimmed to the minimum for herbs. Carbon to nitrogen ratio changed by up to 0.33 (above), and net primary productivity by up to 27 g m-2 (top). Annual evapotranspiration changed up to 0.25 cm. Plant available soil water changed less than 0.01 cm. Soil organic carbon mostly increased, up to 175 g m-2 in temperate broadleaf evergreen forests. Herbaceous cover changed up to 7% (left). Shrub and tree facets changed very little.

Conclusion: The parameter set helps constrain model results and should be retained.

27b. Minimum C to N ratio - Shrubs

Purpose: The variable set minimum_c_n_ratio describes the minimum carbon to nitrogen ratio that may occur in simulated plant parts. Three groups of five values are used, one set for each facet, and the five values represent leaves, fine roots, fine branches, coarse branches, and coarse roots.

Basis for assignment: The values were set based on AGLCIS and AGLIVE in the Century example files.

Baseline values

10., 13., 0., 0., 0., 13., 20., 30., 50., 60., 15., 21., 32., 52., 52 for all units

Sensitivity values:

(shrubs only adjusted)

1 – 10, 14, 20, 38, 48

2 – 11, 16, 23, 42, 52

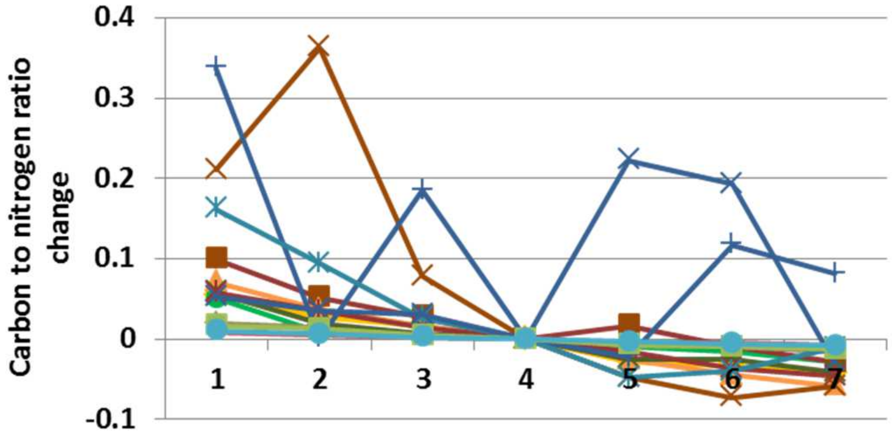
3 – 12, 18, 27, 46, 56

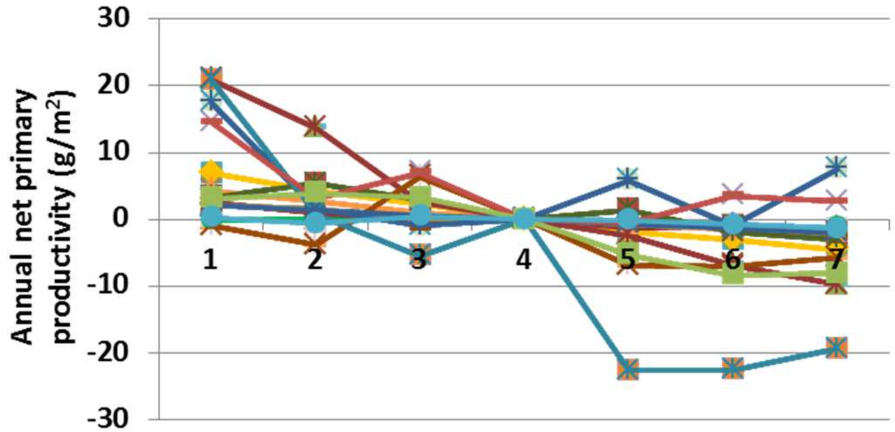
4 – 13, 20, 30, 50, 60

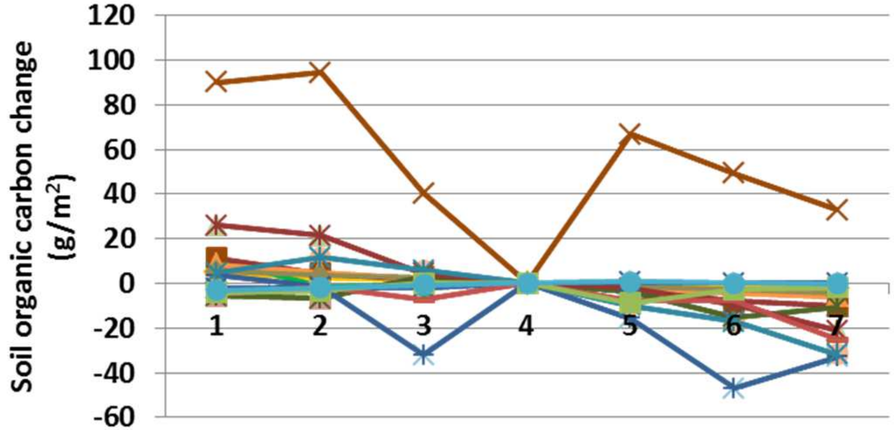
5 – 14, 22, 33, 54, 64

6 – 15, 24, 36, 58, 68

7 – 16, 26, 39, 62, 72







Interpretation: As elsewhere, potential evapotranspiration and snow water equivalent are not sensitivity to this parameter. Soil temperature changes a fraction of a degree. Carbon to nitrogen ratio changed up to 0.37 units (left). Annual net primary productivity and soil organic carbon change a small amount (top, above). Leaf area index changed up to 0.07 units. Coefficients associated with decomposition were essentially unchanged. Herbaceous cover changed up to 4%. Shrub and tree facets changed a fraction of a percent.

Conclusion: The parameter set helps constrain model results and should be retained.

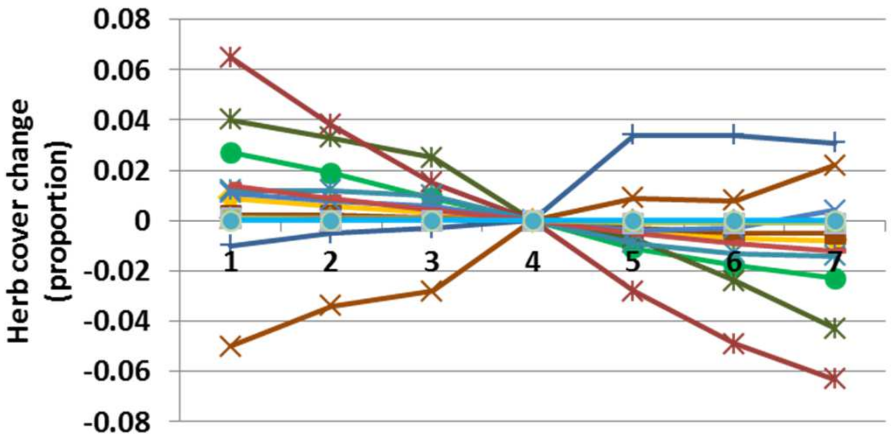
27c. Minimum C to N ratio - Trees

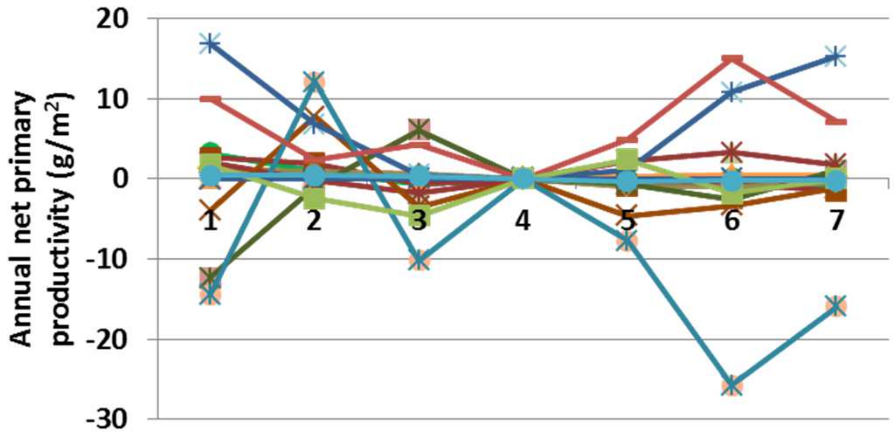
Purpose: The variable set minimum_c_n_ratio describes the minimum carbon to nitrogen ratio that may occur in simulated plant parts. Three groups of five values are used, one set for each facet, and the five values represent leaves, fine roots, fine branches, coarse branches, and coarse roots.

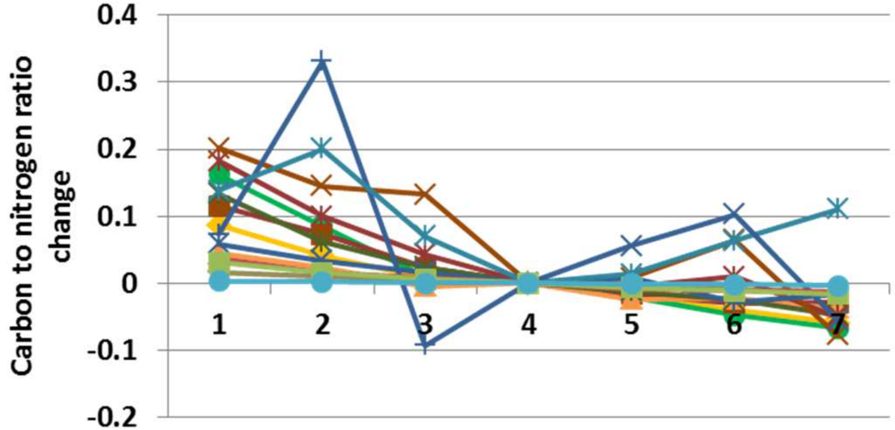
Basis for assignment: The values were set based on AGLCIS and AGLIVE in the Century example files.

Baseline values
10., 13., 0., 0., 0., 13., 20., 30., 50., 60., 15., 21., 32., 52., 52 for all units

Sensitivity values:
(trees only adjusted)
1 – 12, 15, 23, 40, 40
2 – 13, 17, 26, 44, 44
3 – 14, 19, 29, 48, 48
4 – 15, 21, 32, 52, 52
5 – 16, 23, 35, 56, 56
6 – 17, 25, 38, 60, 60
7 – 18, 27, 41, 64, 64







Interpretation: Responses from the model suggest that the carbon to nitrogen ratio in G-Range is rarely trimmed to the minimum for herbs. Carbon to nitrogen ratio changed by up to 0.33 (above), and net primary productivity by up to 27 g m-2 (top). Annual evapotranspiration changed up to 0.25 cm. Plant available soil water changed less than 0.01 cm. Soil organic carbon mostly increased, up to 175 g m-2 in temperate broadleaf evergreen forests. Herbaceous cover changed up to 7% (left). Shrub and tree facets changed very little.

Conclusion: The parameter set helps constrain model results and should be retained.

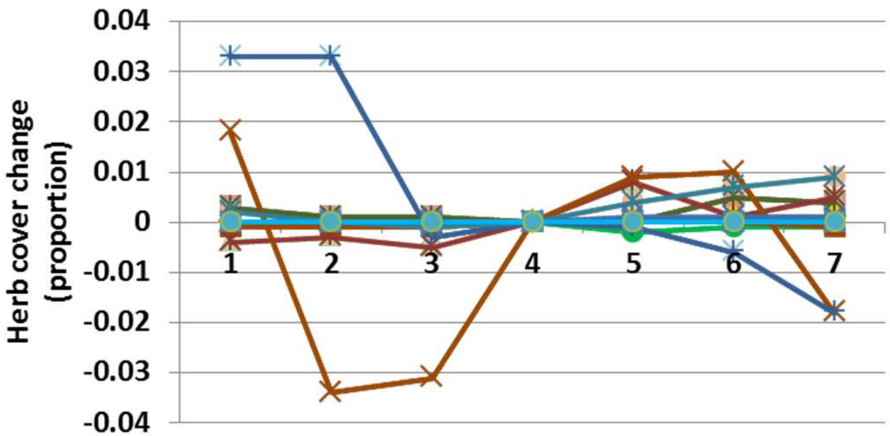
28a. Maximum C to N ratio - Herbs

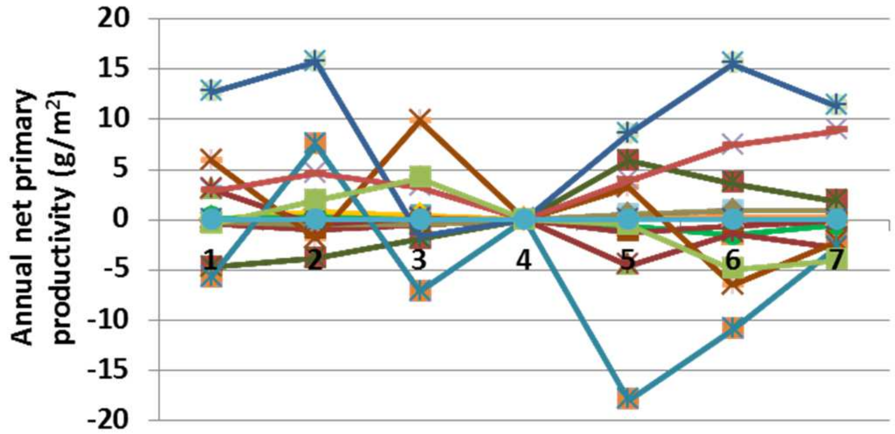
Purpose: The variable set maximum_c_n_ratio describes the maximum carbon to nitrogen ratio that may occur in simulated plant parts. Three groups of five values are used, one set for each facet, and the five values represent leaves, fine roots, fine branches, coarse branches, and coarse roots.

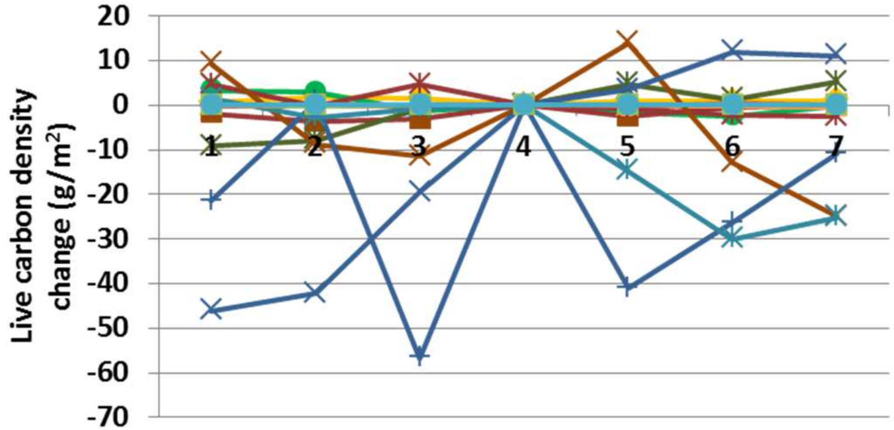
Basis for assignment: The values were set based on AGLCIS and AGLIVE in the Century example files.

Baseline values
30., 33., 0., 0., 33., 40., 50., 80., 90., 35., 51., 62., 92., 95. for all units

Sensitivity values:
(herbs only adjusted, last 3 values not used)
1 – 24, 27, 0, 0, 0
2 – 26, 29, 0, 0, 0
3 – 28, 31, 0, 0, 0
4 – 30, 33, 0, 0, 0
5 – 32, 35, 0, 0, 0
6 – 34, 37, 0, 0, 0
7 – 36, 39, 0, 0, 0







Interpretation: Changes associated with maximum c to n ratio sensitivity are modest. Annual evapotranspiration changed less than 0.2 cm, and temperature a small fraction of a degree. Annual net primary productivity changes up to 20 g m^{-2} (top). Carbon density changed up to 57 g m^{-2} in temperature forests, up to 17 g m^{-2} in other biomes. Herbaceous cover changed up to 4% (left). Shrub and tree facets changed a fraction of a percent. Bare ground expands as herbaceous cover declines.

Conclusion: The parameter set helps constrain model results and should be retained.

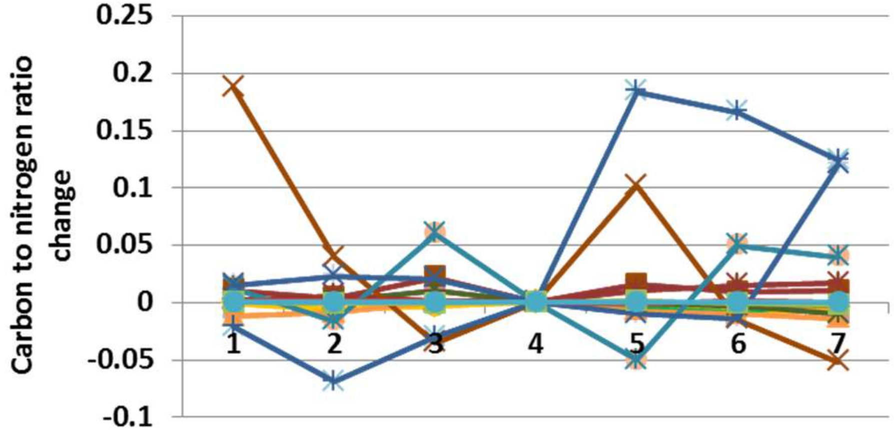
28b. Maximum C to N ratio - Shrubs

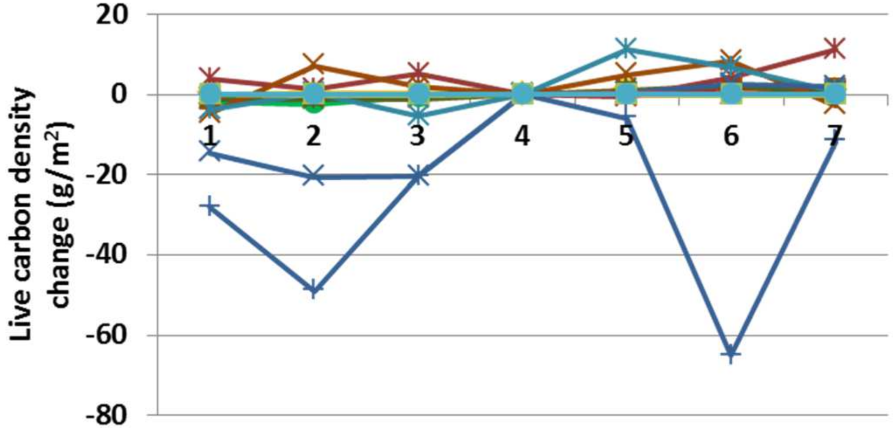
Purpose: The variable set maxmum_c_n_ratio describes the maximum carbon to nitrogen ratio that may occur in simulated plant parts. Three groups of five values are used, one set for each facet, and the five values represent leaves, fine roots, fine branches, coarse branches, and coarse roots.

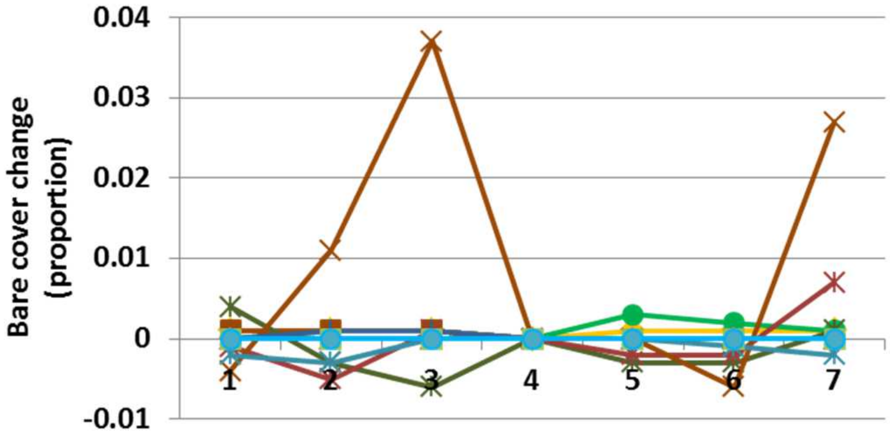
Basis for assignment: The values were set based on AGLCIS and AGLIVE in the Century example files.

Baseline values
30., 33., 0., 0., 33., 40., 50., 80., 90., 35., 51., 62., 92., 95. for all units

Sensitivity values:
(shrubs only adjusted)
1 – 27, 34, 41, 68, 78
2 – 29, 36, 44, 72, 82
3 – 31, 38, 47, 76, 86
4 – 33, 40, 50, 80, 90
5 – 35, 42, 53, 84, 94
6 – 37, 44, 56, 88, 98
7 – 39, 46, 59, 91, 102







Interpretation: In general, changes in responses were minimal, suggesting that maximum carbon to nitrogen ratios were not being enforced in modeling very often, which is good. Decomposition coefficients did not change. Carbon to nitrogen ratios changed a fraction (top), and live carbon density was changed little, except in evergreen forests. Herbaceous cover changed up to 4%, with an accompanying change in bare ground cover (left). Shrub and tree facets changed a fraction of a percent.

Conclusion: The parameter set helps constrain model results and should be retained.

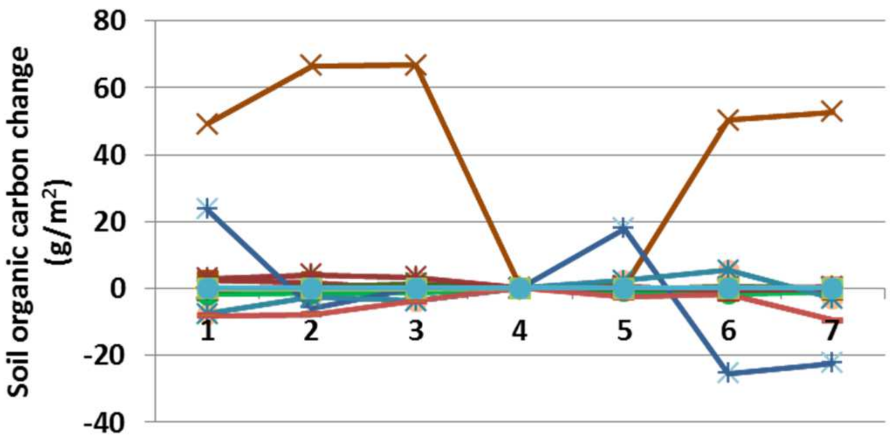
28c. Maximum C to N ratio - Trees

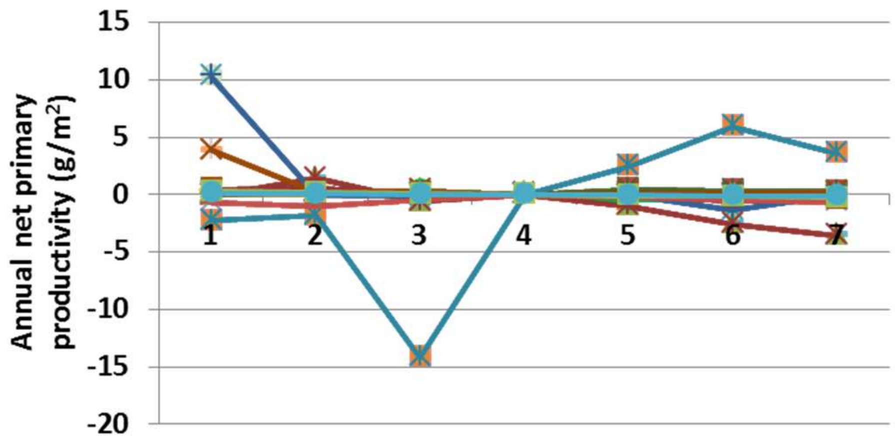
Purpose: The variable set maximum_c_n_ratio describes the maximum carbon to nitrogen ratio that may occur in simulated plant parts. Three groups of five values are used, one set for each facet, and the five values represent leaves, fine roots, fine branches, coarse branches, and coarse roots.

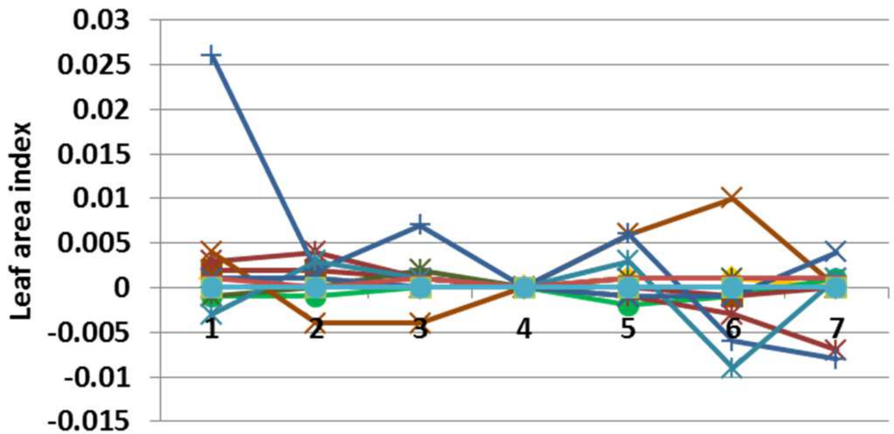
Basis for assignment: The values were set based on AGLCIS and AGLIVE in the Century example files.

Baseline values
30., 33., 0., 0., 33., 40., 50., 80., 90., 35., 51., 62., 92., 95. for all units

Sensitivity values:
(trees only adjusted)
1 – 29, 45, 53, 80, 83
2 – 31, 47, 56, 84, 87
3 – 33, 49, 59, 88, 91
4 – 35, 51, 62, 92, 95
5 – 37, 53, 65, 96, 99
6 – 39, 55, 68, 100, 103
7 – 41, 57, 71, 104, 107







Interpretation: Few sizable changes occurred when maximum carbon to nitrogen ratio in trees was changed. Evapotranspiration changed less than 0.1 cm, and decomposition coefficients did not change. Soil organic carbon changed little, mostly a modest increase in temperature boreal evergreen forest (left). Net primary productivity changed very little (top), as did leaf area index (above). Herbaceous cover changed very little, expect for a 4% change in temperate broadleaf evergreen forest. Shrubs and trees essentially were unchanged.

Conclusion: The parameter set helps constrain model results and should be retained.

29. Maximum leaf area index

Purpose: The variable maximum_leaf_area_index provides an upper limit to leaf area index. An optimum leaf area index is calculated based on the maximum value, plus coarse branch carbon biomass and the k leaf area index coefficient. If the result is below 0.1, the optimum leaf area index is set to 0.1.

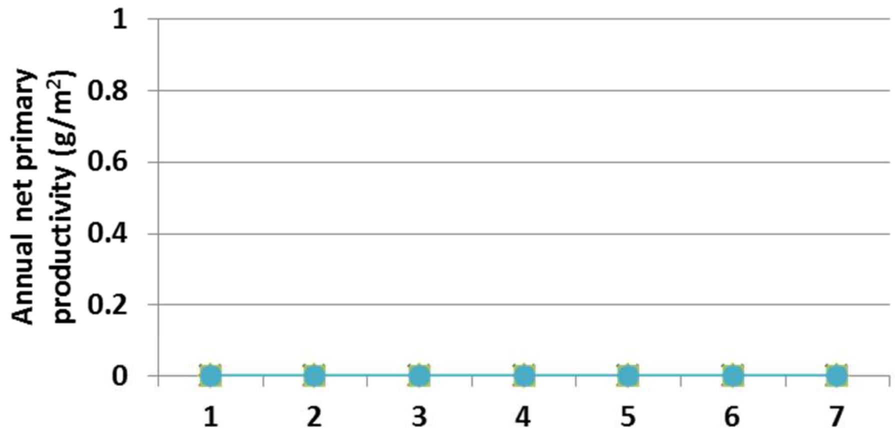
Basis for assignment: The values were set based on MAXLAI within the example files distributed with the Century model.

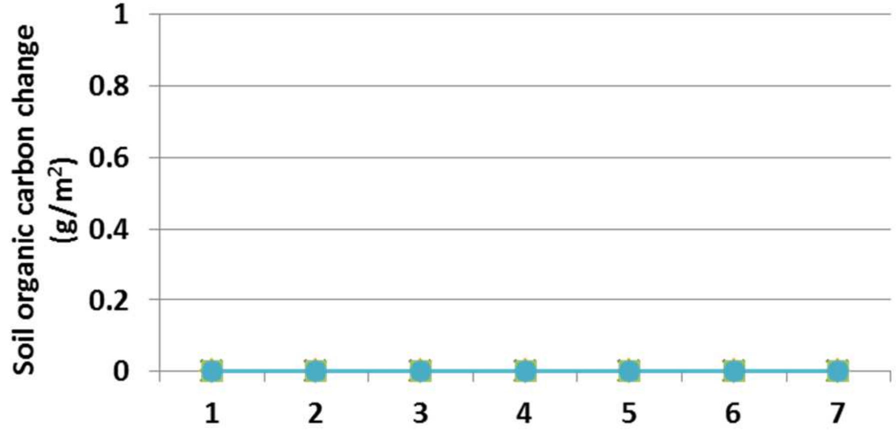
Baseline values

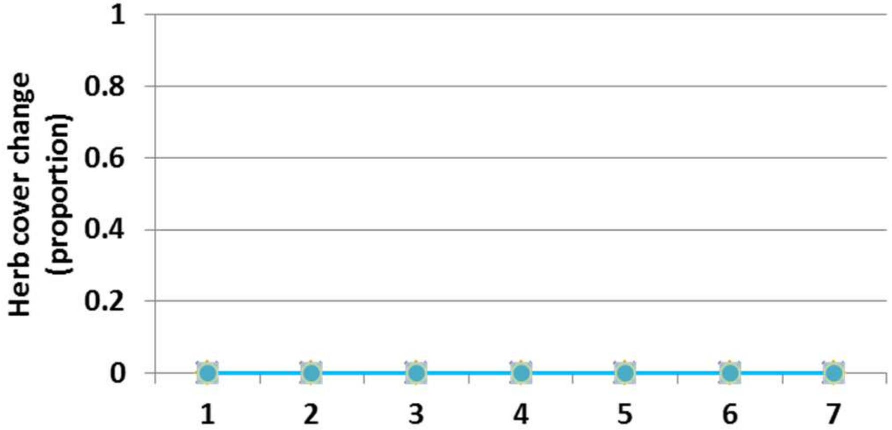
20.0 for units 1 to 8
6.0 for units 9 to 11
4.0 for units 12 to 15

Sensitivity values:

1 – 3.0
2 – 6.0
3 – 9.0
4 – 12.0
5 – 15.0
6 – 18.0
7 – 21.0







Interpretation: Simulation results were not sensitive to changes in maximum leaf area index. That is surprising given its use in the model, to for the foundation for calculating an optimum leaf area index. I have confirmed that the variable is being read in correctly, and will continue research to verify that calculations are being made correctly.

Conclusion: The parameter is central to representing leaf area index in G-Range, and should be retained. More research is required to verify its use in the model.

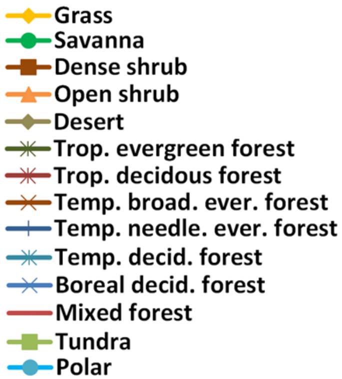
30. K leaf area index

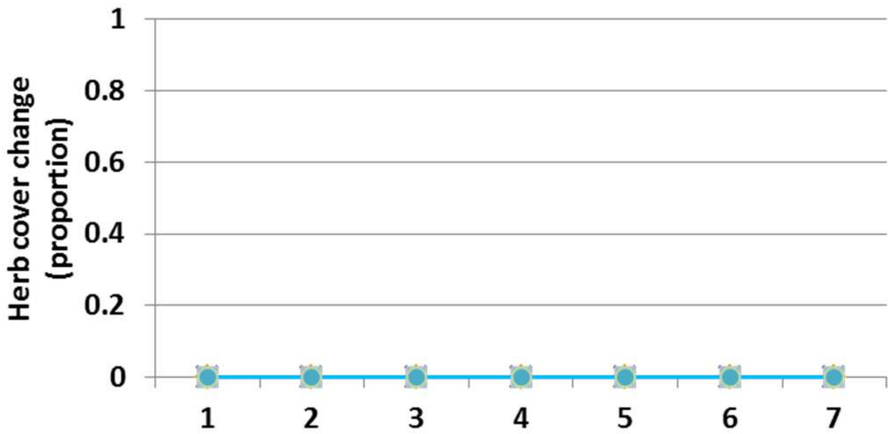
Purpose: The variable k_leaf_area_index is a value used to indicate when half of the maximum leaf area index is attained, in gC m^{-2}. The value is used when calculating an optimum leaf area index for a given facet.

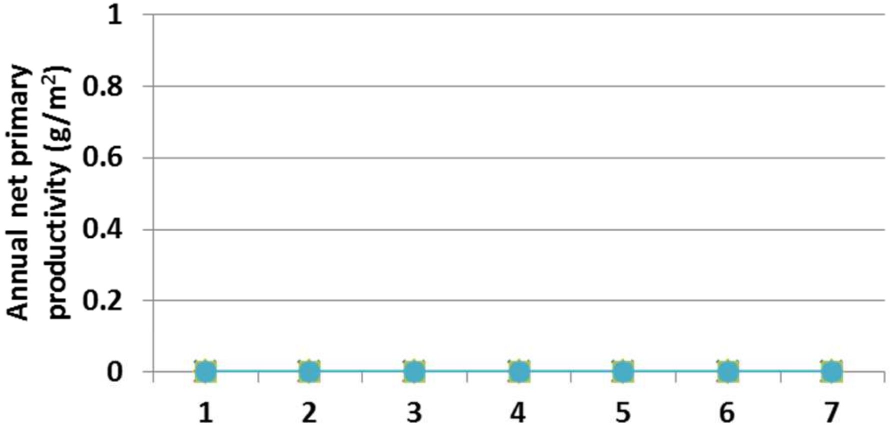
Basis for assignment: The values were set based on KLAI within the example files distributed with the Century model.

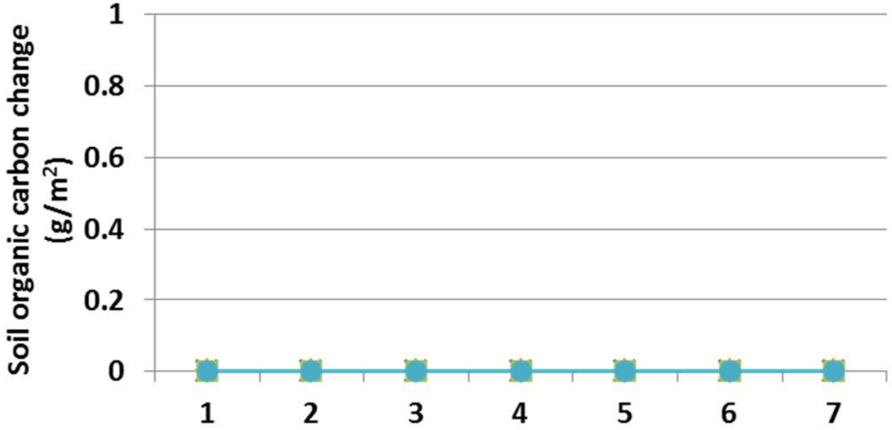
Baseline values
2000 for all units

Sensitivity values:
1 – 1400
2 – 1600
3 – 1800
4 – 2000
5 – 2200
6 – 2400
7 – 2600









Interpretation: Simulation results were not sensitive to changes in K leaf area index. That is surprising given its use in the model, to for the foundation for calculating an optimum leaf area index. I have confirmed that the variable is being read in correctly, and will continue research to verify that calculations are being made correctly.

Conclusion: The parameter is central to representing leaf area index in G-Range, and should be retained. More research is required to verify its use in the model.

31. Biomass to leaf area index factor

Purpose: The variable biomass_to_leaf_area_index_factor is a conversion coefficient that converts biomass of leaves to a leaf area index. The coefficient applies to each of the facets, and is based on carbon in leaves, and so is multiplied by a conversion prior to use.

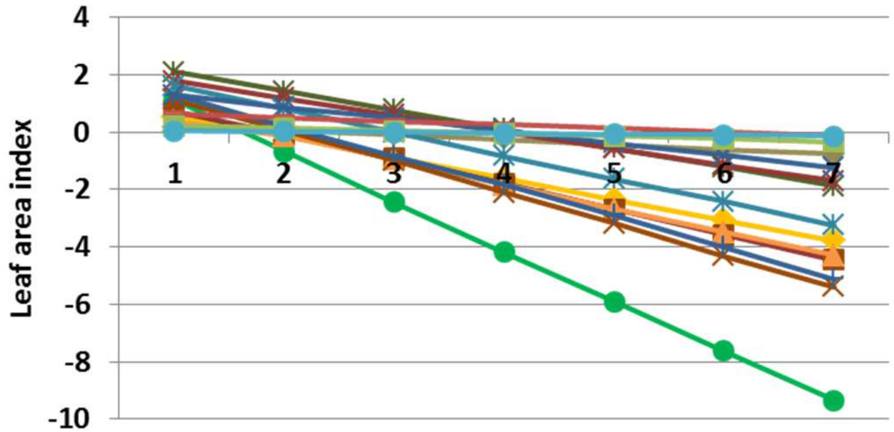
Basis for assignment: The values were set based on BTOLAI within the example files distributed with the Century model. They were modified to improve model fit.

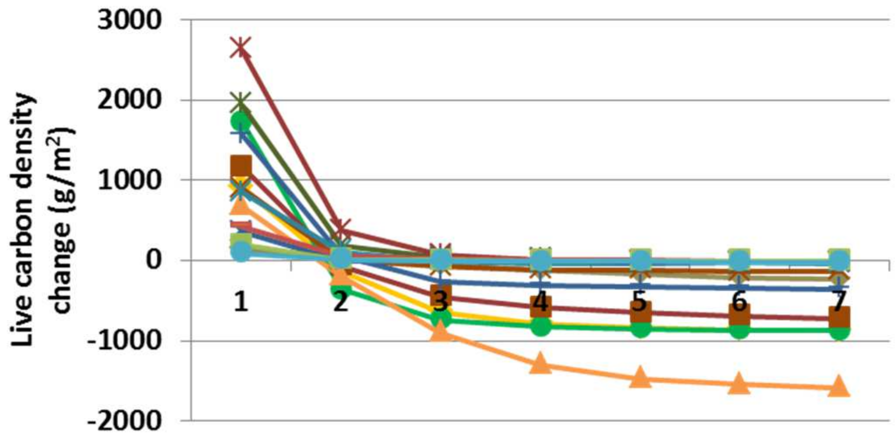
Baseline values

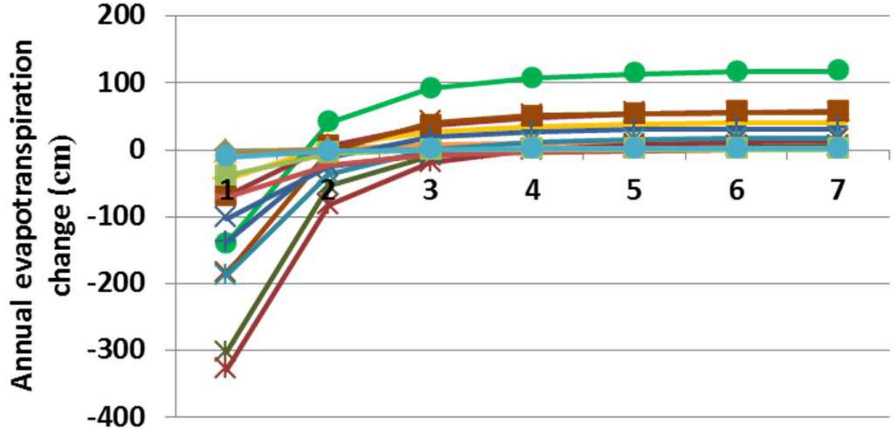
Various values from 0.0029 to 0.0158

Sensitivity values:

1 – 0.001
2 – 0.004
3 – 0.007
4 – 0.010
5 – 0.013
6 – 0.016
7 – 0.019







Interpretation: Large changes occurred in G-Range outputs in response to changes in biomass to leaf area index factor. LAI changed linearly with the coefficient, as expected (left). Other changes were non-linear, such as live carbon density (top) and annual evapotranspiration (above). Net primary productivity changed by 220 g m^{-2}. Herb, shrub, and tree cover increased up to 20% when the coefficient was 0.001, and declined up to 10% for woody plants, and 27% for herbs. Bare ground increased up to 38%.

Conclusion: The parameter is required to convert leaf biomass to leaf area index, and should be retained. The high sensitivity of the model to variation in the parameter suggests that it be well defined.

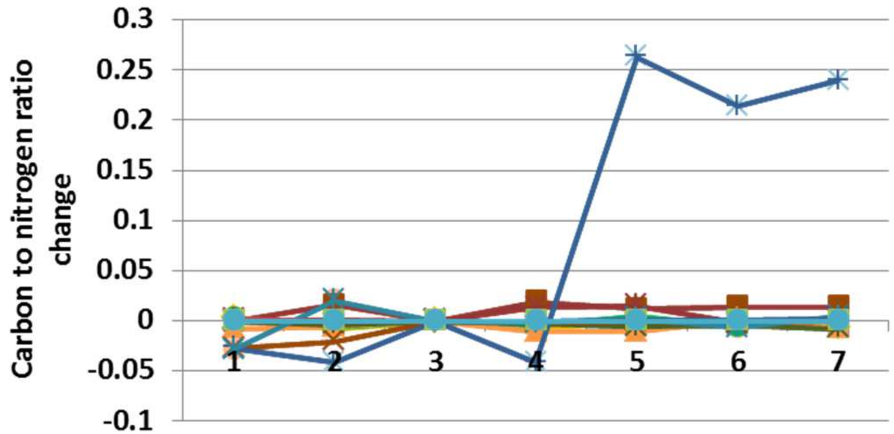
32. Annual fraction volatilized nitrogen

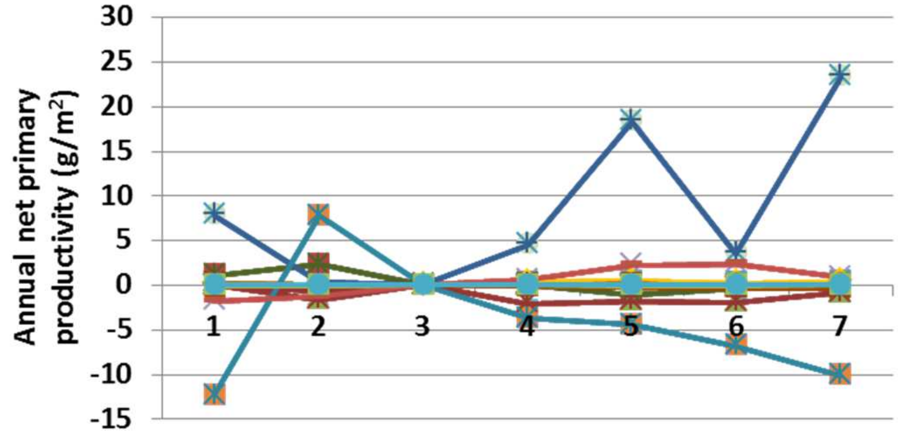
Purpose: The variable annual_fraction_volatilized_n is a unitless coefficient reflecting the annual fraction of nitrogen that is volatilized. Minerlized nitrogen is multiplied by this coefficient to represent losses to volatilization.

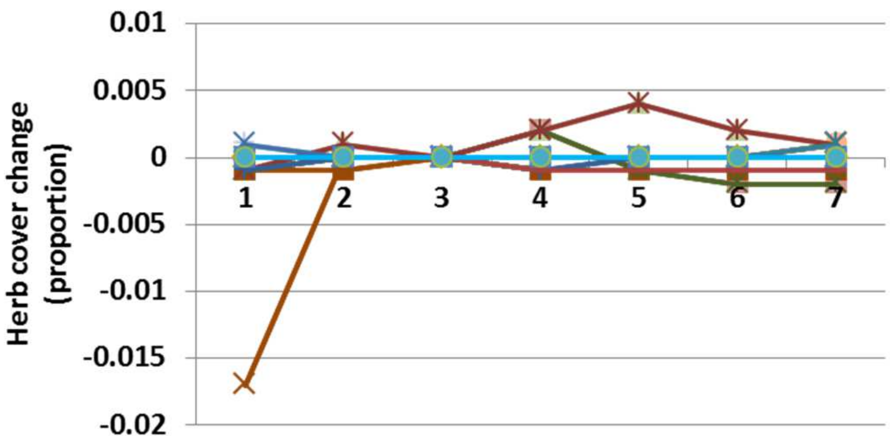
Basis for assignment: The values were set based on VLOSSE within the example files distributed with the Century model.

Baseline values
0.020 for units 1 to 13
0.050 for units 14 and 15

Sensitivity values:
1 – 0.00
2 – 0.01
3 – 0.02
4 – 0.03
5 – 0.04
6 – 0.05
7 – 0.06







Interpretation: The fraction of nitrogen volatilizied is fairly small, and that is reflected in the outputs from G-Range. Annual evapotranspiration changed less than 0.1 cm, and soil temperature and plant available water changed little. Carbon to nitrogen ratio is the only nitrogen-centric measure assessed, and changed up to 0.025, except for temperate needled evergreen forest (top). Annual net primary productivity changed up to 25 g m^{-2} (avove). Herbaceous cover changed very little, except for temperate broadleaf evergreen forest, which declined 1.5% (left).

Conclusion: The parameter describes a process that should be represented in G-Range, and should be retained.

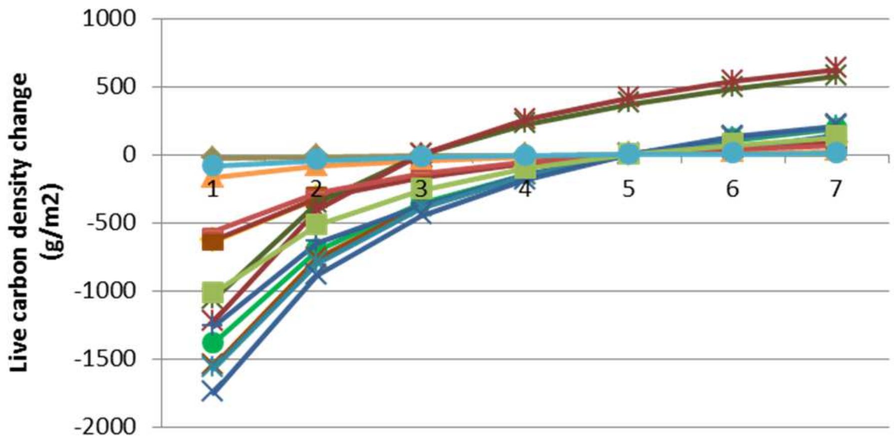
33. Maximum root death rate

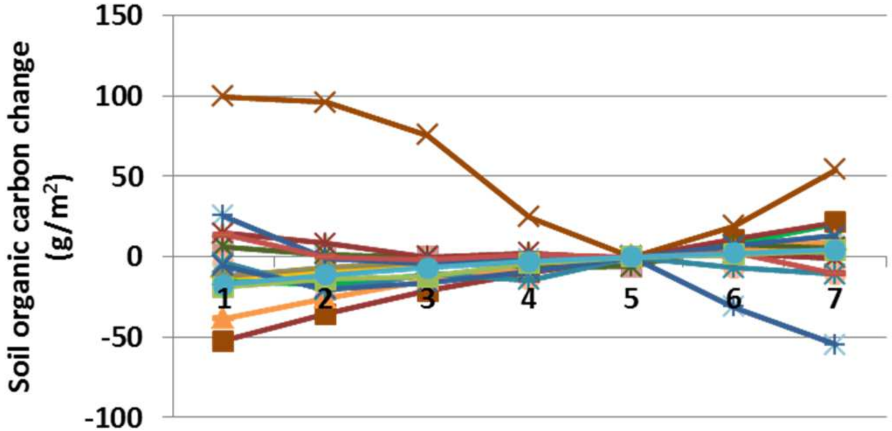
Purpose: The variable maximum_root_death_rate defines the initial maximum death rate of fine roots. The death rate is then modified based on water availability and other constraints.

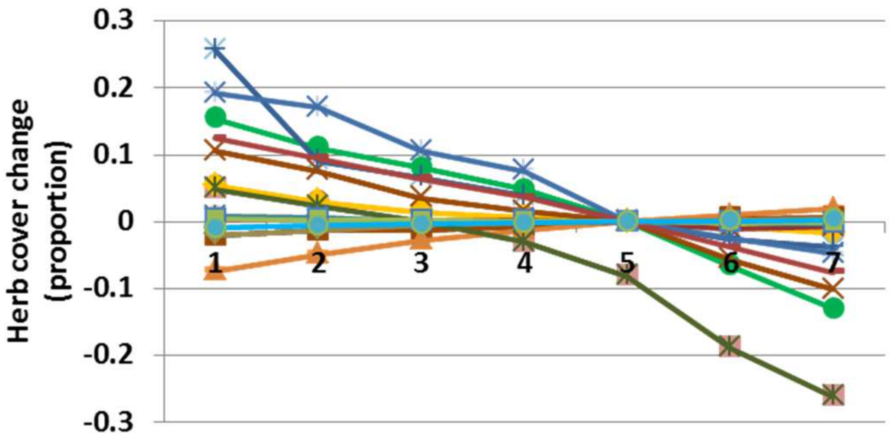
Basis for assignment: The values were inferred and adjusted to improve model fit.

Baseline values
0.20, 0.20, 0.20 for units 1 and 2
0.30, 0.30, 0.30 for units 3 through 15

Sensitivity values:
1 – 0.10, 0.10, 0.10
2 – 0.15, 0.15, 0.15
3 – 0.20, 0.20, 0.20
4 – 0.25, 0.25, 0.25
5 – 0.30, 0.30, 0.30
6 – 0.35, 0.35, 0.35
7 – 0.40, 0.40, 0.40







Interpretation: On inspection of the G-Range code we find that the parameter is only applicable to herbaceous plants. Fine root death rate is controlled in woody plants by other means. Changes to facet cover were large, such as the almost 30% change in herbaceous cover (left). Leaf area carbon density changed markedly (top), but other changes were more modest, such as soil organic carbon (above), leaf area index, which changed let than 0.07, and annual net primary productivity, which changed up to 25 g m^{-2}.

Conclusion: The parameter is important to determine herb death rate. The parameters for woody plants may be removed, and the parameter name changed.

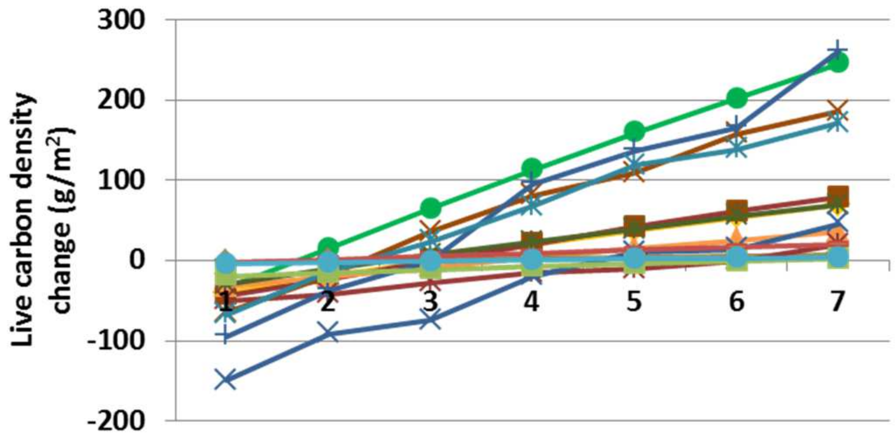
34a. Shoot death rate – Water stress

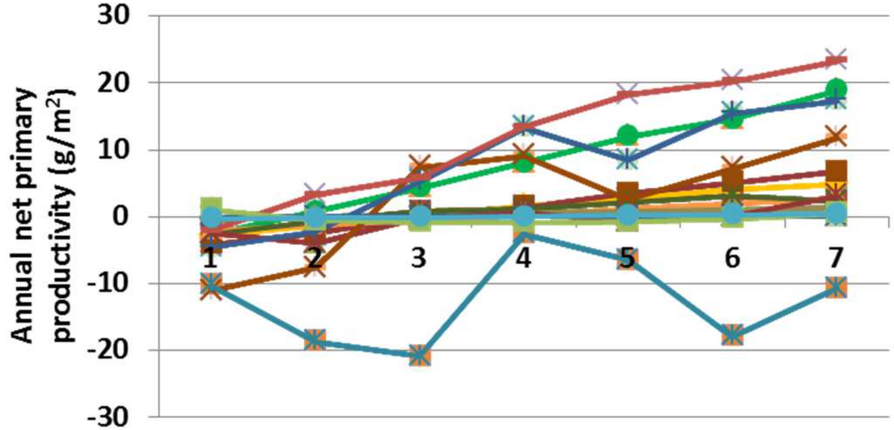
Purpose: The variable set shoot_death_rate controls death rate of herbaceous shoots from three sources, 1) water stress, 2) phenological limits, and 3) shading. The first three values are death rates, the last is a carbon concentration reflecting shading by herbaceous leaves.

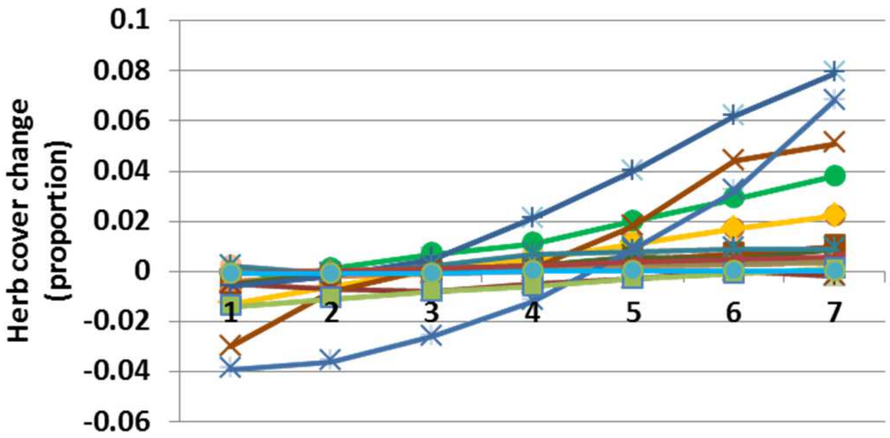
Basis for assignment: Initialized based on FSDETH in the example files of Century, then adjusted to improve model fit.

Baseline values
Various values. Two selected units are:
0.009, 0.150, 0.020, 1800.0 for unit 1
0.012, 0.180, 0.012, 1200.0 for unit 15

Sensitivity values:
(adjusting water stress only)
1 – 0.004
2 – 0.007
3 – 0.010
4 – 0.013
5 – 0.016
6 – 0.019
7 – 0.022







Interpretation: Changes in water stress caused modest but reasonable changes to G-Range outputs. Annual evapotranspiration changed less than 2 cm, and soil temperature changed little. Soil organic carbon change about 100 g m-2, except for temperate boreal evergreen forest, which increased to 210 g m-2. Leaf carbon density changed in-step with water stress sensitivity (top), and annual net primary productivity changed relatively little (above). Herbaceous facet cover changed up to 8% with changes in sensitivity to water stress (left). Woody plants changed little.

Conclusion: The parameter is important in describing herbaceous shoot mortality and will be retained.

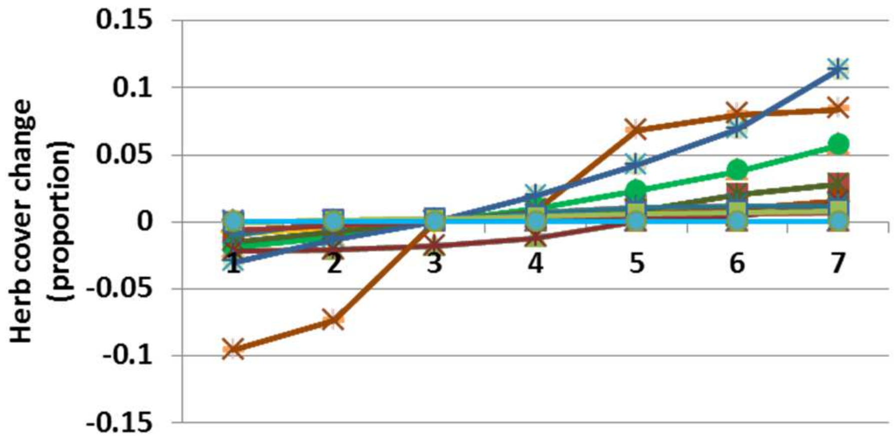
34b. Shoot death rate – Phenology

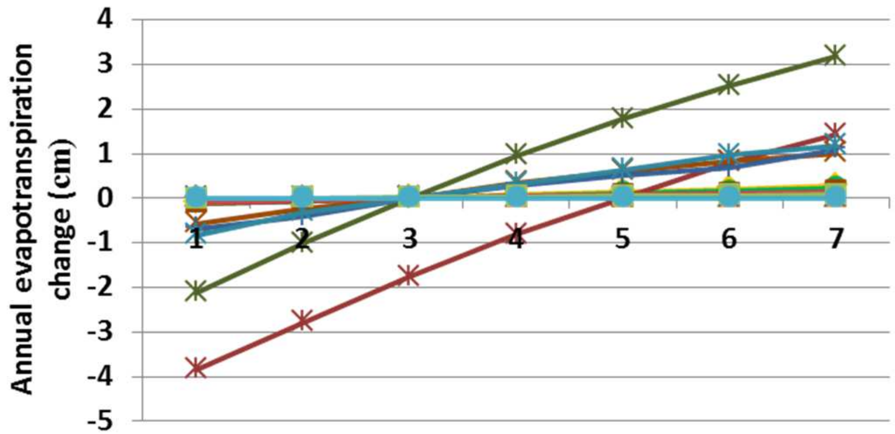
Purpose: The variable set shoot_death_rate controls death rate of herbaceous shoots from three sources, 1) water stress, 2) phenological limits, and 3) shading. The first three values are death rates, the last is a carbon concentration reflecting shading by herbaceous leaves.

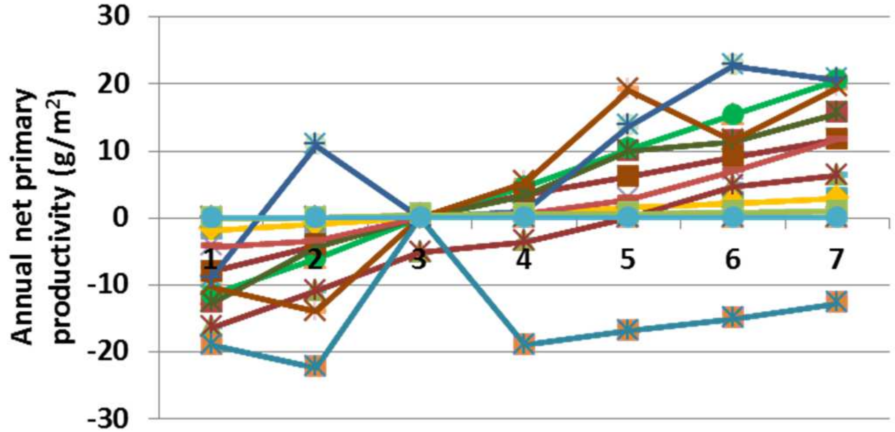
Basis for assignment: Initialized based on FSDETH in the example files of Century, then adjusted to improve model fit.

Baseline values
Various values. Two selected units are:
0.009, 0.150, 0.020, 1800.0 for unit 1
0.012, 0.180, 0.012, 1200.0 for unit 15

Sensitivity values:
(adjusting phenology only)
1 – 0.11
2 – 0.13
3 – 0.15
4 – 0.17
5 – 0.19
6 – 0.21
7 – 0.23







Interpretation: Changes in live carbon density were up to 280 g m^{-2}, as shoot density changed. Leaf area index change less than 0.8. Annual evapotranspiration changed up to 4 cm (top), and plant available water changed less than 0.07 cm. Annual net primary productivity showed modest changes (above). Herbaceous cover changed up to 12% in response to changes in death rate associated with phenology (left). Changes to woody cover were very small. As is typical, changes in herbaceous cover were offset by changes in bare ground cover.

Conclusion: The parameter is important in describing herbaceous shoot mortality and will be retained.

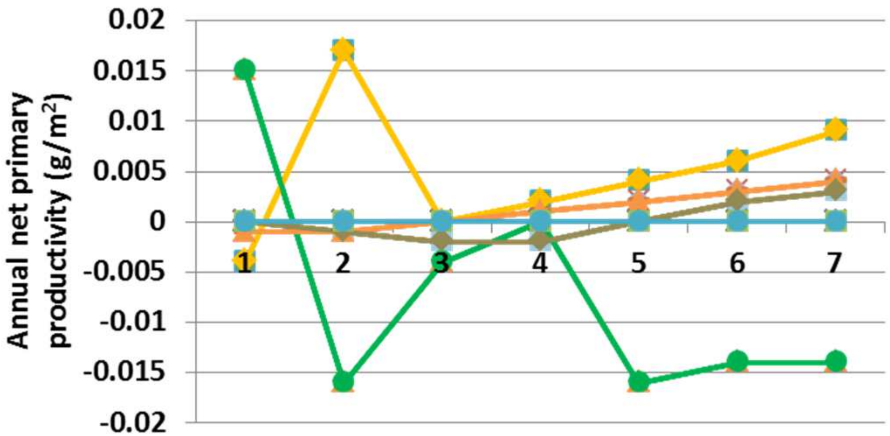
34c. Shoot death rate – Shading

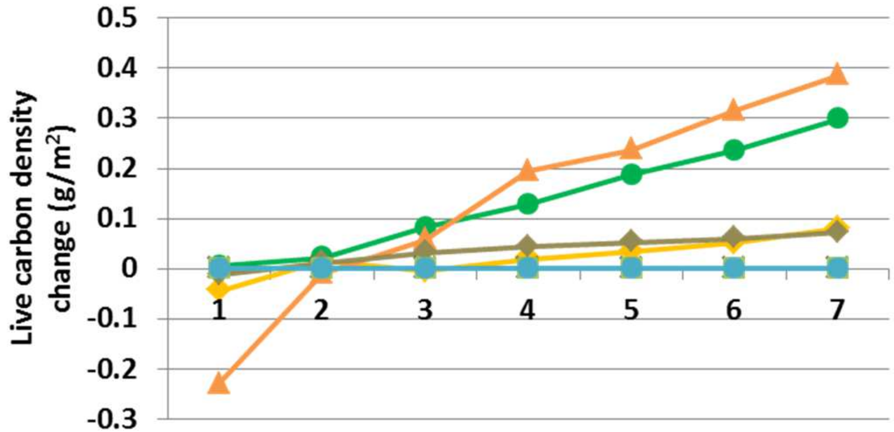
Purpose: The variable set shoot_death_rate controls death rate of herbaceous shoots from three sources, 1) water stress, 2) phenological limits, and 3) shading. The first three values are death rates, the last is a carbon concentration reflecting shading by herbaceous leaves.

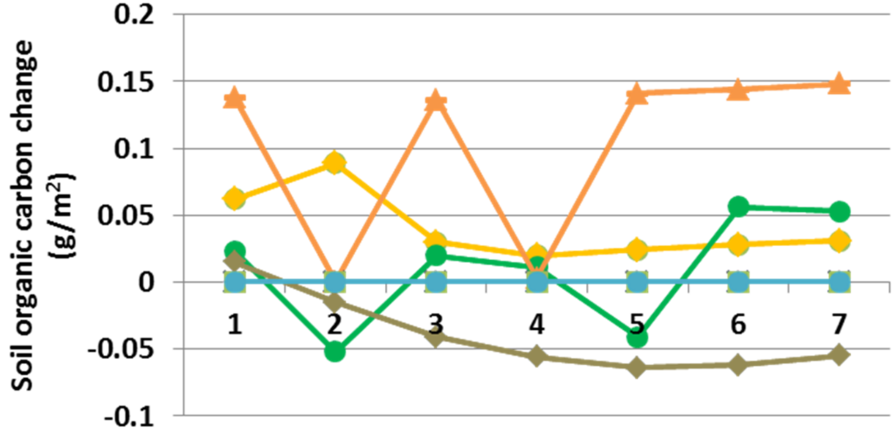
Basis for assignment: Initialized based on FSDETH in the example files of Century, then adjusted to improve model fit.

Baseline values
Various values. Two selected units are:
0.009, 0.150, 0.020, 1800.0 for unit 1
0.012, 0.180, 0.012, 1200.0 for unit 15

Sensitivity values:
(adjusting shading only)
1 – 0.005
2 – 0.009
3 – 0.013
4 – 0.017
5 – 0.021
6 – 0.025
7 – 0.029







Interpretation: There were almost no changes in G-Range output associated with changes to shading from herbaceous leaves on shoot death rate. This is related to the binary nature of inclusion of the shading effect – if carbon density exceeds the fourth value given, the effect is included, if it does not it is not used. Facet covers did not change in response to changes in herbaceous shoot death rate associated with phenology.

Conclusion: The parameter is important in describing herbaceous shoot mortality and will be retained.

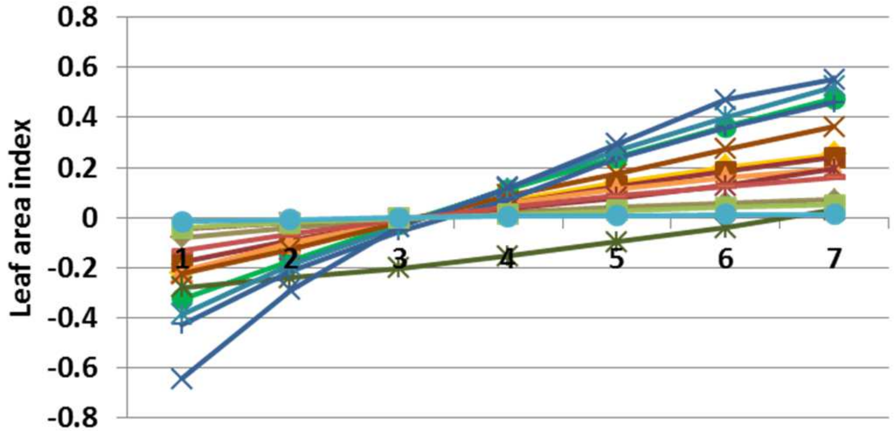
35. Proportion annuals

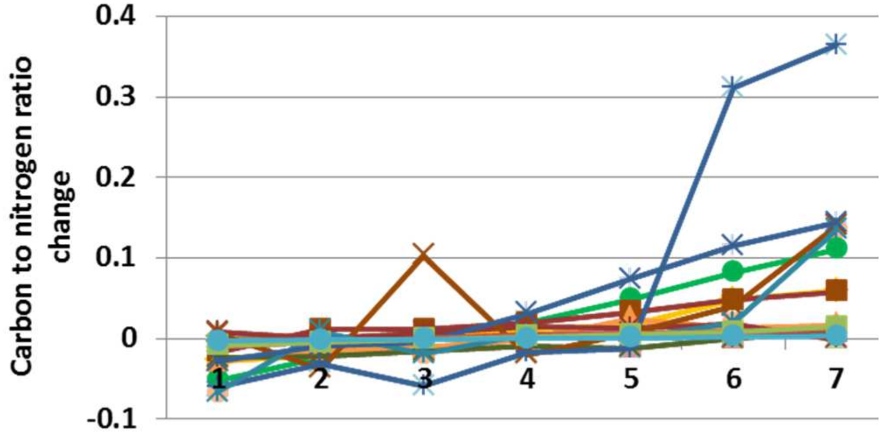
Purpose: The variable propotion_annuals reflects the proportion of herbaceous vegetation that is annuals versus the proportion that is perennial.

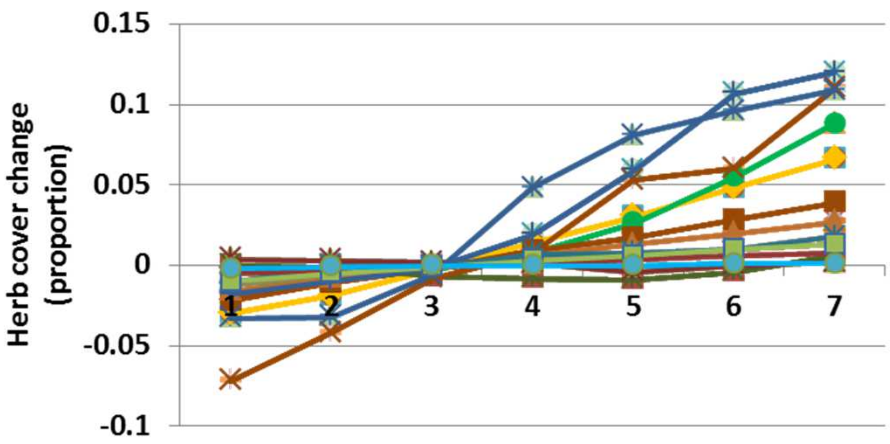
Basis for assignment: The values were inferred, but are weakly defined. More research is needed to improve their assignment.

Baseline values
0.40 for unit 1
0.20 for units 2 to 15

Sensitivity values:
1 – 0.07
2 – 0.13
3 – 0.19
4 – 0.25
5 – 0.31
6 – 0.37
7 – 0.43







Interpretation: Changes due to proportion of annuals led to some changes in G-Range output that were smaller than expected, but these annual summaries do not capture within year differences. Annual evapotranspiration changed up to 2 cm, and soil temperature changed little. Soil organic carbon changed up to 400 g m-2. Carbon to nitrogen ratio changed less than 0.4 (above) and leaf area index over 0.6 units (top). Herbaceous cover changed up to 12%. Woody types changed little.

Conclusion: The parameter represents a critical component of ecosystems and influences intra-annual system dynamics (though not represented here). Values assigned should be refined.

36. Month to remove annuals

Purpose: Annuals die at a rate set by an entry in shoot_death_rate (here, entry 34b), but that rate may not ensure all annuals are removed each year. Month_to_remove_annuals is the period when all remaining annuals are killed.

Basis for assignment: The same value is used throughout, and is set to December. More research into ends of seasons would be beneficial.

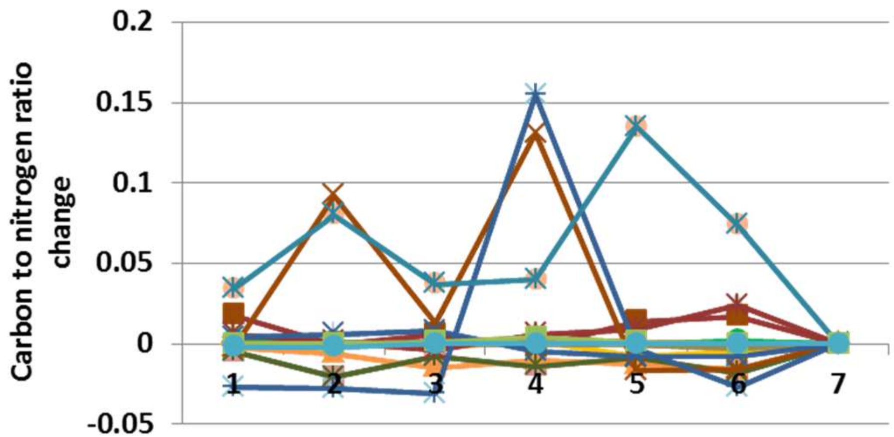
Baseline values

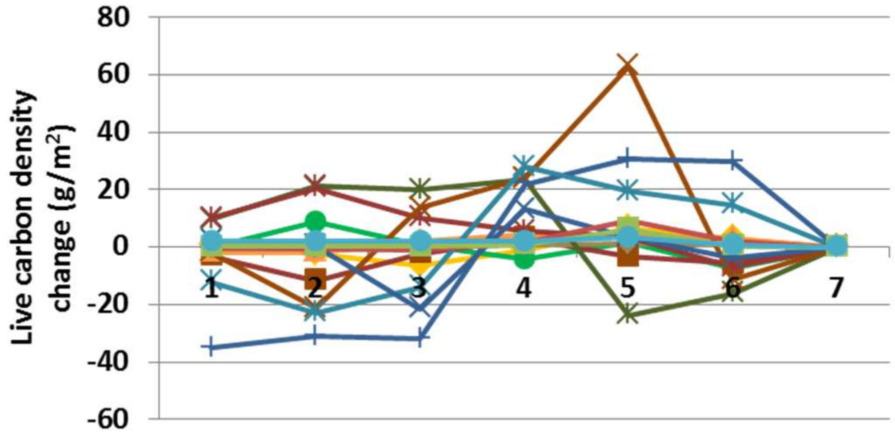
12

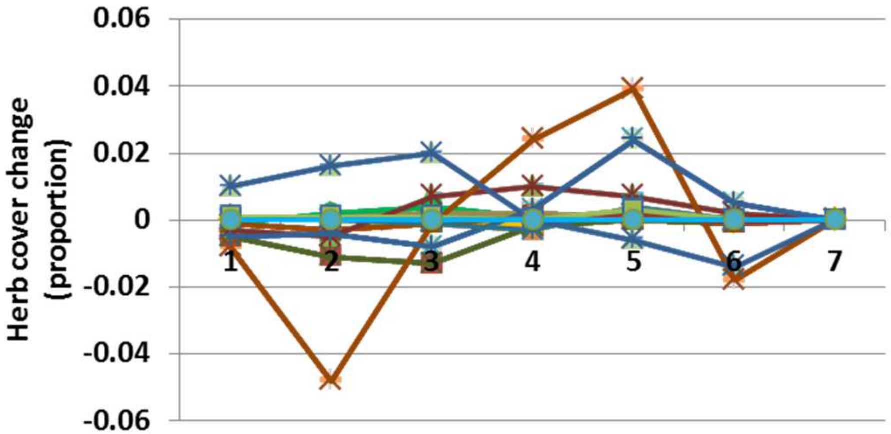
Sensitivity values:

(note unequal intervals)

1 – 1
2 – 2
3 – 4
4 – 6
5 – 8
6 – 10
7 – 12







Interpretation: Changes in G-Range output in response to different months to remove annuals were small. This is expected, given that the rate of death due to phenology should leave few herbs to be removed when the month is reached. For example, carbon to nitrogen ratio changed up to 0.15, and leaf carbon density changed up to 60 g m^{-2}. Annual net primary productivity changed less than 20 g m^{-2}. Herbaceous cover changed up to 5% (left). Woody types changed very little.

Conclusion: The parameter is an important and easily interpretable control to help herbs be well represented, and will be retained.

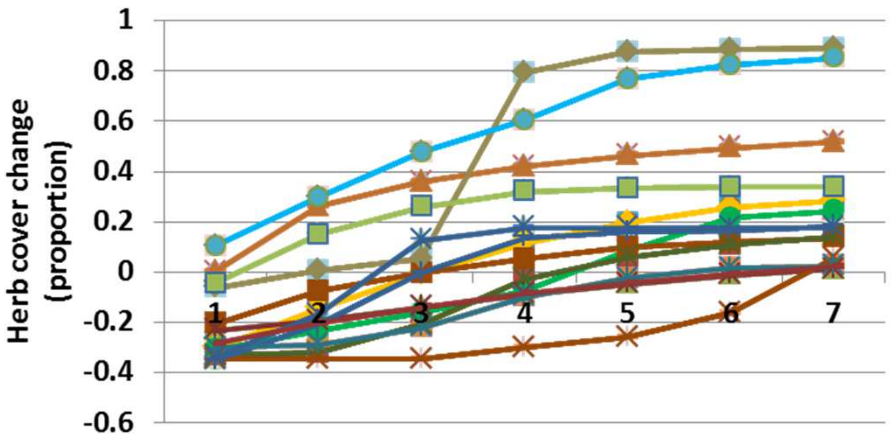
37a. Relative seed production - Herbs

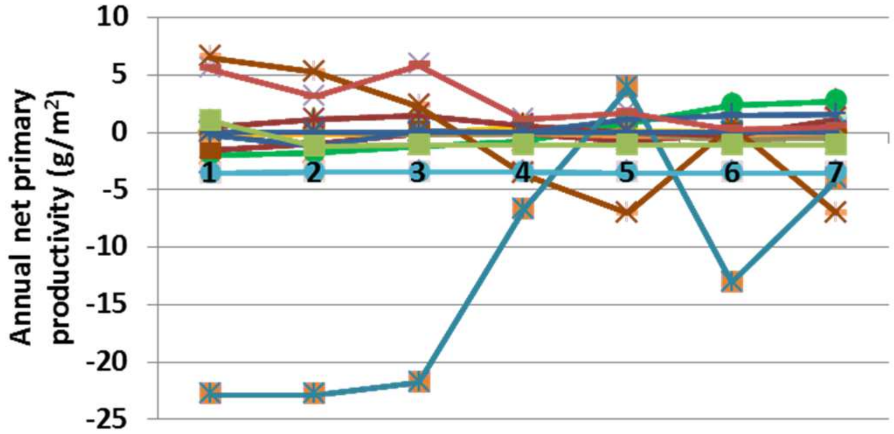
Purpose: The variable set relative_seed_production provides an index to the initial number of seeds produced by herbs, shrubs, and trees. For each facet, the value is then modified based on controls on establishment, such as limitations due to water or litter.

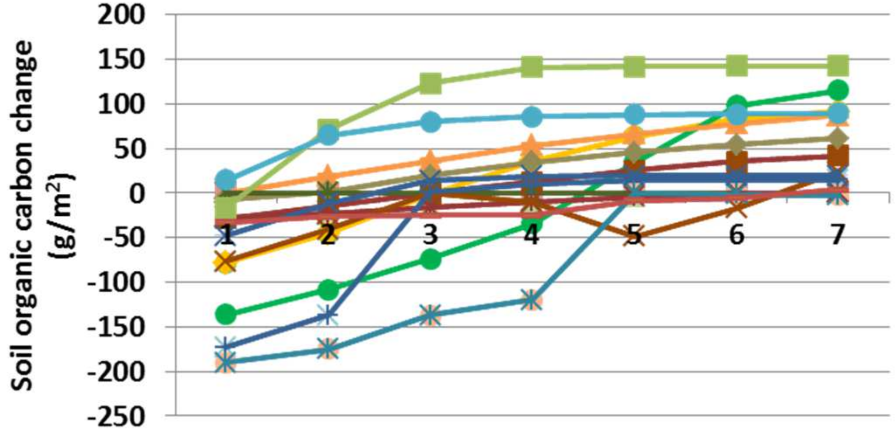
Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values
Various values, from a low of
1350.0, 400.0, 400.0 for the polar unit to
5300.0, 8050.0, 8050.0 for trop. ever. forest.

Sensitivity values:
(herbaceous values changed only)
1 – 2000
2 – 3000
3 – 4000
4 – 5000
5 – 6000
6 – 7000
7 – 8000







Interpretation: As expected, changes in relative seed production can have profound effects on facet cover. Herbaceous cover declined by more than 30% at low relative seed production, and increased by 90% at the highest levels (left). Shrubs and trees did not change significantly. Changes in biochemistry modeling were more modest. Evapotranspiration and temperature changed little. Annual net primary productivity changed less than 25 g m^{-2} (top) and soil organic carbon changed up to 200 g m^{-2} (above).

Conclusion: The parameter is an important control on facet cover, and should be retained.

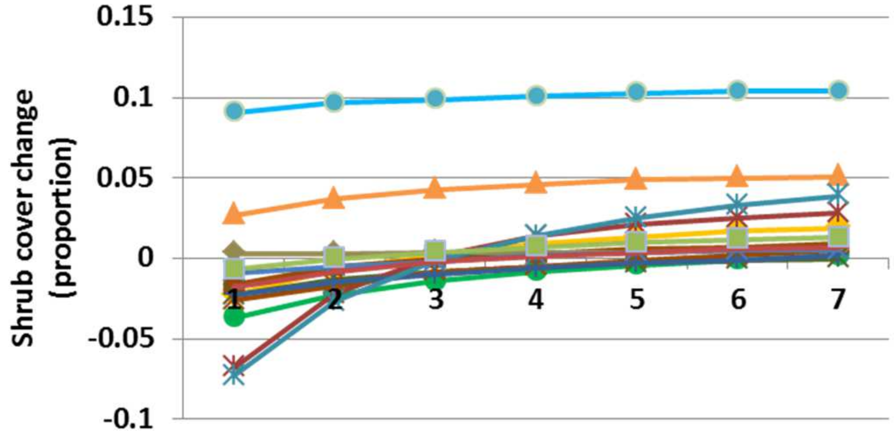
37b. Relative seed production - Shrubs

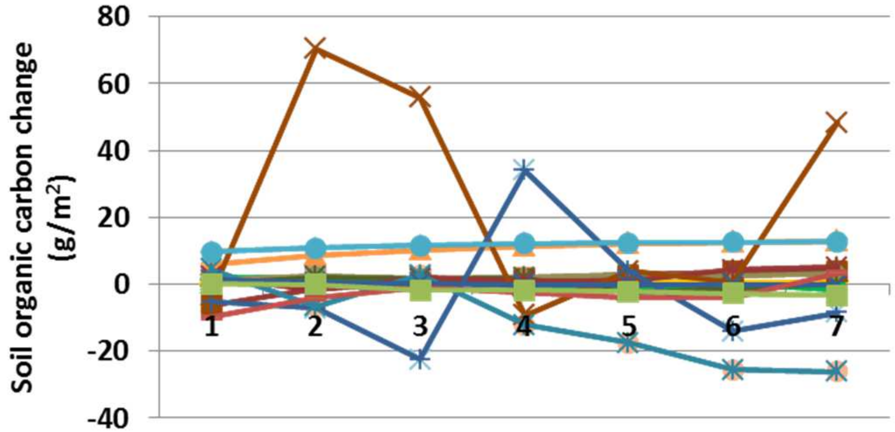
Purpose: The variable set relative_seed_production provides an index to the initial number of seeds produced by herbs, shrubs, and trees. For each facet, the value is then modified based on controls on establishment, such as limitations due to water or litter.

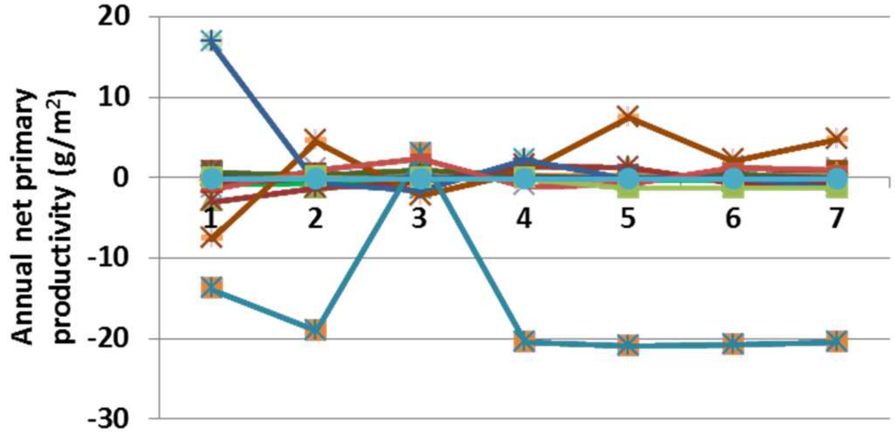
Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values
Various values, from a low of
1350.0, 400.0, 400.0 for the polar unit to
5300.0, 8050.0, 8050.0 for trop. ever. forest.

Sensitivity values:
(shrub values changed only)
1 – 2000
2 – 3000
3 – 4000
4 – 5000
5 – 6000
6 – 7000
7 – 8000







Interpretation: Shrub cover changed up to 11% in response to changes in relative seed production (left), and herbs change in an opposite fashion to shrubs up to 10%. Tree facet cover changed little; changes in bare ground offset other face t changes. Changes in the biochemistry were small, such as up to 70 g m-2 change in soil organic carbon (top), and a change in annual net primary productivity up to 22 g m-2. Plant soil water changed very little, and decomposition coefficients did not change.

Conclusion: The parameter is an important control on facet cover, and should be retained.

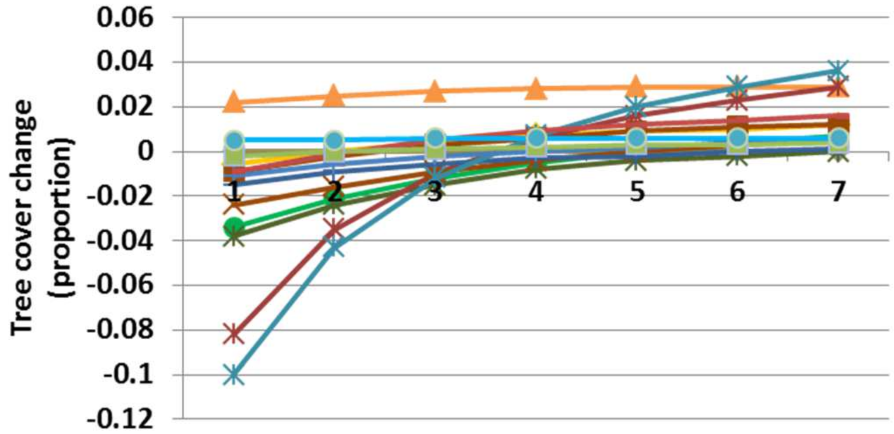
37c. Relative seed production - Trees

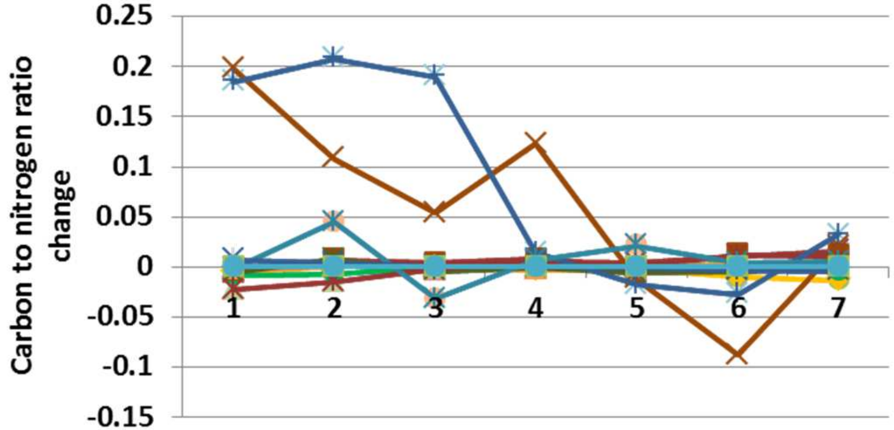
Purpose: The variable set relative_seed_production provides an index to the initial number of seeds produced by herbs, shrubs, and trees. For each facet, the value is then modified based on controls on establishment, such as limitations due to water or litter.

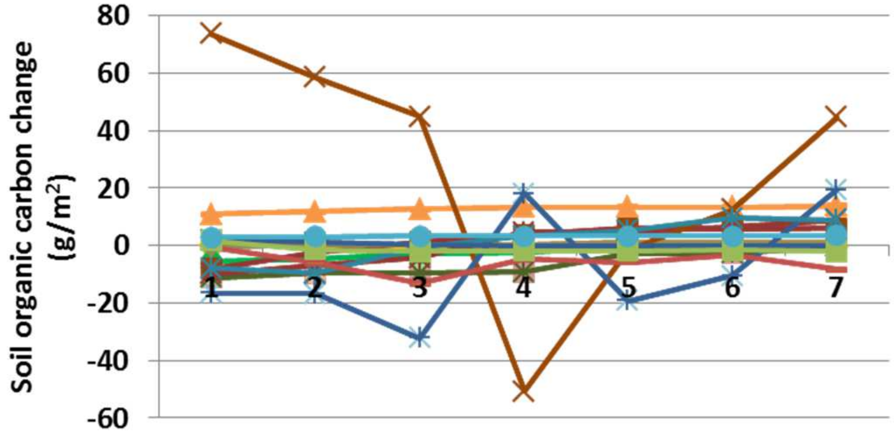
Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values
Various values, from a low of
1350.0, 400.0, 400.0 for the polar unit to
5300.0, 8050.0, 8050.0 for trop. ever. forest.

Sensitivity values:
(tree values changed only)
1 – 2000
2 – 3000
3 – 4000
4 – 5000
5 – 6000
6 – 7000
7 – 8000







Interpretation: Tree cover declined up to 10% when relative seed production was very low. Shrub cover changed by up to 5%, and herbaceous cover changed up to 8%, both increasing as tree cover declined. Leaf area index changed up to 0.04, and annual net primary productivity by up to 15 g m^{-2}. Carbon to nitrogen ratio changed up to 0.22 (top), and soil organic carbon by up to 75 g m^{-2}. Other changes were quite small.

Conclusion: The parameter is an important control on facet cover, and should be retained.

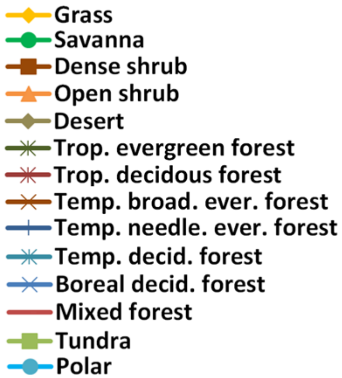
38a. Water effect on establishment - Herbs

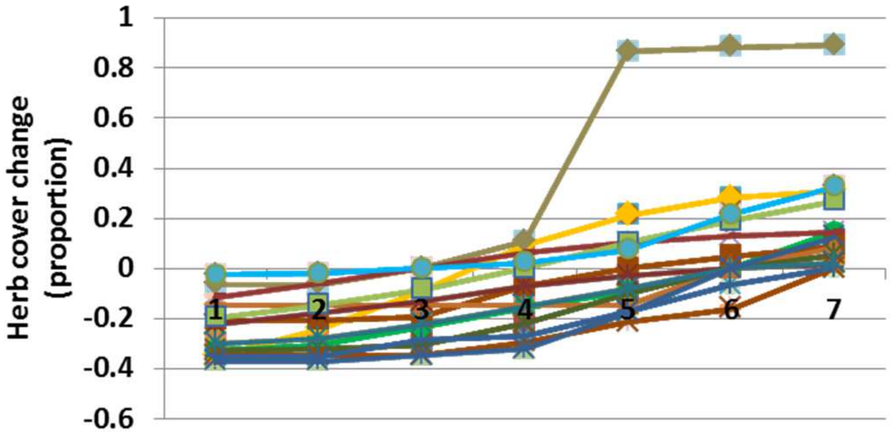
Purpose: The variable set water_effect_on_establishment creates a multiplier for the relative seed production rate based on the ratio of plant available water to potential evapotranspiration. Two pairs of values define a linear regression for each facet.

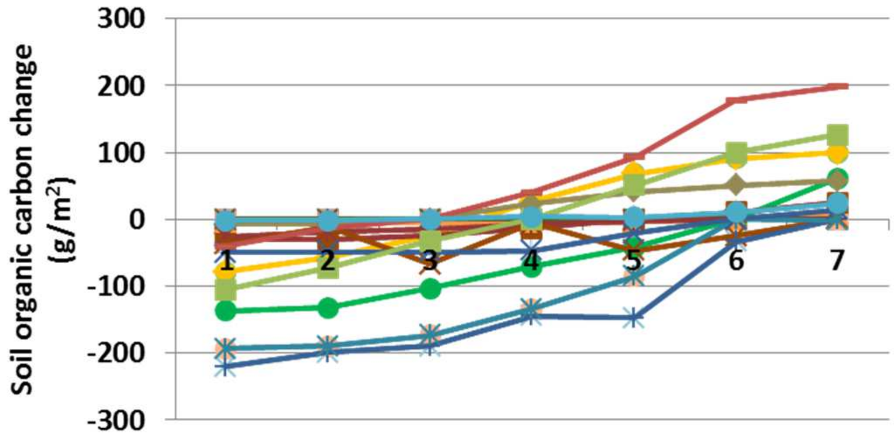
Basis for assignment: The values were inferred, then adjusted to improve model fit.

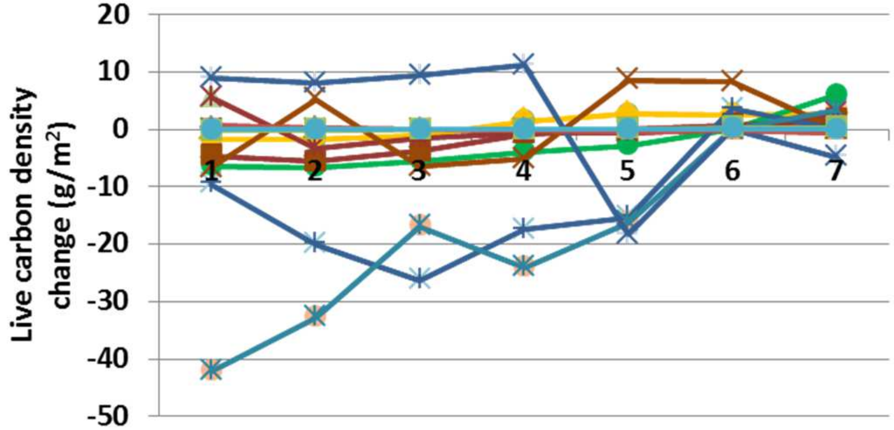
Baseline values
Various values, but of a range and pattern similar to:
0.37, 0.50, 3.0, 1.00, 0.0, 0.76, 6.0, 1.00, 1.0, 0.67, 4.0, 1.00

Sensitivity values:
(herb lower x values changed only)
1 – 0.00
2 – 0.10
3 – 0.20
4 – 0.30
5 – 0.40
6 – 0.50
7 – 0.60









Interpretation: Herbaceous cover changed up to almost 40% for most landscape units, except for desert, where a reduction in water stress lead to herbaceous cover changing up to 90%. Shrubs and trees were essentially unchanged. Parameters affecting establishment had little effect on biochemical modeling, as expected. Annual evapotranspiration, soil temperature, potential evapotranspiration, etc, changed little. Soil organic carbon mostly changed up to 220 g m^{-2} (top). Live carbon density changed by up to 42 g m^{-2}.

Conclusion: The parameter is important to reflect the effect of water limitations on facet cover, and should be retained.

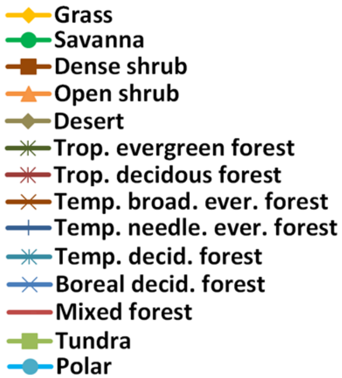
38b. Water effect on establishment - Shrubs

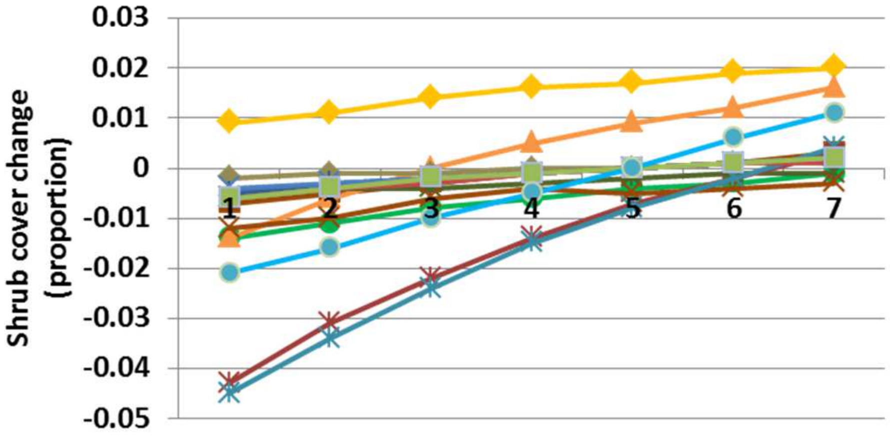
Purpose: The variable set water_effect_on_establishment creates a multiplier for the relative seed production rate based on the ratio of plant available water to potential evapotranspiration. Two pairs of values define a linear regression for each facet.

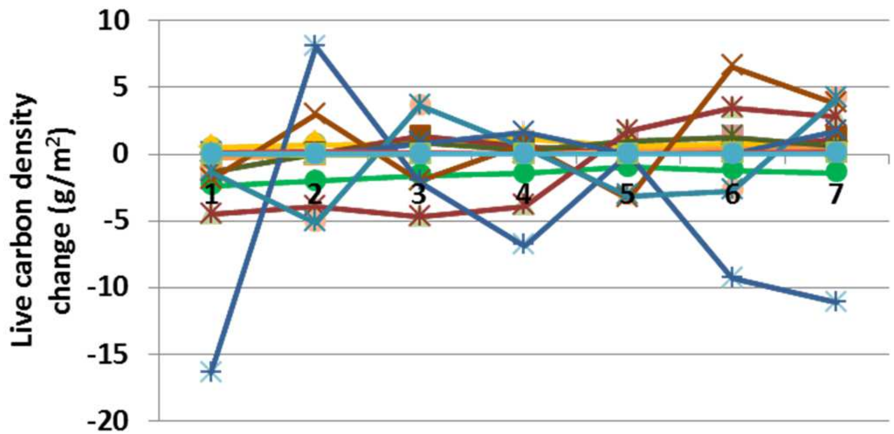
Basis for assignment: The values were inferred, then adjusted to improve model fit.

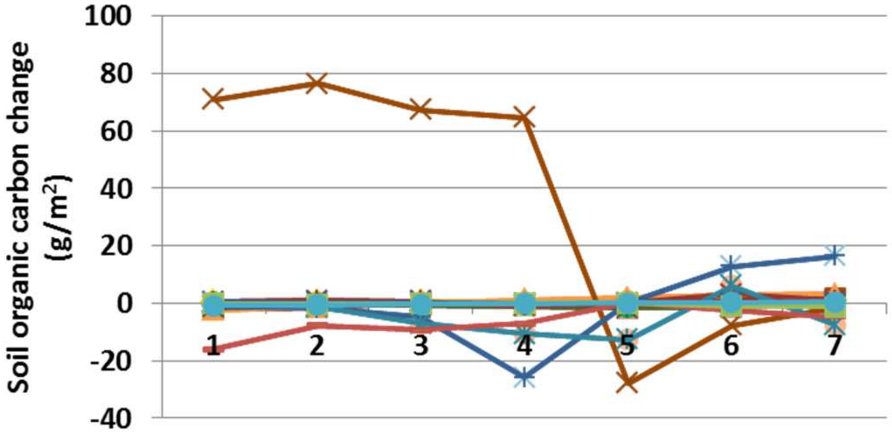
Baseline values
Various values, but of a range and pattern similar to:
0.37, 0.50, 3.0, 1.00, 1.0, 0.76, 6.0, 1.00, 1.0, 0.67, 4.0, 1.00

Sensitivity values:
(shrub lower y values changed only)
1 – 0.40
2 – 0.45
3 – 0.50
4 – 0.55
5 – 0.60
6 – 0.65
7 – 0.70









Interpretation: Shrub cover changed less in response to changes in water stress on establishment than did herbaceous plants, as expected. Temperate forest shrub cover declined up to 4.5% (left). Tree and bare ground cover changed little; the change in shrub cover was offset by changes in herbaceous cover. Other changes were fairly small. Annual net primary productivity changed less than 20 g m^{-2}, and carbon to nitrogen ratio changed less than 0.35. Soil organic carbon changed up to 80 g m^{-2} (above), and live carbon density changed relatively little (top).

Conclusion: The parameter is important to reflect the effect of water limitations on facet cover, and should be retained.

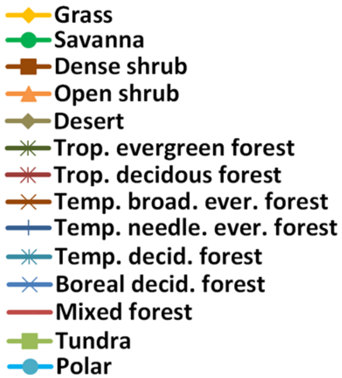
38c. Water effect on establishment - Trees

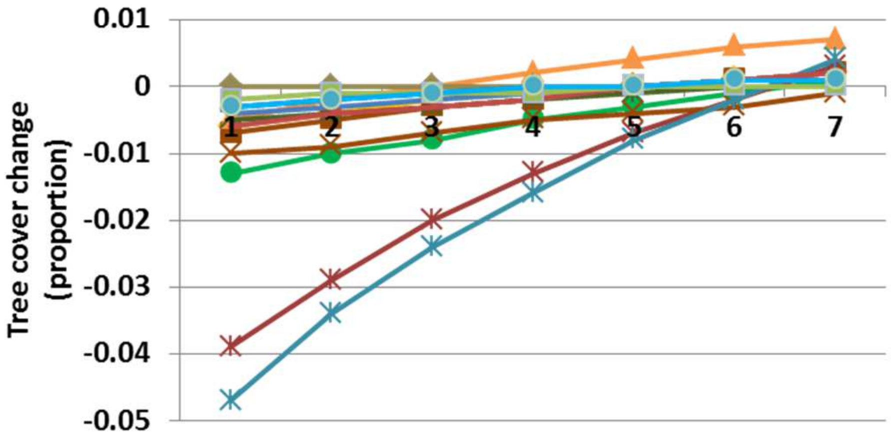
Purpose: The variable set water_effect_on_establishment creates a multiplier for the relative seed production rate based on the ratio of plant available water to potential evapotranspiration. Two pairs of values define a linear regression for each facet.

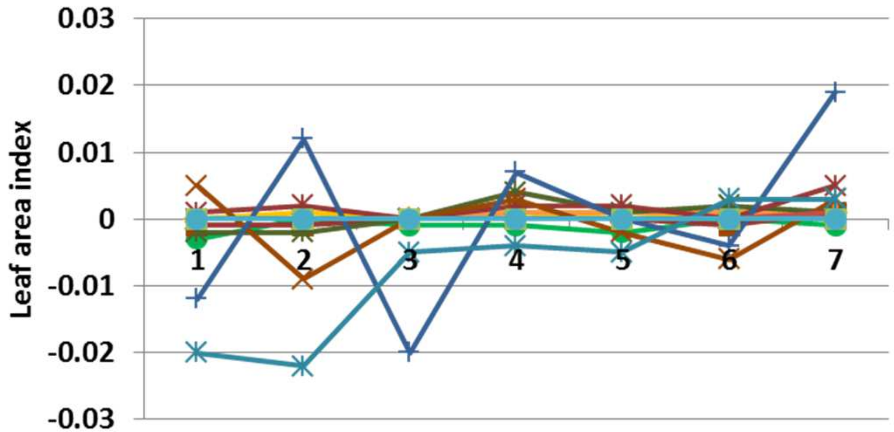
Basis for assignment: The values were inferred, then adjusted to improve model fit.

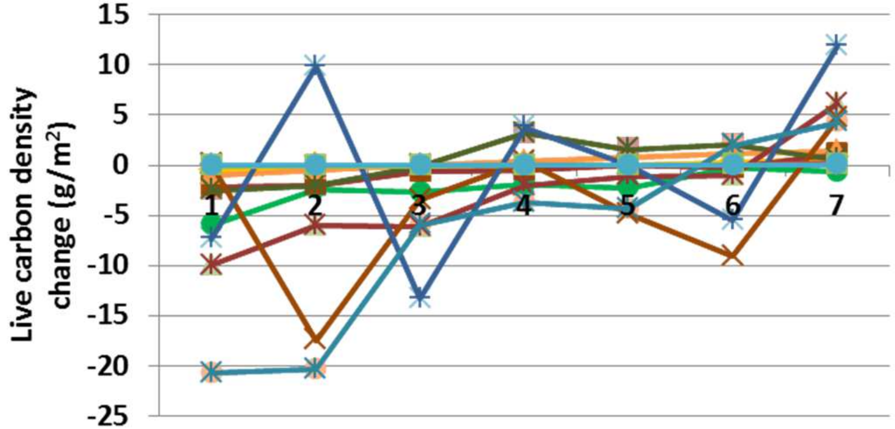
Baseline values
Various values, but of a range and pattern similar to:
0.37, 0.50, 3.0, 1.00, 1.0, 0.76, 6.0, 1.00, 1.0, 0.67, 4.0, 1.00

Sensitivity values:
(tree lower y values changed only)
1 – 0.40
2 – 0.45
3 – 0.50
4 – 0.55
5 – 0.60
6 – 0.65
7 – 0.70









Interpretation: Tree cover changed only a small amount due to changes in water stress, with most changes less than 1.5%, except for tropical and temperate deciduous forests (left). Shrubs changed up to 2.4%, and herbs changed up to 7%. Other changes in G-Range output were fairly modest. Evapotranspiration, soil temperature, plant-available water, and decomposition coefficients changed little. Soil organic carbon increased up to 70 g m-2. Annual net primary production changed up to 15 g m-2. Live carbon density (above) changed up to 22 g m-2, and leaf area index changed little (top).

Conclusion: The parameter is important to reflect the effect of water limitations on facet cover, and should be retained.

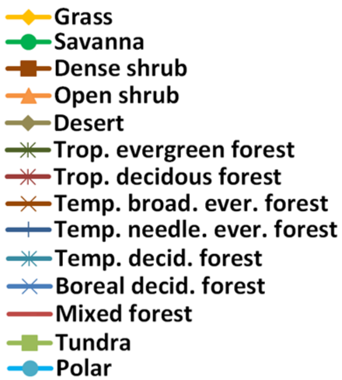
39a. Herb root effect on establishment - Herbs

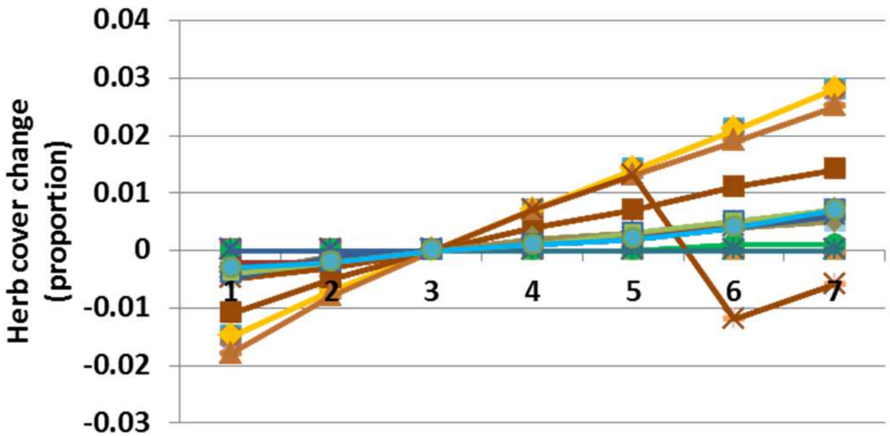
Purpose: The variable set herb_root_effect_on_establishment creates a multiplier for the relative seed production rate based on the biomass of herbaceous roots, reflecting root crowding. Two pairs of values define a linear regression for each facet.

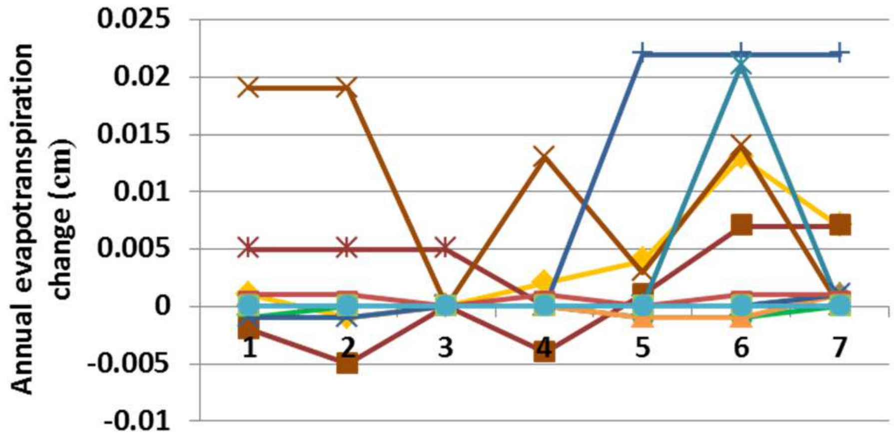
Basis for assignment: The values were inferred, then adjusted to improve model fit.

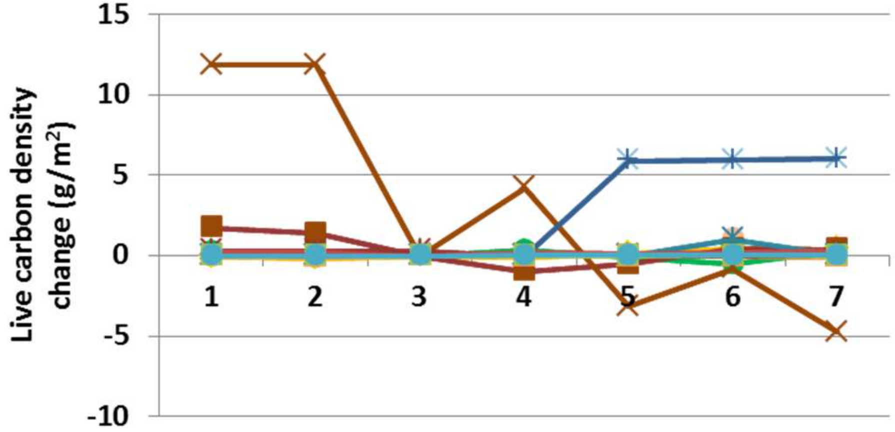
Baseline values
Various values, but of a range and pattern similar to:
50.0, 1., 300., 0.50, 100.0, 1., 500.0, 0.0, 150.0, 1., 600.0, 0.0

Sensitivity values:
(herb upper x values changed only)
1 – 200
2 – 250
3 – 300
4 – 350
5 – 400
6 – 450
7 – 500









Interpretation: Changes in biogeochemical results from G-Range were very small in response to changes in herbaceous root effects on the establishment of herbs. Examples shown include annual evapotranspiration that changed a fraction, and live carbon density that changed less than 13 g m-2. Net primary propuctivity was essentially unchanged. Herbaceous cover changed little (up to 2%) with changes in herb root effects on establishment. Woody facets did not change at all.

Conclusion: The parameter is important to reflect the effect of competition for space by roots on facet cover, which may be important in some locations.

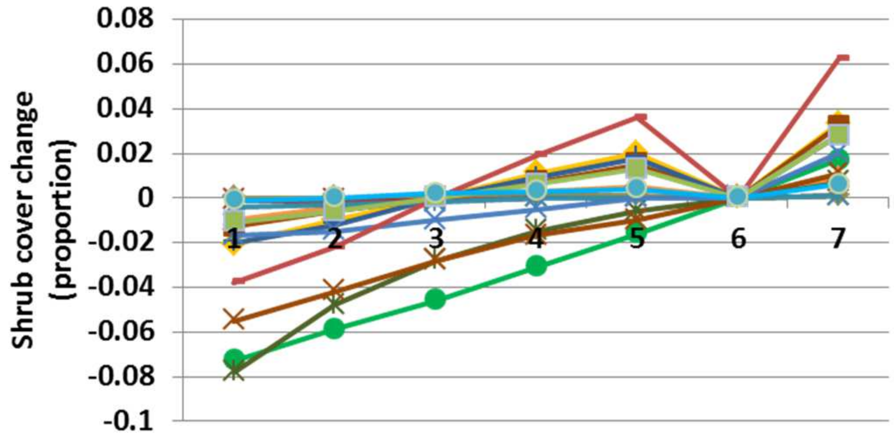
39b. Herb root effect on establishment - Shrubs

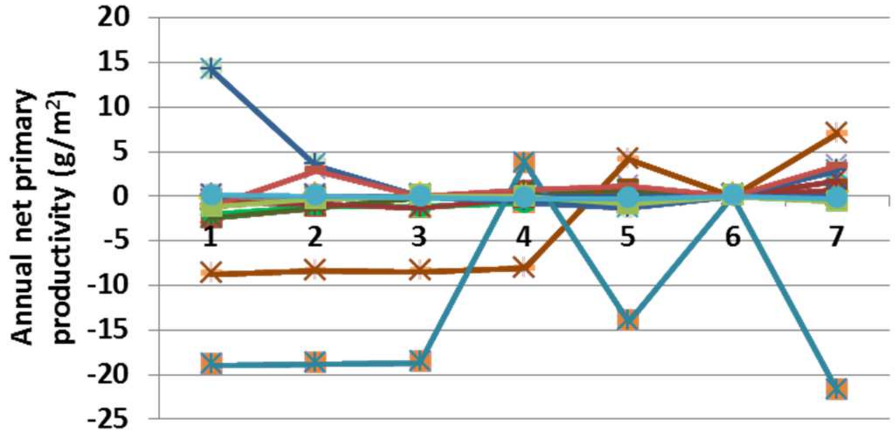
Purpose: The variable set herb_root_effect_on_establishment creates a multiplier for the relative seed production rate based on the biomass of herbaceous roots, reflecting root crowding. Two pairs of values define a linear regression for each facet.

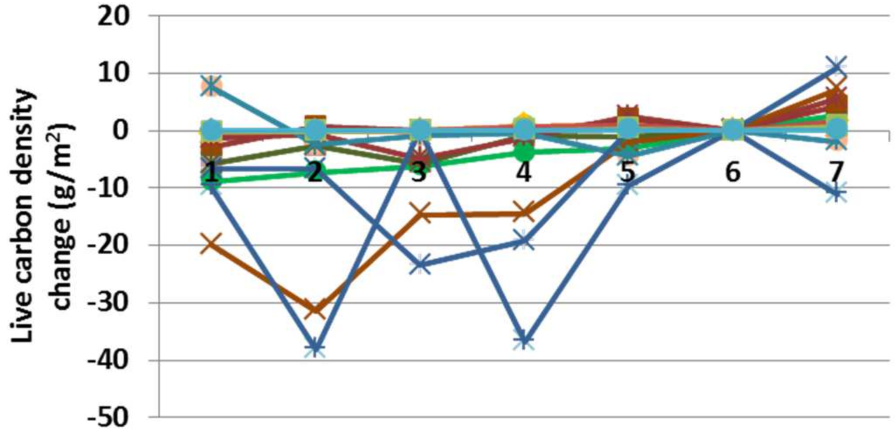
Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values
Various values, but of a range and pattern similar to:
50.0, 1., 300., 0.50, 100.0, 1., 500.0, 0.0, 150.0, 1., 600.0, 0.0

Sensitivity values:
(shrub upper x values changed only)
1 – 300
2 – 400
3 – 500
4 – 600
5 – 700
6 – 800
7 – 900







Interpretation: As elsewhere, changes to parameters affecting establishment had larger effects on facet cover than on nutrient modeling results, as expected. Annual evapotranspiration, soil temperature, plant available water, and decomposition coefficients were essentially unchanged. Annual net primary productivity changed only 20 g m^{-2} (top) and live carbon density by up to 40 g m^{-2}. Shrub cover changed up to 8% in response to herbaceous crowding of roots. Herbaceous roots changed up to 13%, in a pattern opposite to that of shrub change. Tree cover changed little.

Conclusion: The parameter is important to reflect the effect of competition for space by roots on facet cover.

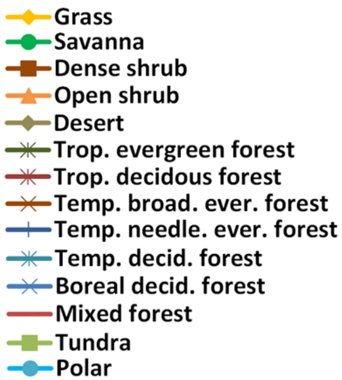
39c. Herb root effect on establishment - Trees

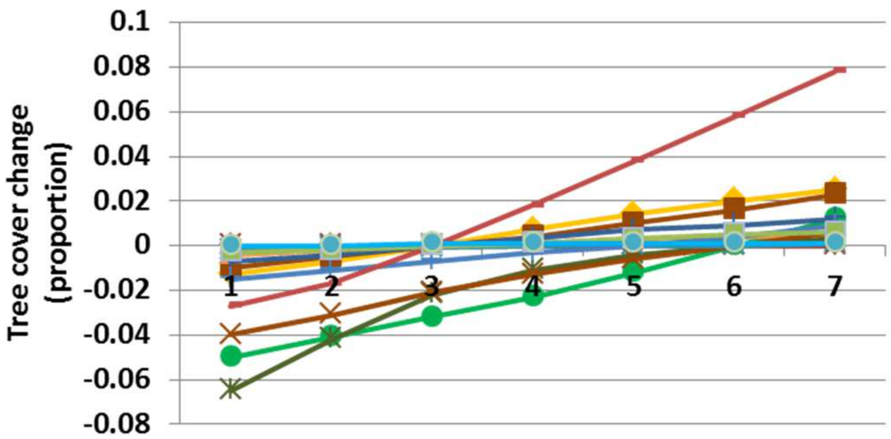
Purpose: The variable set herb_root_effect_on_establishment creates a multiplier for the relative seed production rate based on the biomass of herbaceous roots, reflecting root crowding. Two pairs of values define a linear regression for each facet.

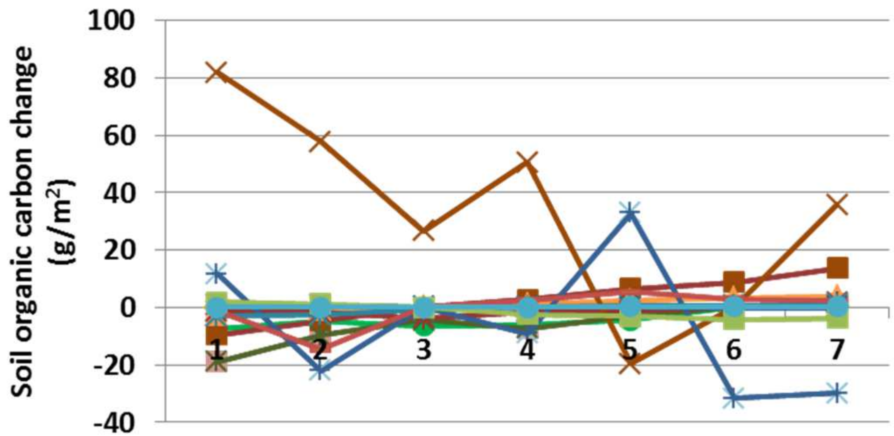
Basis for assignment: The values were inferred, then adjusted to improve model fit.

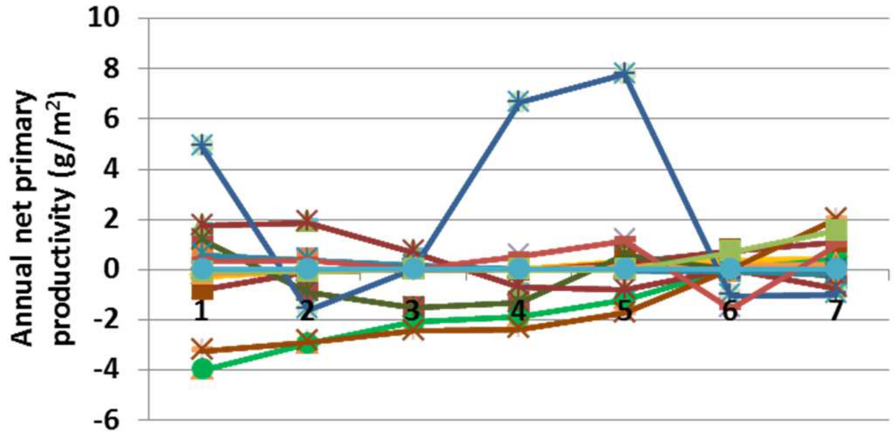
Baseline values
Various values, but of a range and pattern similar to:
50.0, 1., 300., 0.50, 100.0, 1., 500.0, 0.0, 150.0, 1., 600.0, 0.0

Sensitivity values:
(tree upper x values changed only)
1 – 300
2 – 400
3 – 500
4 – 600
5 – 700
6 – 800
7 – 900









Interpretation: Tree facet cover changed up to 8% in response to changes in establishment associated with herbaceous roots. Tree cover increased as the competition with herbaceous roots was reduced, as expected. Shrub cover changed little, but herbaceous cover changed up to 10% and bare ground cover up to 6.8%. Changes in other G-Range outputs assessed were small, such as the up to 80 g m^{-2} increase in soil organic carbon and the 8 g m^{-2} change in annual net primary productivity. Leaf area index changed less than 0.01, and live carbon density by up to 40 g m^{-2}.

Conclusion: The parameter is important to reflect the effect of competition for space by roots on facet cover.

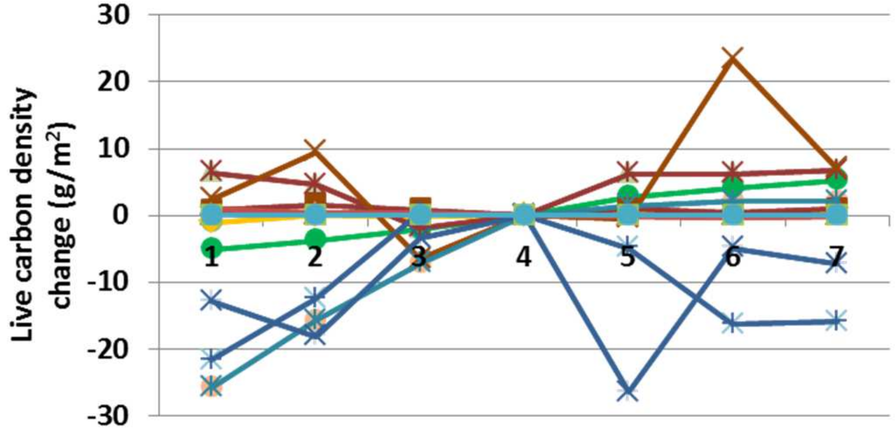
40a. Litter effect on establishment - Herbs

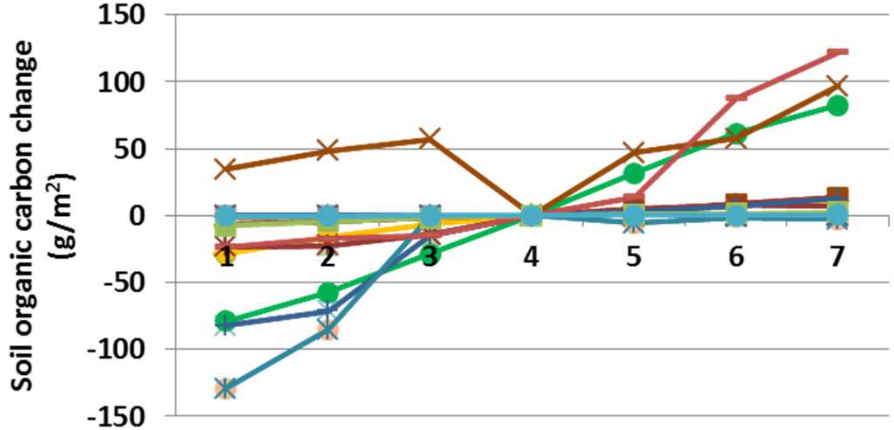
Purpose: The variable set litter_effect_on_establish creates a multiplier for the relative seed production rate based on the interference litter may have on seed establishment. Two pairs of values define a linear regression for each facet.

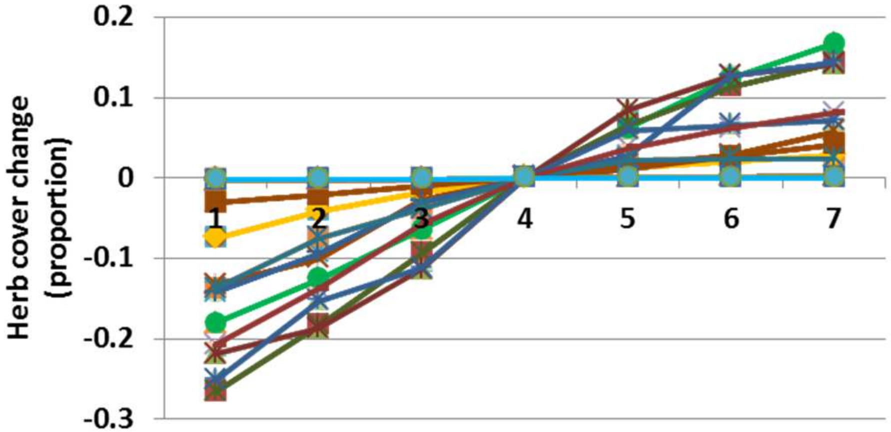
Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values
Various values, but of a range and pattern similar to:
300., 1., 1000., 0.1, 300., 1., 1000., 0.7, 300., 1., 1000., 0.7

Sensitivity values:
(herb upper x values changed only)
1 – 700
2 – 800
3 – 900
4 – 1000
5 – 1100
6 – 1200
7 – 1300







Interpretation: The changes to nutrients and productivity in association with changes in sensitivity to litter biomass were minor. Potential and annual evapotranspiration were essentially unchanged, as were plant available water and coefficients associated with decomposition. Annual net primary productivity changed by less than 20 g m-2, and live carbon density by less than 27 g m-2 (top). Soil organic carbon changed up to 130 g m-2. Herbaceous facet cover changed in a regular manner, up to 27% (left). Shrub and tree cover were essentially unchanged.

Conclusion: The parameter is important to reflect the effect of heavy litter on seed establishment and on facet cover.

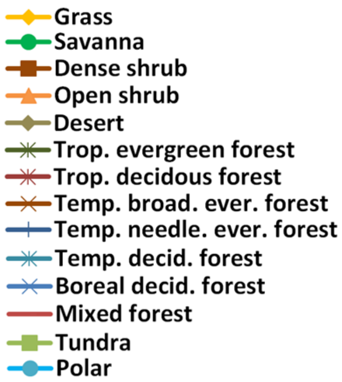
40b. Litter effect on establishment - Shrubs

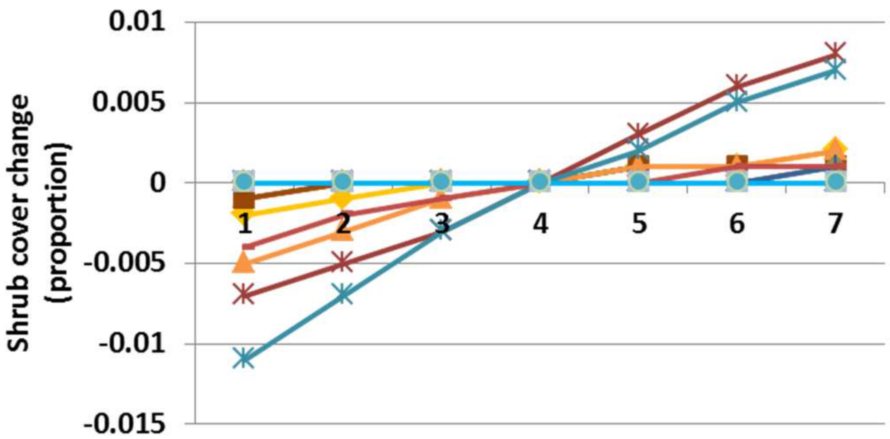
Purpose: The variable set litter_effect_on_establish creates a multiplier for the relative seed production rate based on the interference litter may have on seed establishment. Two pairs of values define a linear regression for each facet.

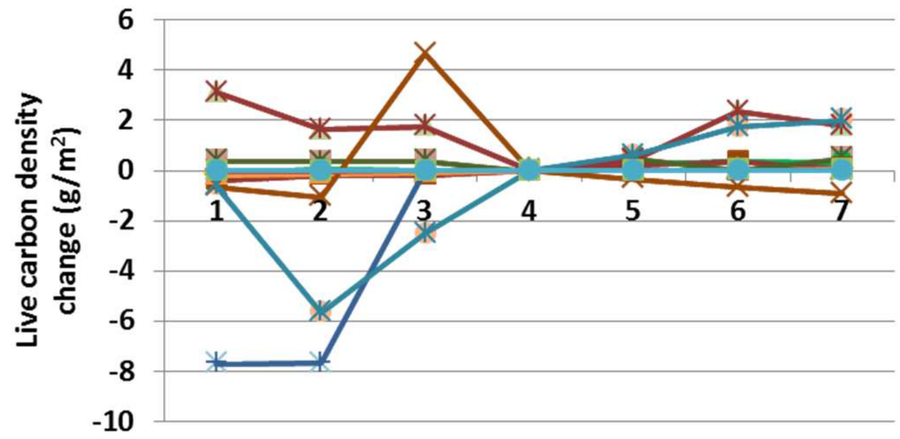
Basis for assignment: The values were inferred, then adjusted to improve model fit.

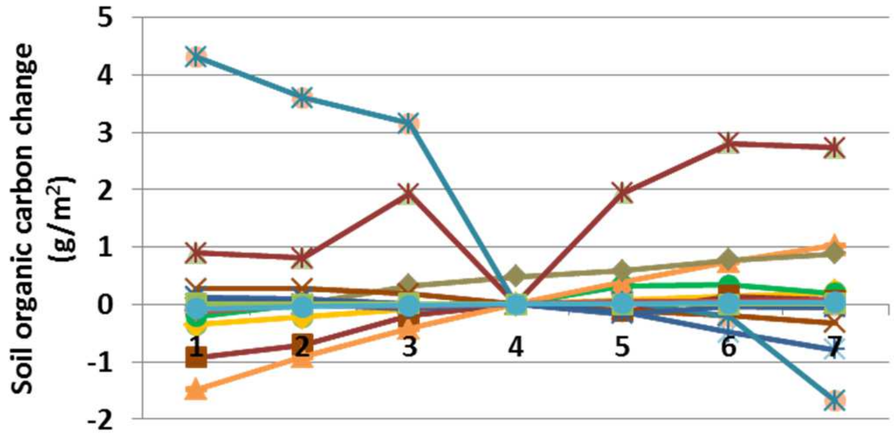
Baseline values
Various values, but of a range and pattern similar to:
300., 1., 1000., 0.1, 300., 1., 1000., 0.7, 300., 1., 1000., 0.7

Sensitivity values:
(shrub upper x values changed only)
1 – 700
2 – 800
3 – 900
4 – 1000
5 – 1100
6 – 1200
7 – 1300









Interpretation: Only small changes in shrub cover were associated with changes in the effect litter had on establishment (left); it appears shrubs were rarely limited by litter. Herbs changed less than 2%, and trees were unchanged. Plant processes and production changed very little as well, such as the live carbon density shown (top) and soil organic carbon that changed up to just 4.2 g $^{m-2}$.

Conclusion: The parameter is important to reflect the effect of heavy litter on seed establishment and on facet cover. In the current parameterization, however, the effect is very small.

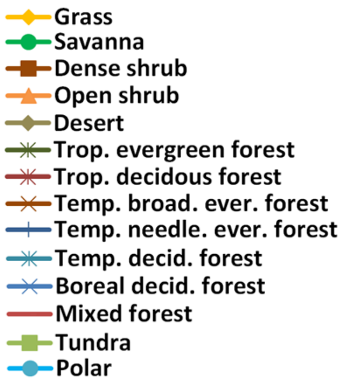
40c. Litter effect on establishment - Trees

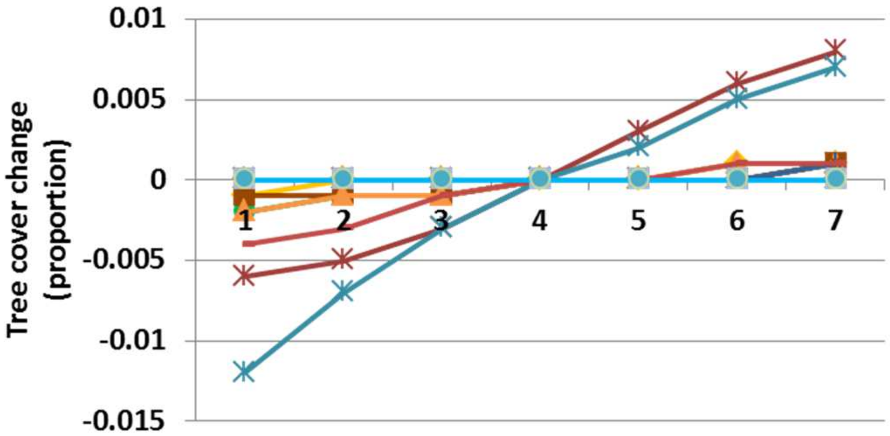
Purpose: The variable set litter_effect_on_establish creates a multiplier for the relative seed production rate based on the interference litter may have on seed establishment. Two pairs of values define a linear regression for each facet.

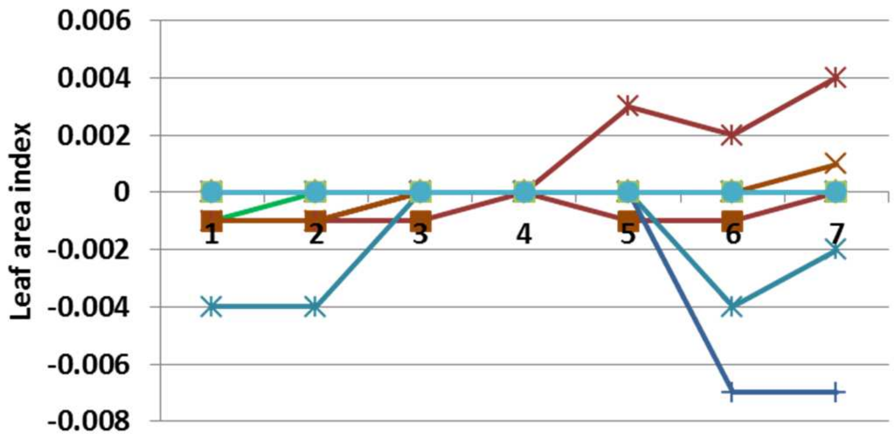
Basis for assignment: The values were inferred, then adjusted to improve model fit.

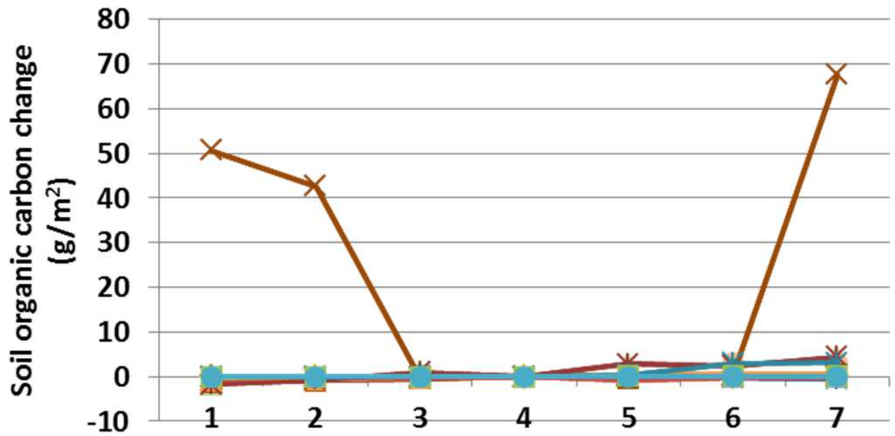
Baseline values
Various values, but of a range and pattern similar to:
300., 1., 1000., 0.1, 300., 1., 1000., 0.7, 300., 1., 1000., 0.7

Sensitivity values:
(shrub upper x values changed only)
1 – 700
2 – 800
3 – 900
4 – 1000
5 – 1100
6 – 1200
7 – 1300









Interpretation: Like for the shrubs, tree cover was not really influenced by changes in sensitivity of establishment to sensitivity to litter. Tree cover changed less than 2% for the values tested (left), shrubs were essentially unchanged, and herbs changed less than 1%, except for temperature broadleaf evergreen forest, which declined 3% at the lowest sensitivities. Results from nutrient and productivity modeling were essentially unchanged, such as for soil organic carbon (above) and leaf area index (top).

Conclusion: The parameter is important to reflect the effect of heavy litter on seed establishment and on facet cover. In the current parameterization, however, the effect is very small.

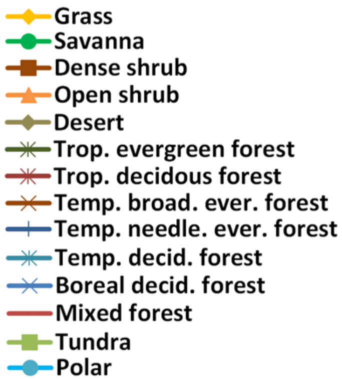
41a. Woody cover effect on establishment - Herbs

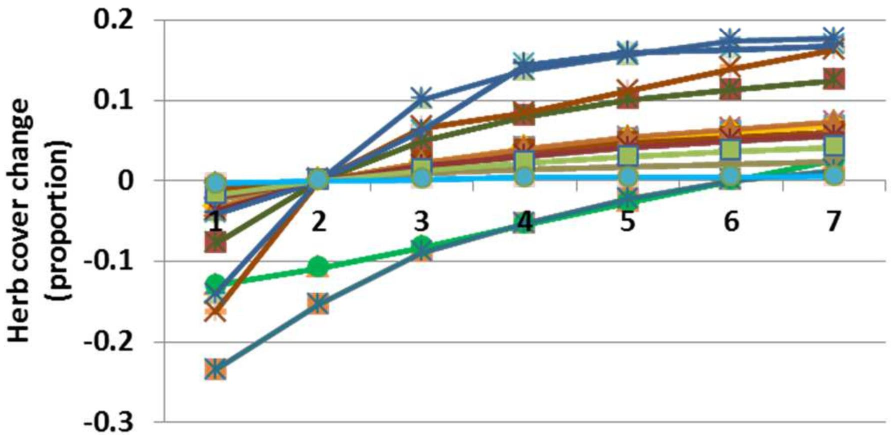
Purpose: The variable set woody_cover_effect_on_establish creates a multiplier for the relative seed production rate based on the interference shading by woody plants may have on seed establishment. Two pairs of values define a linear regression for each facet.

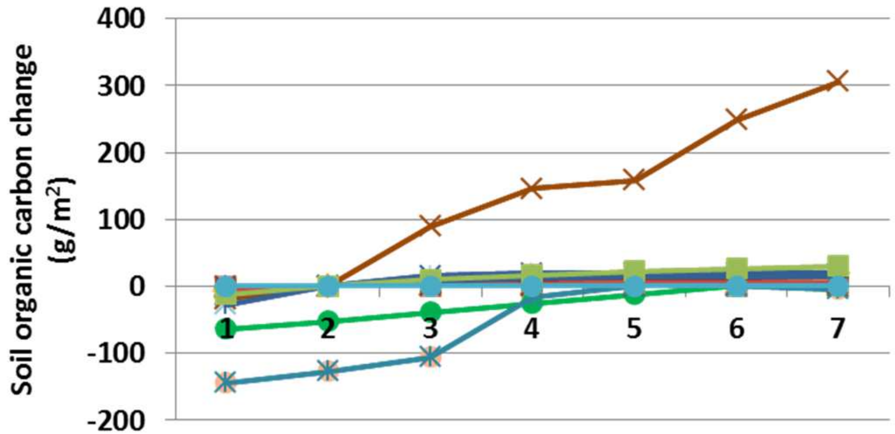
Basis for assignment: The values were inferred, then adjusted to improve model fit.

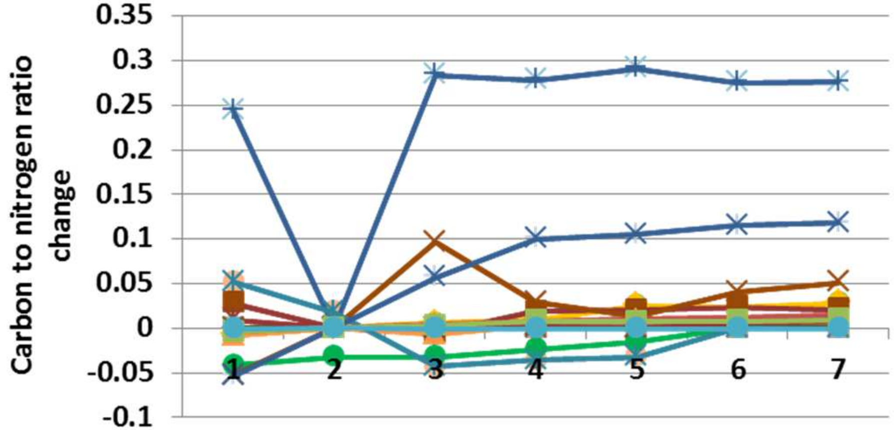
Baseline values
Various values, but two examples cover most units:
0.0, 1.0, 0.4, 0.0, 0.0, 1.0, 0.5, 0.0, 0.0, 1.0, 0.35, 0.0
0.0, 1.0, 0.4, 0.0, 0.0, 1.0, 0.3, 0.0, 0.0, 1.0, 0.25, 0.0

Sensitivity values:
(herb upper x values changed only)
1 – 0.35
2 – 0.40
3 – 0.45
4 – 0.50
5 – 0.55
6 – 0.60
7 – 0.65









Interpretation: Changes in results in response to sensitivity to woody cover were small. Annual evapotranspiration changed less than 0.2 cm, and soil temperature and plant-available water were essentially unchanged. Soil organic carbon up to 310 g m-2 (top), and carbon to nitrogen ratio changed up to 0.3. Live carbon density and annual net primary production each changed less than 35 g m-2, and leaf area index by 0.05. Herbaceous cover changed up to 24% (left), and shrubs and trees were essentially unchanged.

Conclusion: The parameter is important to reflect the effect of woody plants can have on vegetation in their understory.

41b. Woody cover effect on establishment - Shrubs

Purpose: The variable set woody_cover_effect_on_establish creates a multiplier for the relative seed production rate based on the interference shading by woody plants may have on seed establishment. Two pairs of values define a linear regression for each facet.

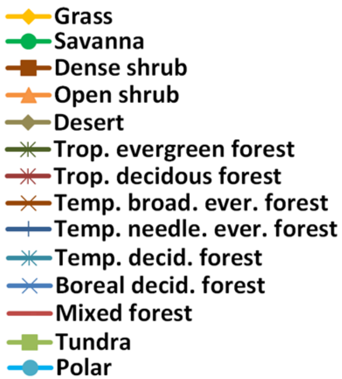
Basis for assignment: The values were inferred, then adjusted to improve model fit.

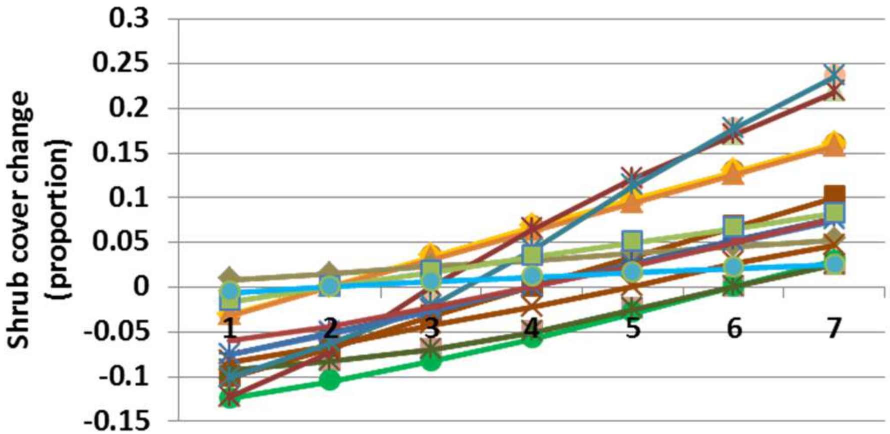
Baseline values

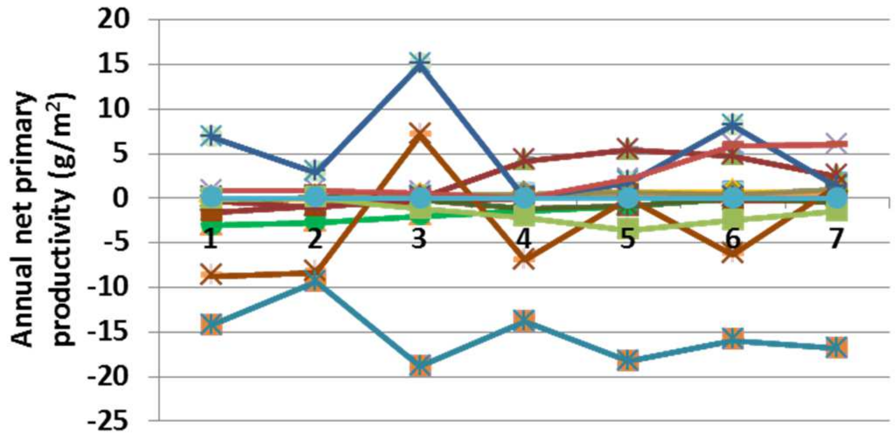
Various values, but two examples cover most units:
0.0, 1.0, 0.4, 0.0, 0.0, 1.0, 0.5, 0.0, 0.0, 1.0, 0.35, 0.0
0.0, 1.0, 0.4, 0.0, 0.0, 1.0, 0.3, 0.0, 0.0, 1.0, 0.25, 0.0

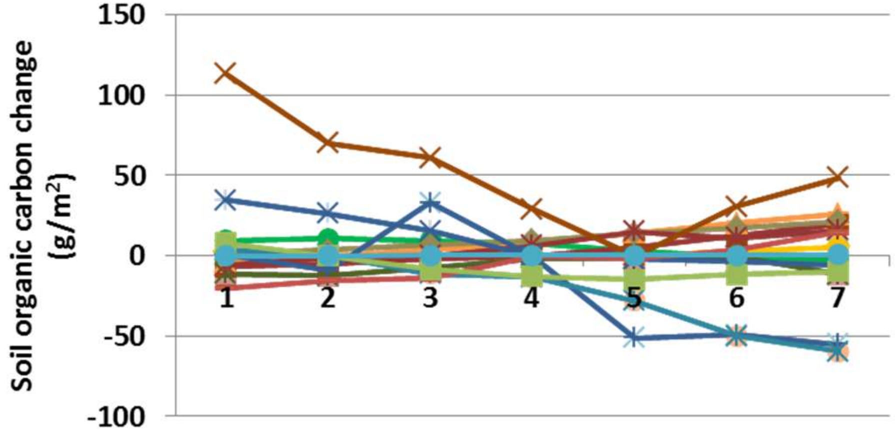
Sensitivity values:

(shrub upper x values changed only)
1 – 0.25
2 – 0.30
3 – 0.35
4 – 0.40
5 – 0.45
6 – 0.50
7 – 0.55









Interpretation: Changes in nutrient and productivity results from G-Range were small when the effect of woody plants on establishment was changed. Responses such as annual and potential evapotranspiration, soil temperature, plant-available water, and decomposition coefficients were essentially unchanged. Net primary productivity changed up to 19 g m^{-2} (top), and soil organic carbon by up to 120 g m^{-2}. Shrub cover was sensitive, with changes up to 23% (left). Generally, the changes in shrubs were compensated by changes in herbs, with opposite change to shrubs of up to 25%.

Conclusion: The parameter is important to reflect the effect of woody plants can have on vegetation in their understory.

41c. Woody cover effect on establishment - Trees

Purpose: The variable set woody_cover_effect_on_establish creates a multiplier for the relative seed production rate based on the interference shading by woody plants may have on seed establishment. Two pairs of values define a linear regression for each facet.

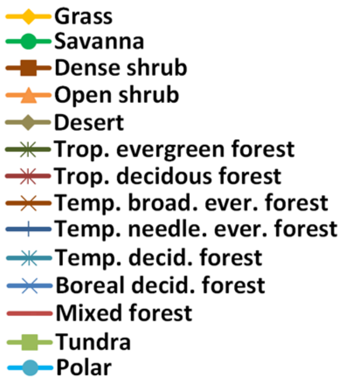
Basis for assignment: The values were inferred, then adjusted to improve model fit.

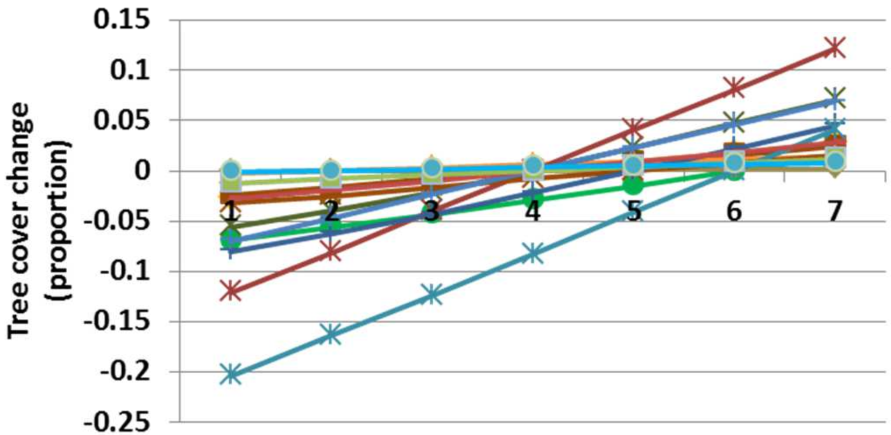
Baseline values

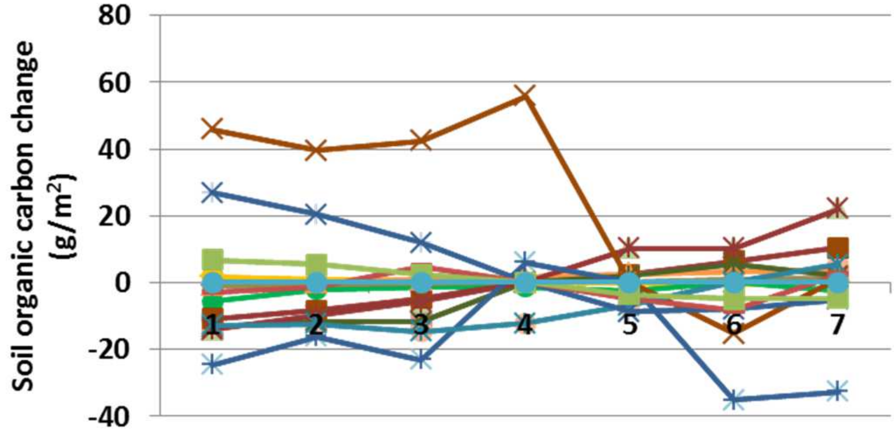
Various values, but two examples cover most units:
0.0, 1.0, 0.4, 0.0, 0.0, 1.0, 0.5, 0.0, 0.0, 1.0, 0.35, 0.0
0.0, 1.0, 0.4, 0.0, 0.0, 1.0, 0.3, 0.0, 0.0, 1.0, 0.25, 0.0

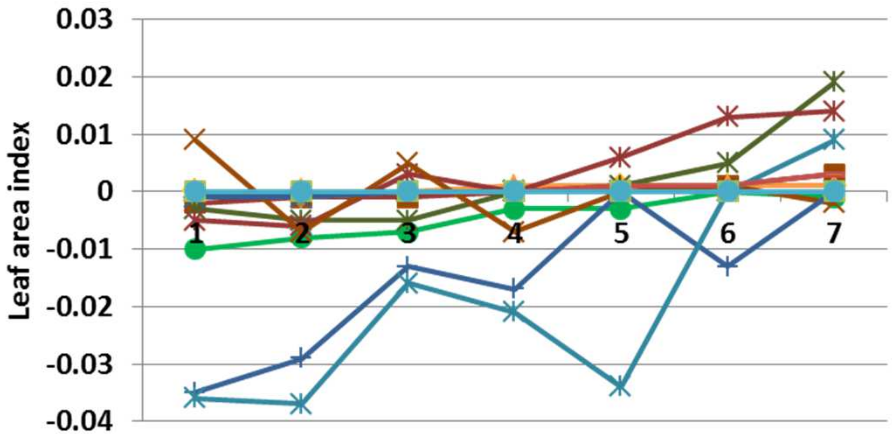
Sensitivity values:

(tree upper x values changed only)
1 – 0.20
2 – 0.25
3 – 0.30
4 – 0.35
5 – 0.40
6 – 0.45
7 – 0.50









Interpretation: Changes in annual evapotranspiration, soil temperature, plant-available water, and decomposition coefficients were all small. Other responses showed small changes as well, such as leaf area index changing up to 0.037 (above), net primary production changing less than 12 g m^{-2}, live carbon density changing up to 50 g m^{-2}, and soil organic carbon changing less than 60 g m^{-2}. Tree cover changed linearly with changes in sensitivity to woody cover (left), up to 21%. Shrubs changed up to 6%, and herbs changed in a fashion opposite to trees, up to 17% cover.

Conclusion: The parameter is important to reflect the effect of woody plants can have on vegetation in their understory.

42a. Nominal plant death rate - Herbs

Purpose: The variable set nominal_plant_death_rate provides one value per facet, reflecting the baseline mortality rate of plants of that facet.

Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values

Various values, three examples suggest the range for units:
0.0065, 0.0002, 0.0002
0.0020, 0.0009, 0.0002
0.0072, 0.0012, 0.0010

Sensitivity values:

(herbs only changed)
1 – 0.003
2 – 0.004
3 – 0.005
4 – 0.006
5 – 0.007
6 – 0.008
7 – 0.009

Interpretation: Results for nominal plant death rate are not available due to technical difficulties. Presumably G-Range is highly sensitivity to nominal plant death rates.

Conclusion: The parameter is critical to determining baseline mortality in plants.

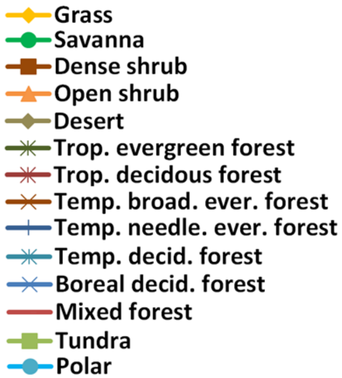
42a. Nominal plant death rate - Shrubs

Purpose: The variable set nominal_plant_death_rate provides one value per facet, reflecting the baseline mortality rate of plants of that facet.

Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values
Various values, three examples suggest the range for units:
0.0065, 0.0002, 0.0002
0.0020, 0.0009, 0.0002
0.0072, 0.0012, 0.0010

Sensitivity values:
(shrubs only changed)
1 – 0.0002
2 – 0.0005
3 – 0.0008
4 – 0.0011
5 – 0.0014
6 – 0.0017
7 – 0.0020



Interpretation: Results for nominal plant death rate are not available due to technical difficulties. Presumably G-Range is highly sensitivity to nominal plant death rates.

Conclusion: The parameter is critical to determining baseline mortality in plants.

42a. Nominal plant death rate - Trees

Purpose: The variable set nominal_plant_death_rate provides one value per facet, reflecting the baseline mortality rate of plants of that facet.

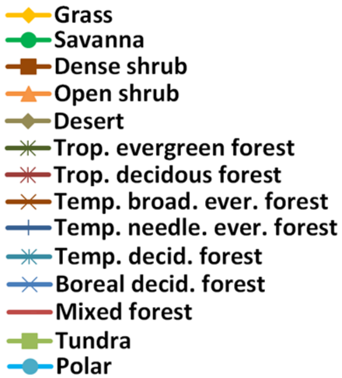
Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values

Various values, three examples suggest the range for units:
0.0065, 0.0002, 0.0002
0.0020, 0.0009, 0.0002
0.0072, 0.0012, 0.0010

Sensitivity values:

(trees only changed)
1 – 0.0002
2 – 0.0005
3 – 0.0008
4 – 0.0011
5 – 0.0014
6 – 0.0017
7 – 0.0020



Interpretation: Results for nominal plant death rate are not available due to technical difficulties. Presumably G-Range is highly sensitivity to nominal plant death rates.

Conclusion: The parameter is critical to determining baseline mortality in plants.

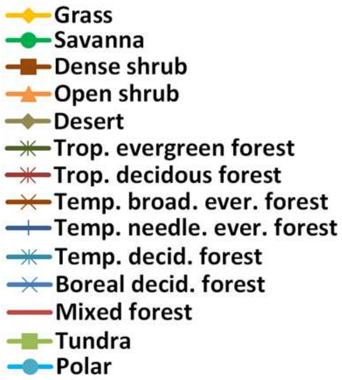
43a. Water effect on death rate - Herbs

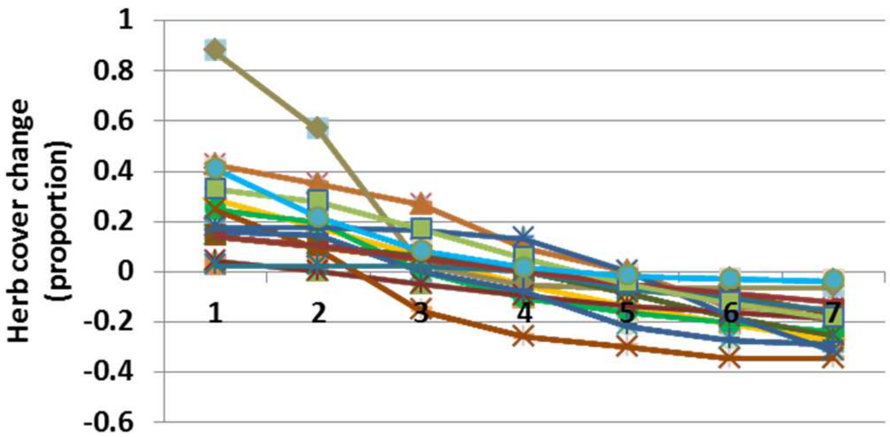
Purpose: The variable set water_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the available water to potential evapotranspiration ratio and its relation to plant death.

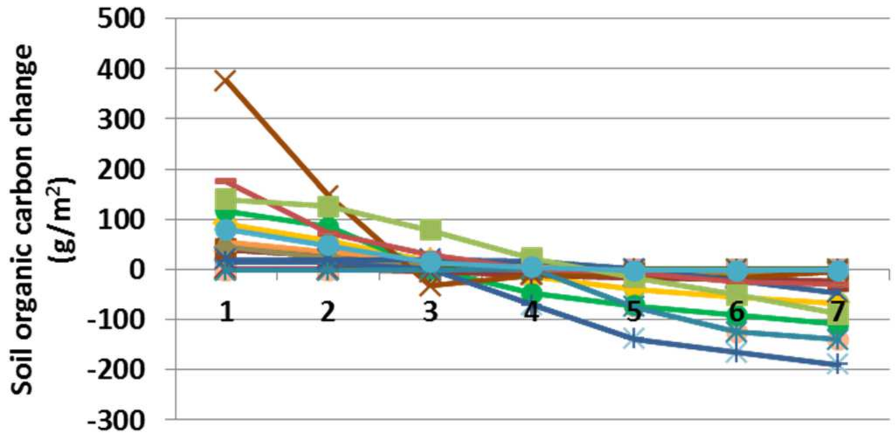
Basis for assignment: The values were inferred, then adjusted to improve model fit.

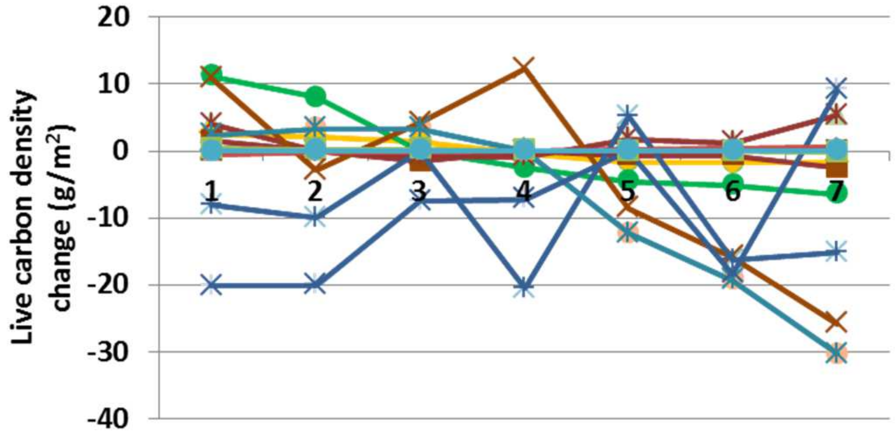
Baseline values
Various values, two examples suggest the nature of entries:
0.0, 0.08, 2.5, 0.0, 0.0, 0.0015, 2.0, 0.0, 0.0, 0.001, 2.0, 0.0
0.0, 0.10, 3.5, 0.0, 0.0, 0.0080, 2.5, 0.0, 0.0, 0.005, 2.5, 0.0

Sensitivity values:
(herbs lower y changed)
1 – 0.02
2 – 0.04
3 – 0.06
4 – 0.08
5 – 0.10
6 – 0.12
7 – 0.14









Interpretation: Annual evapotranspiration, plant-available soil water, soil temperature, and decomposition coefficients changed little in response to different sensitivity of herbs to water availability. Modest changes were seen in other responses, such as soil organic carbon changing up to 380 g m^{-2} (top), net primary productivity changed up to 23 g m^{-2}, and live carbon density changed up to 30 g m^{-2}. Herbaceous cover changed greatly with changes in sensitivity to water, up to 43% in most landscape units, and up to 88% in deserts (left). Shrub and tree facet cover changed little.

Conclusion: The parameter captures an important source of mortality for plants, water stress, and will be retained.

43b. Water effect on death rate - Shrubs

Purpose: The variable set water_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the available water to potential evapotranspiration ratio and its relation to plant death.

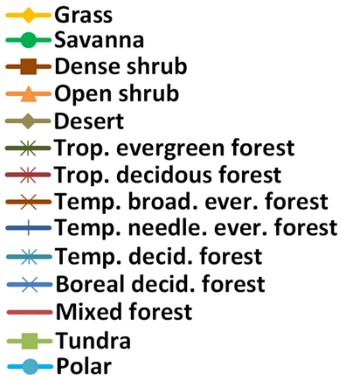
Basis for assignment: The values were inferred, then adjusted to improve model fit.

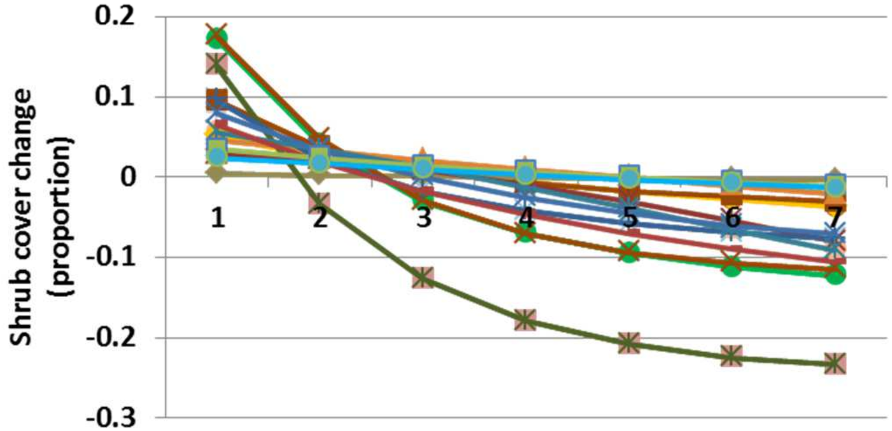
Baseline values

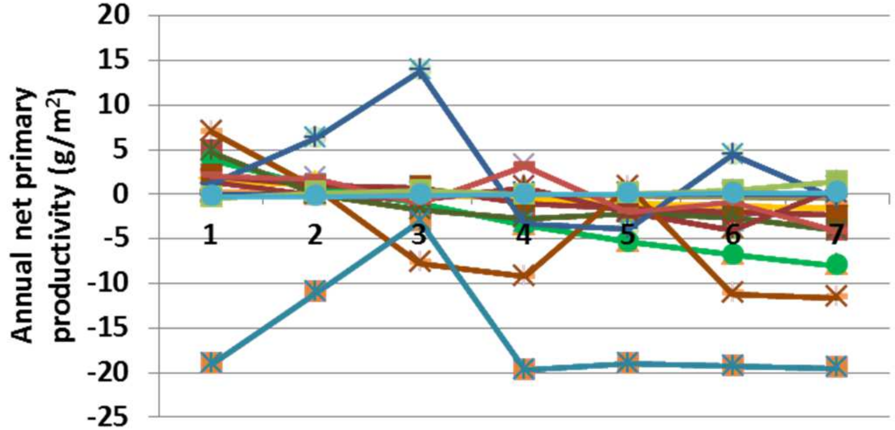
Various values, two examples suggest the nature of entries:
0.0, 0.08, 2.5, 0.0, 0.0, 0.0015, 2.0, 0.0, 0.0, 0.001, 2.0, 0.0
0.0, 0.10, 3.5, 0.0, 0.0, 0.0080, 2.5, 0.0, 0.0, 0.005, 2.5, 0.0

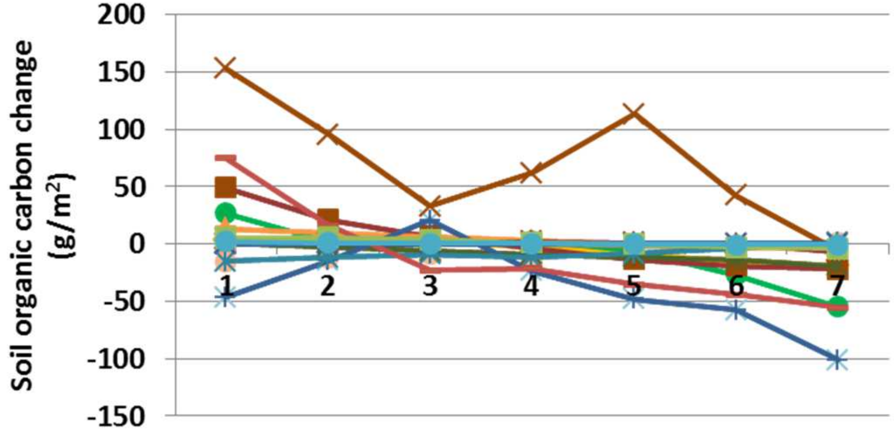
Sensitivity values:

(shrubs lower y changed)
1 – 0.000
2 – 0.002
3 – 0.004
4 – 0.006
5 – 0.008
6 – 0.010
7 – 0.012









Interpretation: Changes in annual net primary productivity were modest, up to 20 g m^{-2} (top), and soil organic carbon changed up to 150 g m^{-2} (above). Carbon to nitrogen ratio changed up to 0.34, and live carbon density by 41 g m^{-2}. Leaf area index changed up to 0.057. Other changes in temperature and evapotranspiration were small. Shrub cover changes up to 24% in response to differences in sensitivity to water stress (left), and herbs change in an opposite pattern. Bare ground also changed up to 11%. Trees were essentially unchanged.

Conclusion: The parameter captures a variety an important source of mortality for plants, water stress, and will be retained.

43c. Water effect on death rate - Trees

Purpose: The variable set water_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the available water to potential evapotranspiration ratio and its relation to plant death.

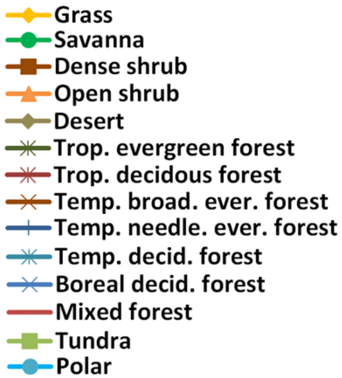
Basis for assignment: The values were inferred, then adjusted to improve model fit.

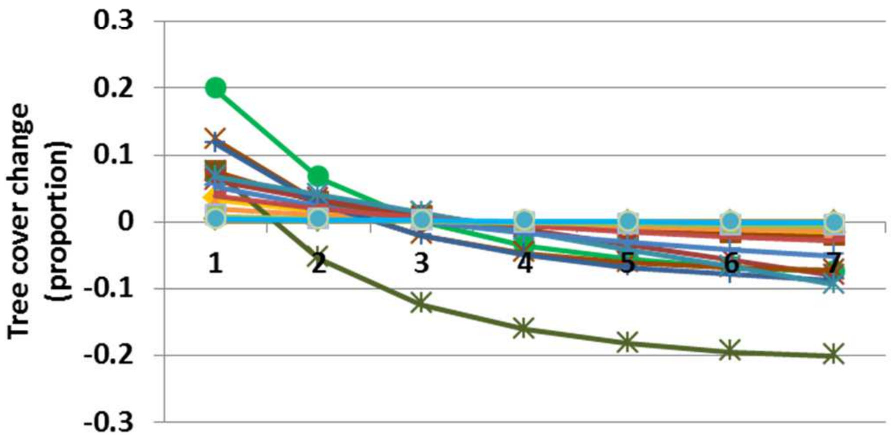
Baseline values

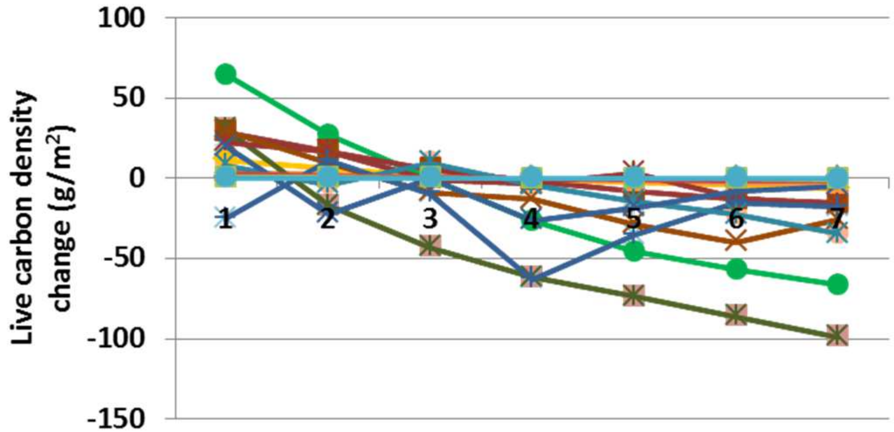
Various values, two examples suggest the nature of entries:
0.0, 0.08, 2.5, 0.0, 0.0, 0.0015, 2.0, 0.0, 0.0, 0.001, 2.0, 0.0
0.0, 0.10, 3.5, 0.0, 0.0, 0.0080, 2.5, 0.0, 0.0, 0.005, 2.5, 0.0

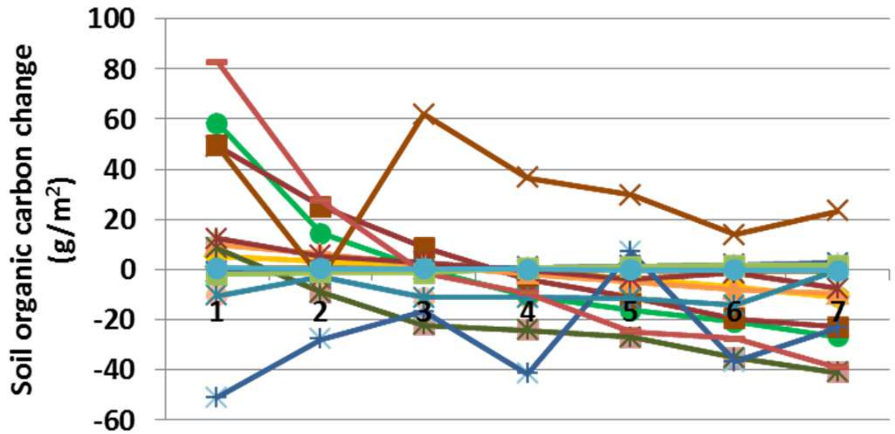
Sensitivity values:

(trees lower y changed)
1 – 0.000
2 – 0.002
3 – 0.004
4 – 0.006
5 – 0.008
6 – 0.010
7 – 0.012









Interpretation: As for most of the variables that primarily affect facet cover, the changes in productivity, nutrient modeling, etc. were small. Evaporation, temperature, plant-available soil water and decomposition coefficients changed little. Leaf area index changed up to 0.066, and net primary productivity changed up to 22 g m^{-2}. Live carbon density changed up to 100 g m^{-2} (top) and soil organic carbon up to 82 g m^{-2} (above). Changes in tree cover were up to 20% (left), and shrubs were unchanged, except for tropical deciduous forest, at 4.7%. Herbs changed opposite to trees, up to 29%.

Conclusion: The parameter captures a variety an important source of mortality for plants, water stress, and will be retained.

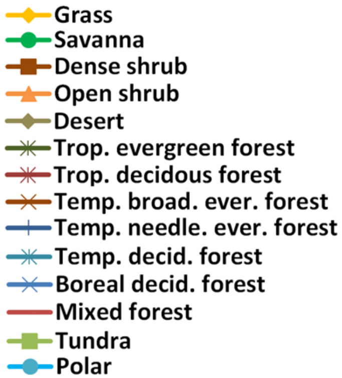
44a. Grazing effect on death rate - Herbs

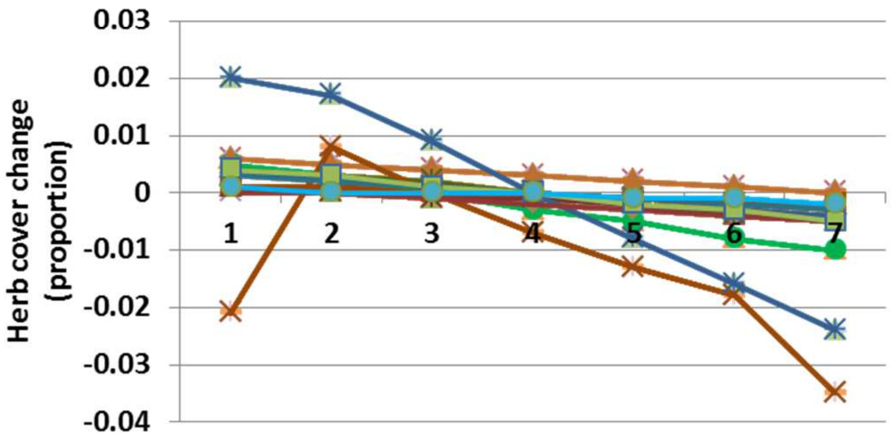
Purpose: The variable set grazing_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the grazing frequency and its relation to plant death.

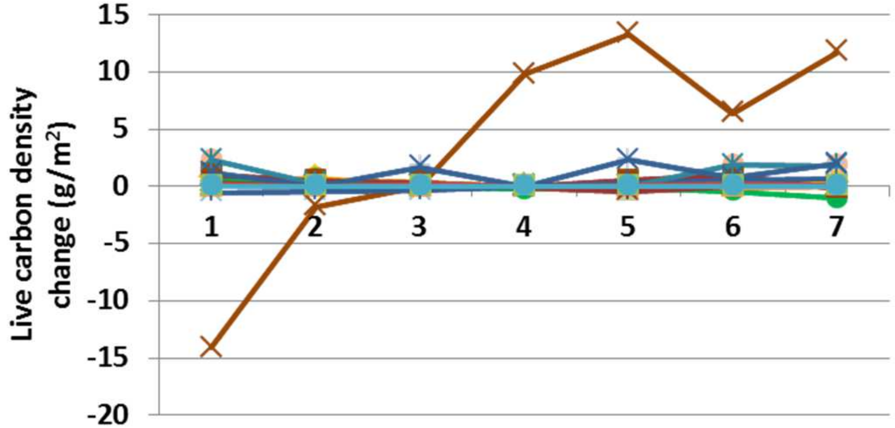
Basis for assignment: The values were inferred, then adjusted to improve model fit.

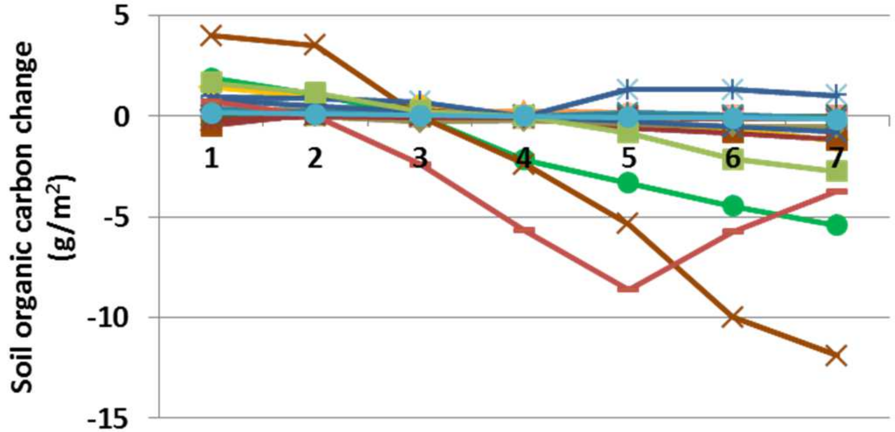
Baseline values
Various but similar values; two examples are:
0.0, 0.0, 1.0, 0.06, 0.0, 0.0, 1.0, 0.003, 0.0, 0.0, 1.0, 0.003
0.0, 0.0, 1.0, 0.04, 0.0, 0.0, 1.0, 0.006, 0.0, 0.0, 1.0, 0.007

Sensitivity values:
(herbs upper y value changed)
1 – 0.03
2 – 0.04
3 – 0.05
4 – 0.06
5 – 0.07
6 – 0.08
7 – 0.09









Interpretation: Changes in herbaceous facet cover were small, at 3.5%, in response to sensitivity to grazing frequency (left). Shrubs and trees were essentially unchanged, and bare ground therefore changed in opposition to herbs. As may be suspected from such small changes, the differences in other outputs from G-Range that were reported were quite small, such as live carbon density (top) and soil organic carbon (above), which changed less than 13 g m^{-2}.

Conclusion: The parameter captures a variety an important source of mortality for plants, grazing stress, and should be better quantified.

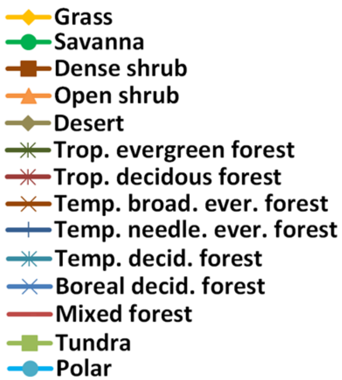
44b. Grazing effect on death rate - Shrubs

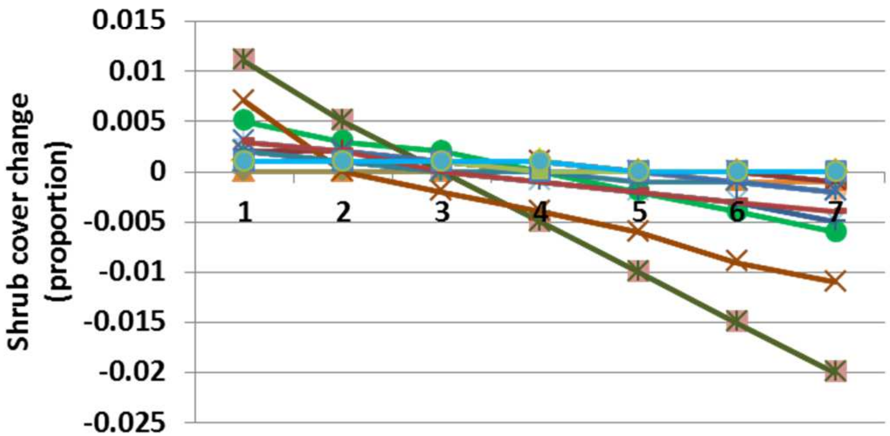
Purpose: The variable set grazing_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the grazing frequency and its relation to plant death.

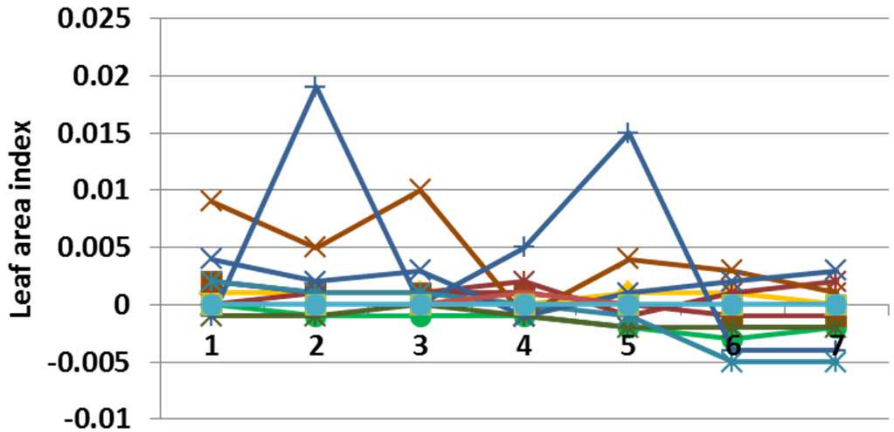
Basis for assignment: The values were inferred, then adjusted to improve model fit.

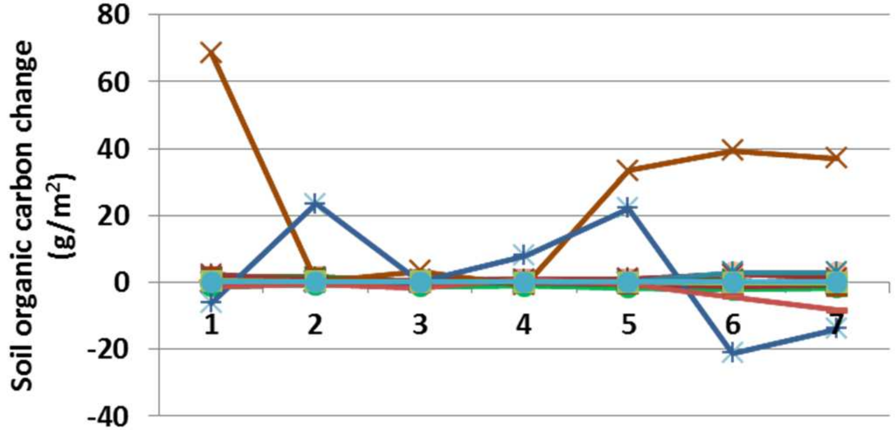
Baseline values
Various but similar values; two examples are:
0.0, 0.0, 1.0, 0.06, 0.0, 0.0, 1.0, 0.003, 0.0, 0.0, 1.0, 0.003
0.0, 0.0, 1.0, 0.04, 0.0, 0.0, 1.0, 0.006, 0.0, 0.0, 1.0, 0.007

Sensitivity values:
(shrubs upper y value changed)
1 – 0.0000
2 – 0.0015
3 – 0.0030
4 – 0.0045
5 – 0.0060
6 – 0.0075
7 – 0.0090









Interpretation: Again, an effect on death rates, in this case grazing effect on shrub death, led to only small changes in G-Range output. Decomposition coefficients, plant-available water, soil temperature, and annual evapotranspiration changed little. Carbon to nitrogen ratio changed up to 0.19, and live carbon density changed up to 14.5 g m-2. Soil organic carbon changed up to 70 g m-2 (above) and leaf area index changed by almost 0.02 (top). Shrub cover changed up to 2% (left), in response to sensitivity to grazing. Herbs changed up to 2.9% in a pattern opposite to shrubs. Trees were unchanged.

Conclusion: The parameter captures a variety an important source of mortality for plants, grazing stress, and should be better quantified.

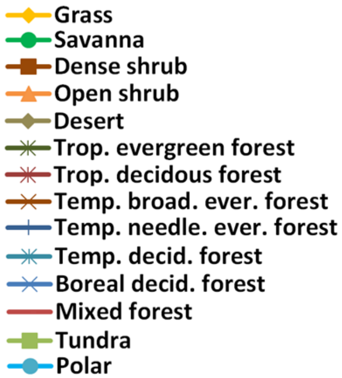
44c. Grazing effect on death rate - Trees

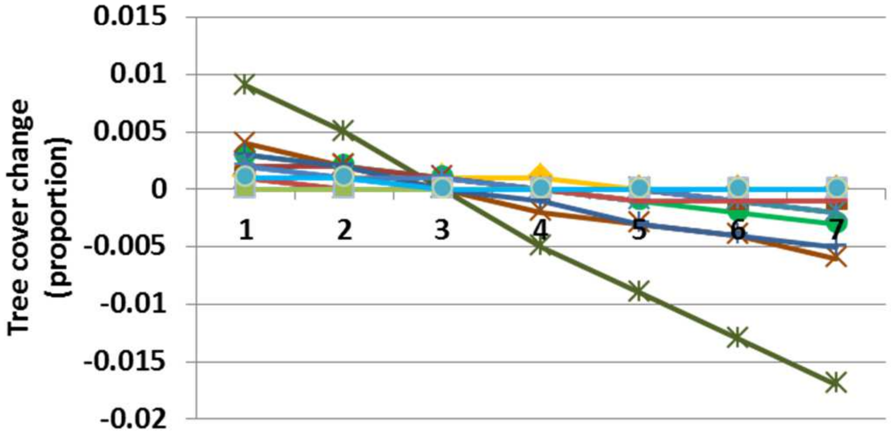
Purpose: The variable set grazing_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the grazing frequency and its relation to plant death.

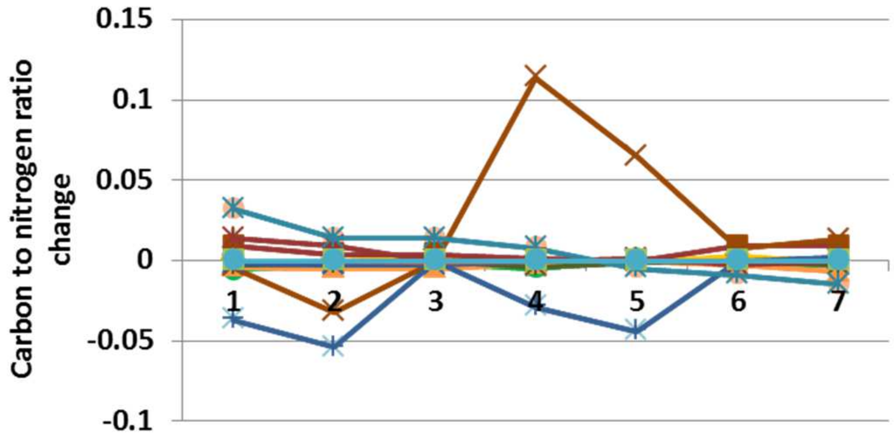
Basis for assignment: The values were inferred, then adjusted to improve model fit.

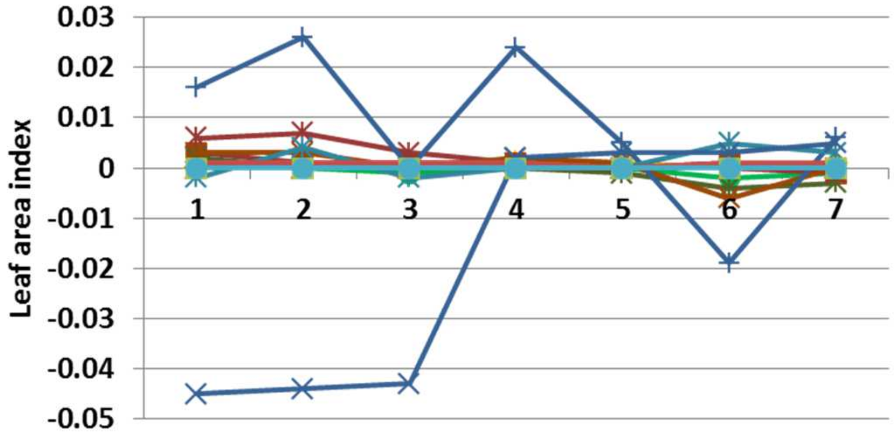
Baseline values
Various but similar values; two examples are:
0.0, 0.0, 1.0, 0.06, 0.0, 0.0, 1.0, 0.003, 0.0, 0.0, 1.0, 0.003
0.0, 0.0, 1.0, 0.04, 0.0, 0.0, 1.0, 0.006, 0.0, 0.0, 1.0, 0.007

Sensitivity values:
(trees upper y value changed)
1 – 0.0000
2 – 0.0015
3 – 0.0030
4 – 0.0045
5 – 0.0060
6 – 0.0075
7 – 0.0090









Interpretation: Changes in nutrient concentrations and productivity, etc. were fairly small. Annual evapotranspiration changed up to 0.08 cm, and soil temperature and plant-available water were essentially unchanged. Soil organic carbon changed up to 67 g m-2, and live carbon density changed up to 23 g m-2. Carbon to nitrogen ratio changed up to 0.12 (top), and leaf area index changed up to 0.045 (above). Trees changed little in response to sensitivity in grazing, less than 2% (left). Shrubs were essentially unchanged. Herbs changed up to 3.2%, in a pattern generally opposite that of trees.

Conclusion: The parameter captures a variety an important source of mortality for plants, grazing stress, and should be better quantified.

45a. Shading effect on death rate - Herbs

Purpose: The variable set shading_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the leaf area index and its relation to plant death.

Basis for assignment: The values were inferred, then adjusted to improve model fit.

Baseline values

Various but similar values; two examples are:

0.0, 0.0, 5.0, 0.06, 0.0, 0.0, 4.0, 0.003, 0.0, 0.0, 4.0, 0.003

0.0, 0.0, 5.0, 0.04, 0.0, 0.0, 4.0, 0.005, 0.0, 0.0, 4.0, 0.005

Sensitivity values:

(herbs upper y value changed)

1 – 0.02

2 – 0.03

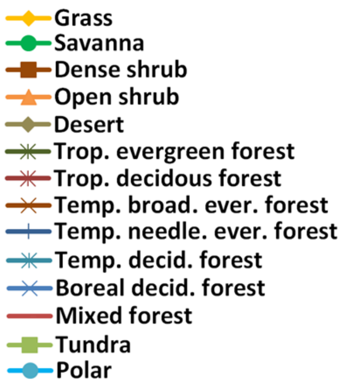
3 – 0.04

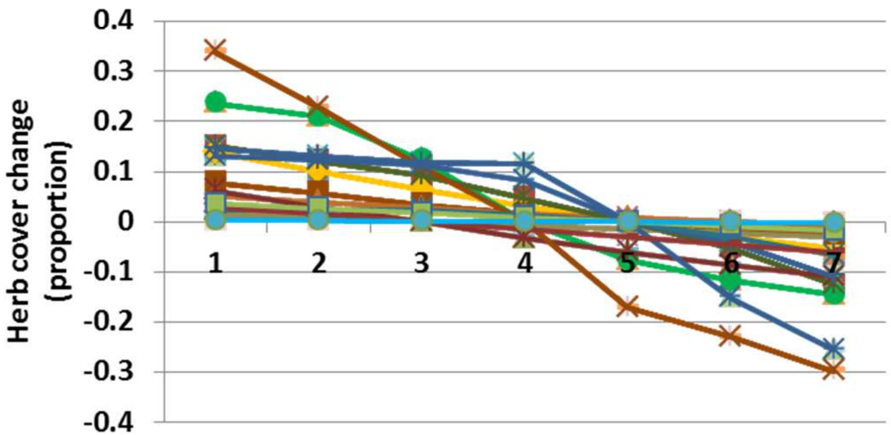
4 – 0.05

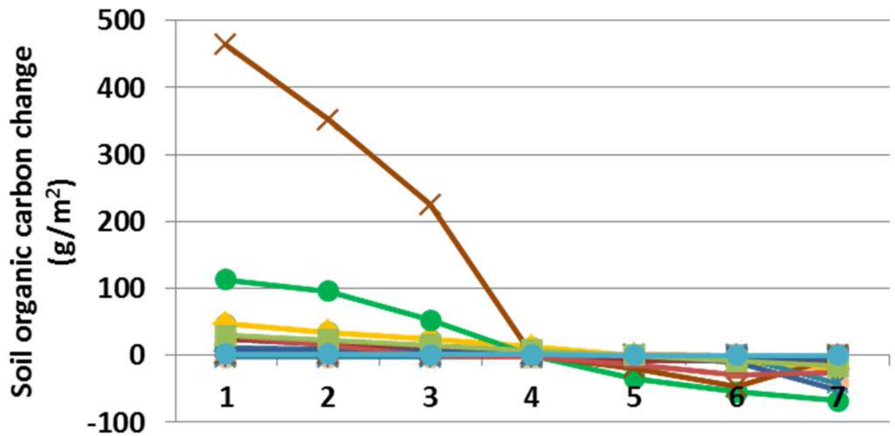
5 – 0.06

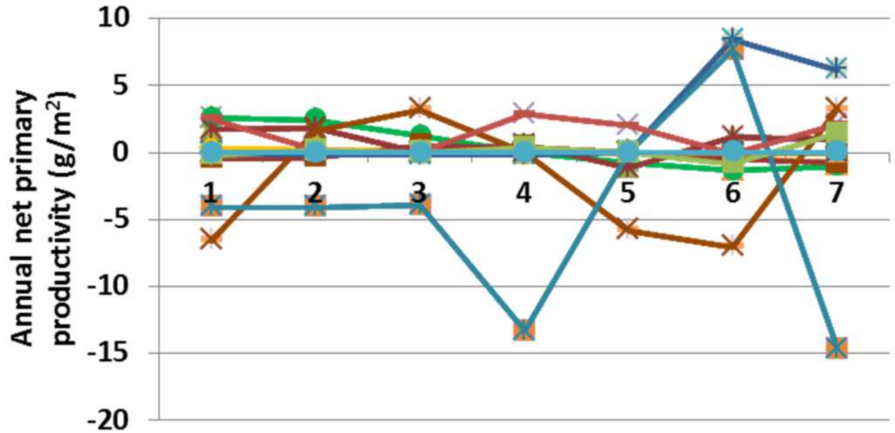
6 – 0.07

7 – 0.08









Interpretation: Changes in herbaceous death in response to shading caused significant changes to herb cover and smaller changes in other measures. Annual evapotranspiration changed up to 00.065. Soil temperature and plant-available water were essentially unchanged. Carbon to nitrogen ratio changed up to 0.27. Soil organic carbon (top) changed up to 463 g m^{-2}, and net primary productivity changed up to 15 g m^{-2}. Changes in herbaceous cover were relatively large, up to 34% (left). Shrubs and trees were unchanged, and so bare ground changed opposite to herbs.

Conclusion: The parameter captures a variety an important source of mortality for plants, competition for light, and will be retained.

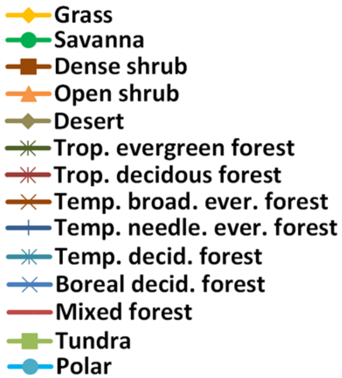
45b. Shading effect on death rate - Shrubs

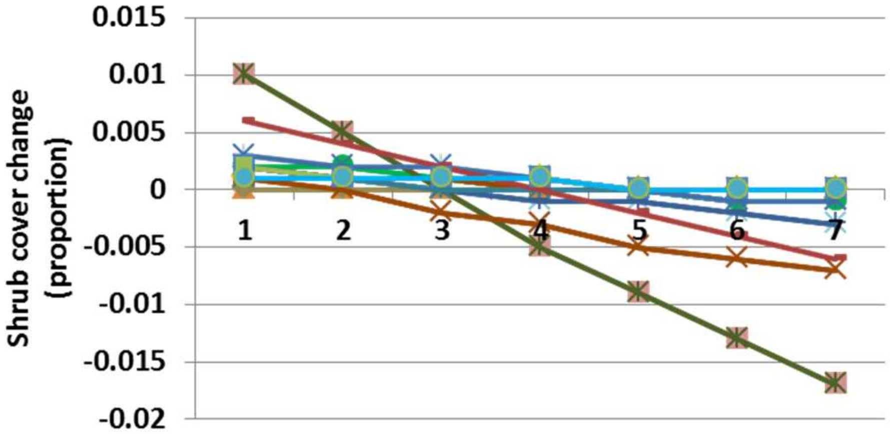
Purpose: The variable set shading_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the leaf area index and its relation to plant death.

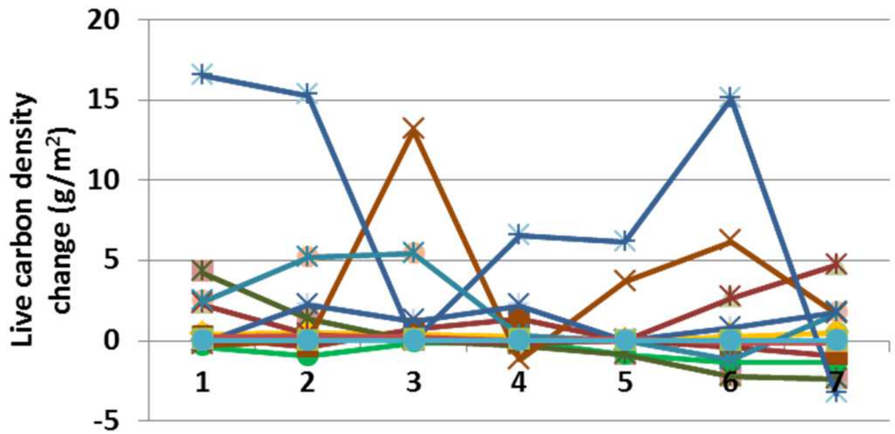
Basis for assignment: The values were inferred, then adjusted to improve model fit.

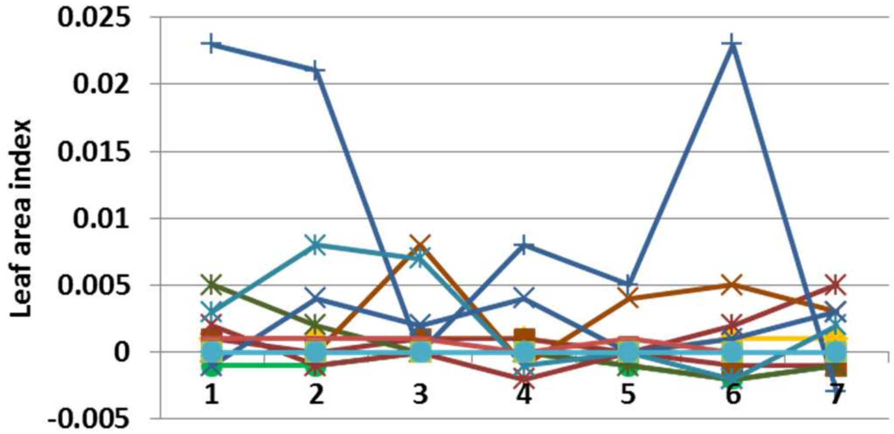
Baseline values
Various but similar values; two examples are:
0.0, 0.0, 5.0, 0.06, 0.0, 0.0, 4.0, 0.003, 0.0, 0.0, 4.0, 0.003
0.0, 0.0, 5.0, 0.04, 0.0, 0.0, 4.0, 0.005, 0.0, 0.0, 4.0, 0.005

Sensitivity values:
(shrubs upper y value changed)
1 – 0.001
2 – 0.002
3 – 0.003
4 – 0.004
5 – 0.005
6 – 0.006
7 – 0.007









Interpretation: Changes in annual evapotranspiration were up to 0.042, and soil temperature and potential evapotranspiration were essentially unchanged. Decomposition coefficients did not change. Soil organic carbon changed up to 20 g m^{-2}, and live carbon density changed up to 17 g m^{-2} (top). Leaf area index changed up to 0.023, and net primary productivity by 14.5 g m^{-2}. Shrub cover changed modestly under the values tested, up to 1.7% (left), and herb cover changed up to 2.1%. Tree facet cover was unchanged.

Conclusion: The parameter captures a variety an important source of mortality for plants, competition for light, and will be retained.

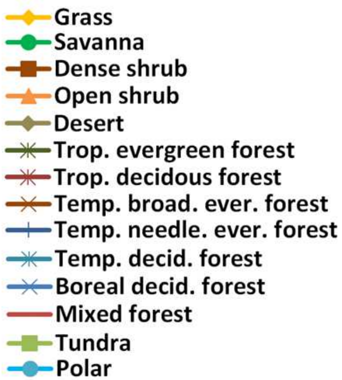
45c. Shading effect on death rate - Trees

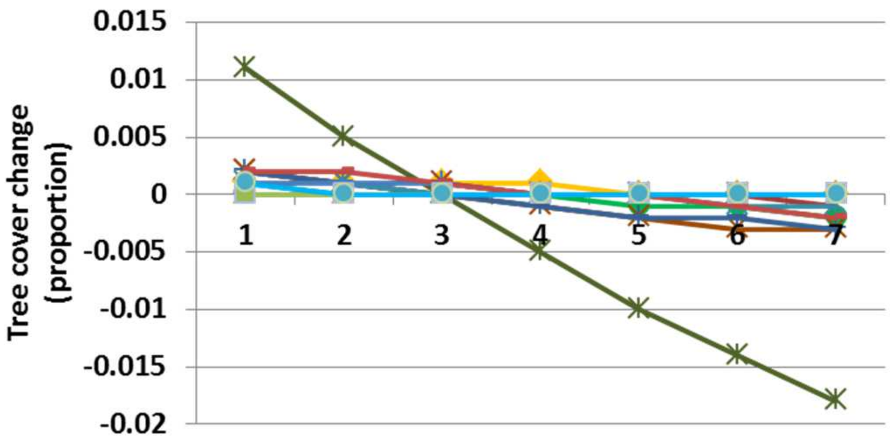
Purpose: The variable set shading_effect_on_death_rate provides two sets of values per facet that define a linear regression. That regression is defined by the leaf area index and its relation to plant death.

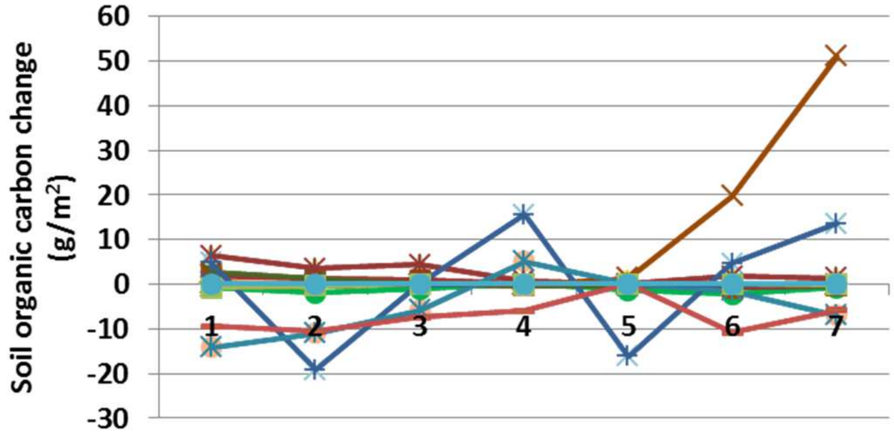
Basis for assignment: The values were inferred, then adjusted to improve model fit.

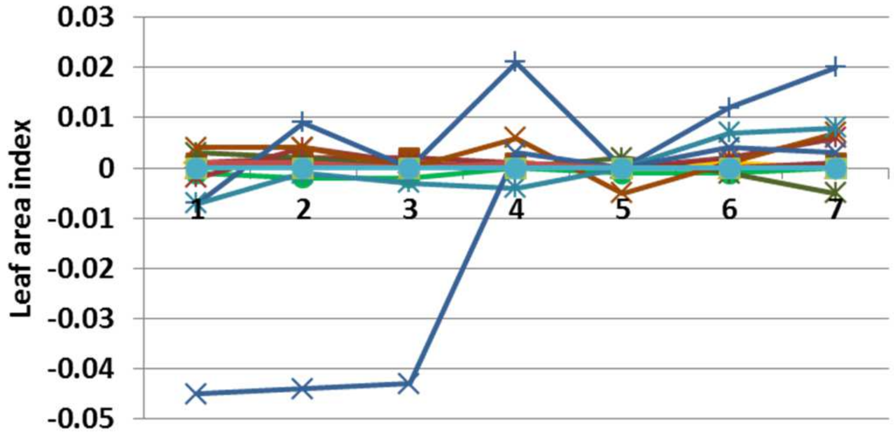
Baseline values
Various but similar values; two examples are:
0.0, 0.0, 5.0, 0.06, 0.0, 0.0, 4.0, 0.003, 0.0, 0.0, 4.0, 0.003
0.0, 0.0, 5.0, 0.04, 0.0, 0.0, 4.0, 0.005, 0.0, 0.0, 4.0, 0.005

Sensitivity values:
(trees upper y value changed)
1 – 0.001
2 – 0.002
3 – 0.003
4 – 0.004
5 – 0.005
6 – 0.006
7 – 0.007









Interpretation: Changes in soil organic carbon were small (top), with temperate boreal evergreen forest changing up to 51 g m-2. Annual net primary production changed up to 19 g m-2, and live carbon density changed up to 23 g m-2. Carbon to nitrogen ratio changed up to 0.083. Decomposition coefficients, plant-available soil water, and soil temperature was unchanged. Tree cover changed less than 2% (left), with tropical evergreen forest showing the largest change. Shrubs were essentially unchanged, and herbs changed up to 2.5%.

Conclusion: The parameter captures a variety an important source of mortality for plants, competition for light, and will be retained.

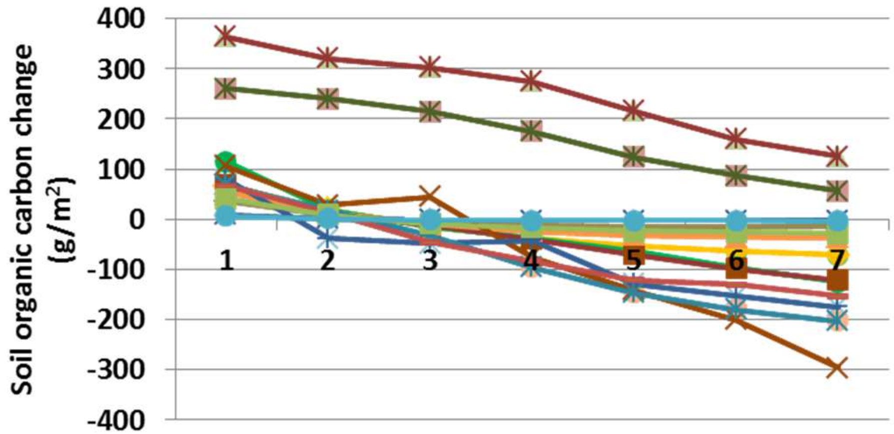
46a. Fall rate of standing dead - Herbs

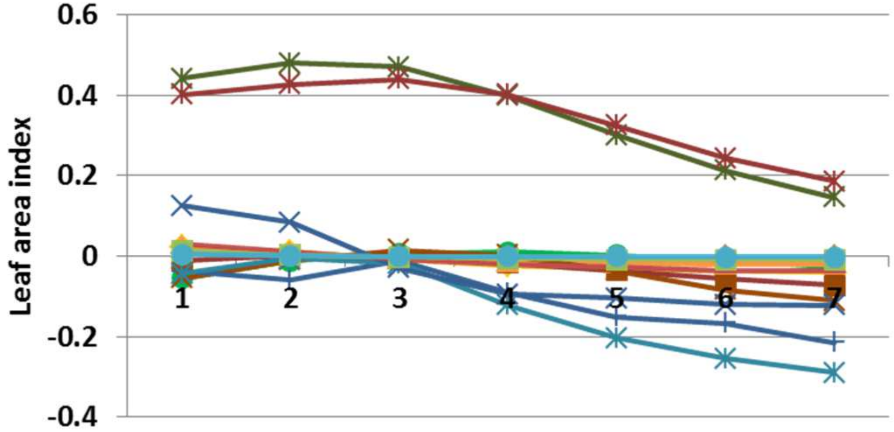
Purpose: The variable fall_rate_of_standing_dead controls the rate at which dead vegetation falls to litter, with three values provided, one for each facet.

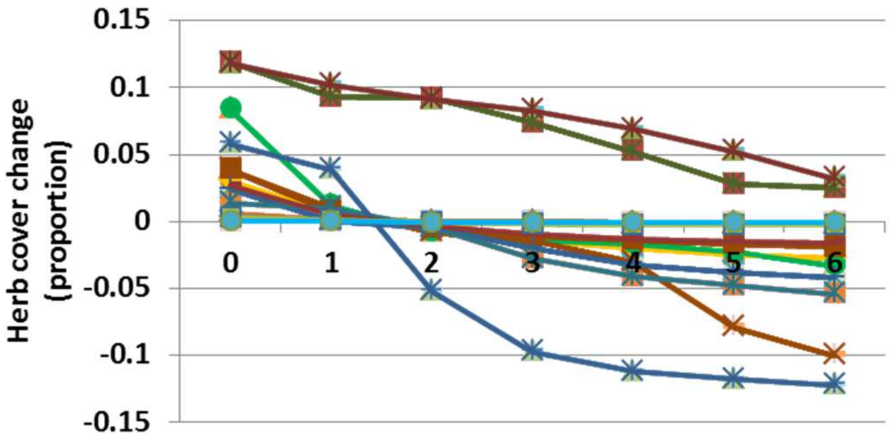
Basis for assignment: The values were initialized by the variable FALR within example applications of the Savanna model.

Baseline values
0.10, 0.10, 0.10 for unit 1
0.12, 0.15, 0.15 for unit 2
0.02, 0.05, 0.05 for units 3 to 15

Sensitivity values:
(herbaceous values changed)
1 – 0.005
2 – 0.015
3 – 0.025
4 – 0.035
5 – 0.045
6 – 0.055
7 – 0.065







Interpretation: Leaf area index declined as the rate of standing dead increased (above), and soil organic carbon changed up to 364 g m^{-2} (top). Primary production changed up to 69 g m^{-2} in a pattern similar to leaf area index. Carbon to nitrogen ratio changed up to 0.32. Plant-available soil water changed up to 5.3 cm. Herbaceous cover changed up to 12% in response to differences in the fall rate of standing dead material (left). Shrubs changed up to 1.8%, in a general pattern similar to herbs, and trees changed up to 1%. Bare ground changed opposite to the other groups.

Conclusion: The parameter captures an ecosystem process known to be important, with standing dead providing extra forage for animals.

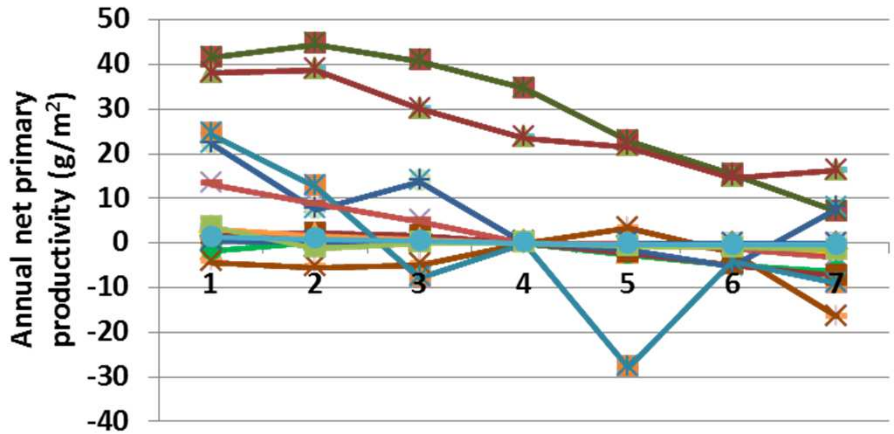
46b. Fall rate of standing dead - Shrubs

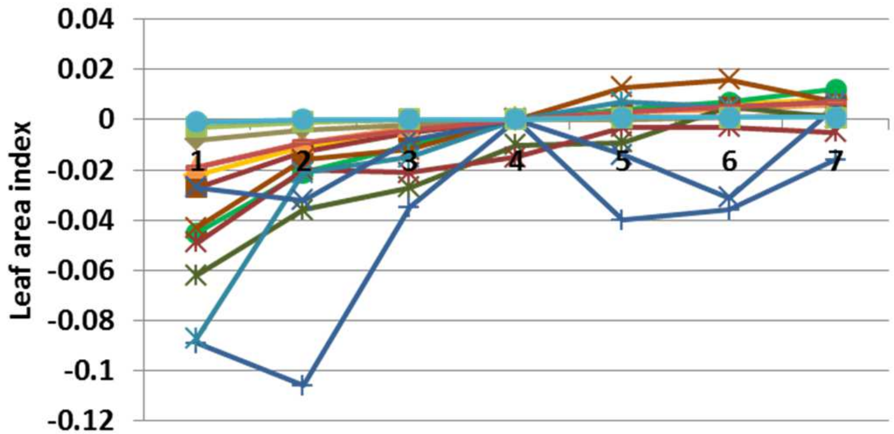
Purpose: The variable fall_rate_of_standing_dead controls the rate at which dead vegetation falls to litter, with three values provided, one for each facet.

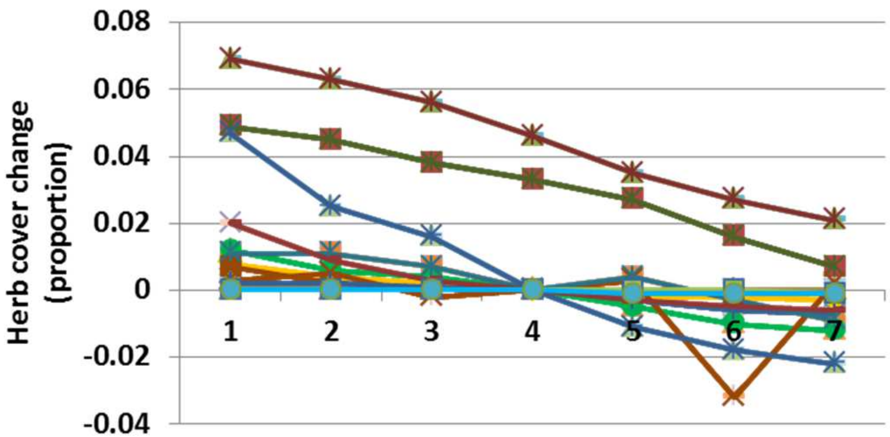
Basis for assignment: The values were initialized by the variable FALR within example applications of the Savanna model.

Baseline values
0.10, 0.10, 0.10 for unit 1
0.12, 0.15, 0.15 for unit 2
0.02, 0.05, 0.05 for units 3 to 15

Sensitivity values:
(shrub values changed)
1 – 0.02
2 – 0.03
3 – 0.04
4 – 0.05
5 – 0.06
6 – 0.07
7 – 0.08







Interpretation: Annual evapotranspiration decreased up to 1.7 cm with low rates of standing dead fall in shrubs. Plant-available water changed up to 0.38 cm. Net primary productivity changed up to 45 g m^{-2} (top), less so in non-tropical forest landscape units. Soil organic carbon changed in a manner similar to primary productivity, up to 239 g m^{-2} for the tropical forests. Leaf area index changed less than 0.12 (above). Changes in the rate of fall of standing dead material from shrubs did not change shrub cover very much (< 0.5%), but herb cover did change up to 7% (left). Tree cover changed less than 1%.

Conclusion: The parameter captures an ecosystem process known to be important, with standing dead providing extra forage for animals.

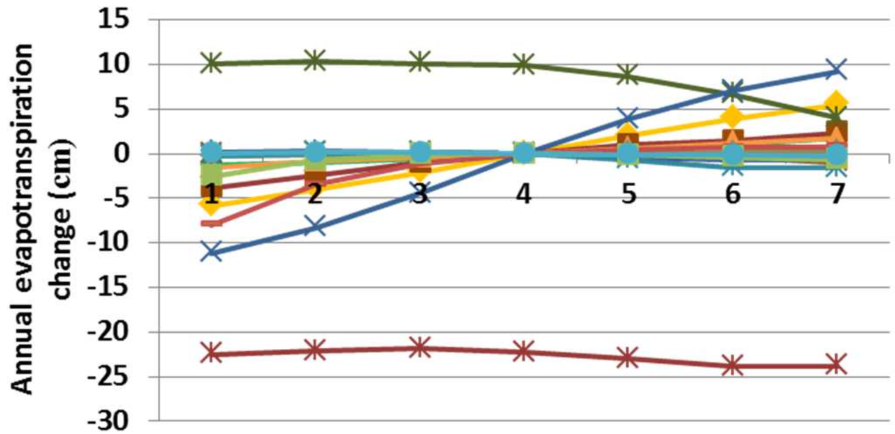
46c. Fall rate of standing dead - Trees

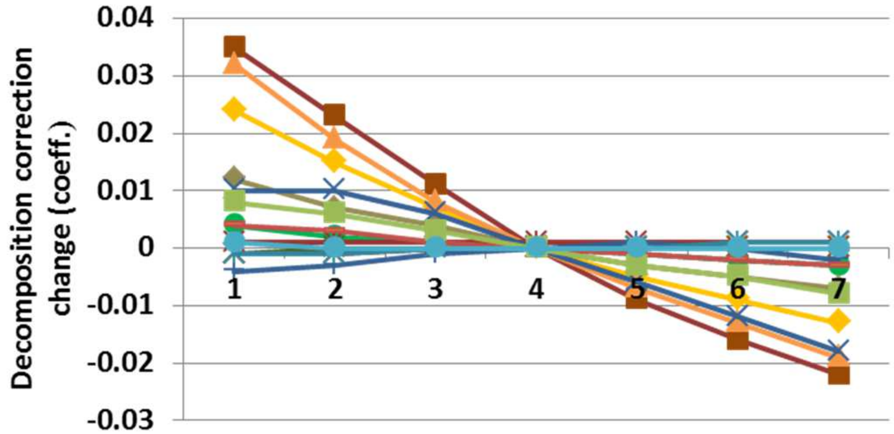
Purpose: The variable fall_rate_of_standing_dead controls the rate at which dead vegetation falls to litter, with three values provided, one for each facet.

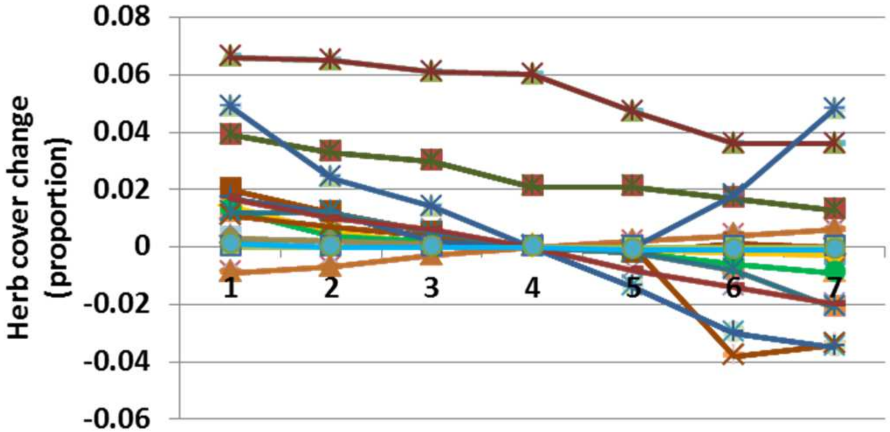
Basis for assignment: The values were initialized by the variable FALR within example applications of the Savanna model.

Baseline values
0.10, 0.10, 0.10 for unit 1
0.12, 0.15, 0.15 for unit 2
0.02, 0.05, 0.05 for units 3 to 15

Sensitivity values:
(tree values changed)
1 – 0.02
2 – 0.03
3 – 0.04
4 – 0.05
5 – 0.06
6 – 0.07
7 – 0.08







Interpretation: Relatively large changes in G-Range output were seen. Responses shown above are included not because others were small, but because these responses are uncommon. Net primary production changed up to 27 g m^{-2}, and soil organic carbon by 239 g m^{-2}. Annual evapotranspiration changed up to 24 cm (top), and decomposition coefficients by 0.035 (above). Changes in the rate of standing dead fall from trees led to up to 1.1% change in tree facet cover, and similar magnitudes of change in shrubs. Herbaceous cover (left) showed complex changes up to 6.6%.

Conclusion: The parameter captures an ecosystem process known to be important, with standing dead providing extra forage for animals.

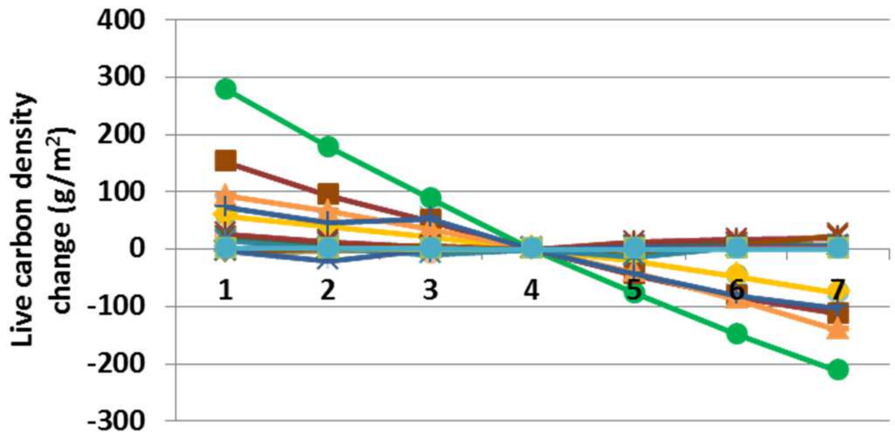
47. Death rate of deciduous leaves

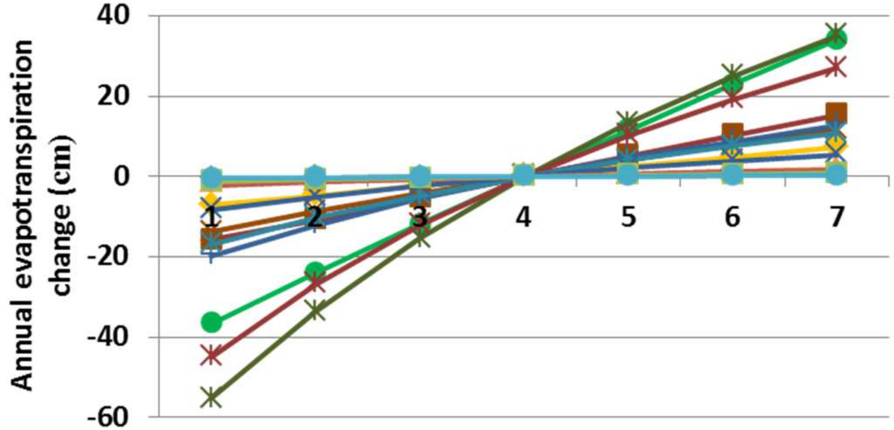
Purpose: The variable death_rate_of_deciduous_leaves controls the rate of death of leaves following their senescence. The rate would presumably be set to approach all deciduous leaves dead by the time phenology is reset.

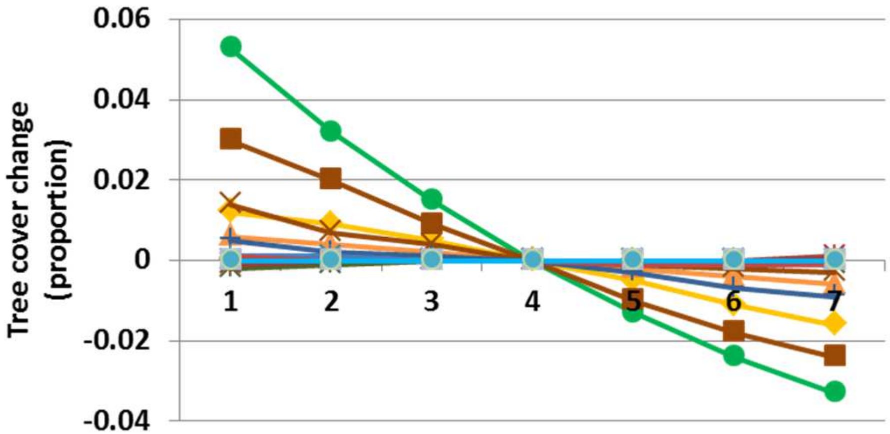
Basis for assignment: The value was inferred.

Baseline values
0.40 in all units

Sensitivity values:
1 – 0.25
2 – 0.30
3 – 0.35
4 – 0.40
5 – 0.45
6 – 0.50
7 – 0.55







Interpretation: Plant-available soil water changed up to 2.2 cm, and decomposition coefficients up to 0.06. Annual evapotranspiration changed up to 55 cm (above). Soil organic carbon increased 142 g m-2 in savannas under low leaf death rates. Live carbon density changed up to 278 g m-2, primary productivity up to 37.7 g m-2, and leaf area index by 0.67. Trees and shrub cover changed in a manner that was similar in pattern and magnitude (left), up to 6.1% for shrubs in the savanna landscape unit. Herb cover showed mixed responses, with changes up to 8.7%.

Conclusion: The parameter captures an ecosystem process of secondary importance, but helpful to show more realistic responses.

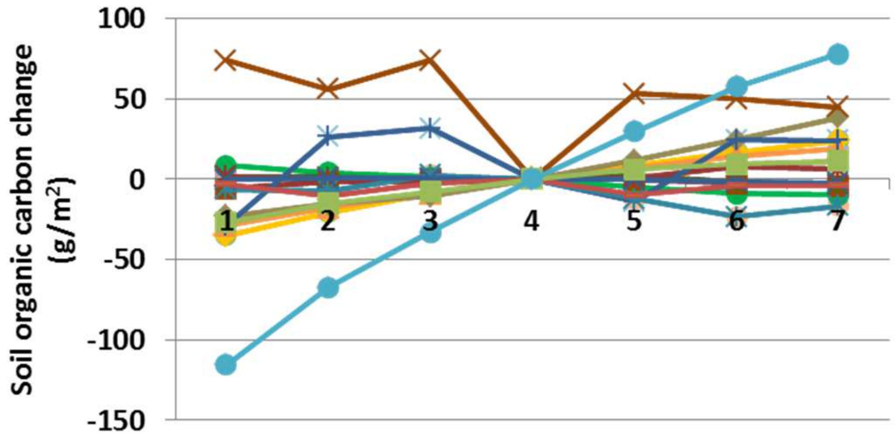
48. Drought deciduous

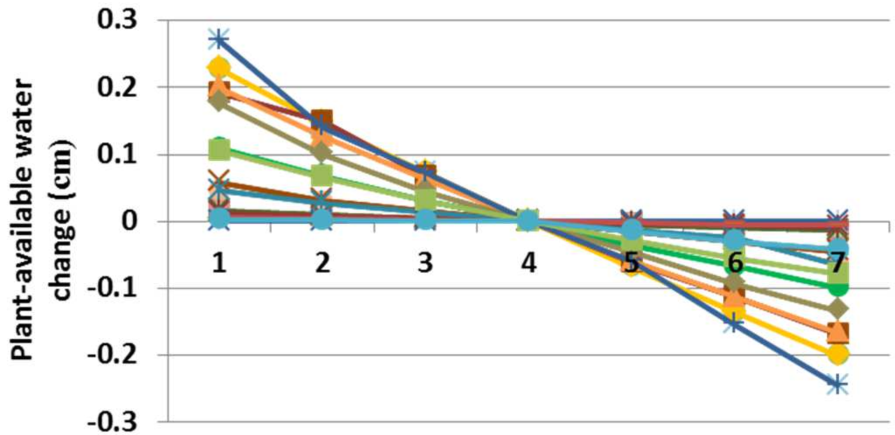
Purpose: The variable drought_deciduous identifies the proportion of plants in a landscape unit and of a given facet type that are drought deciduous. A portion of leaves related to water availability and the death rate of deciduous leaves and this parameter is used to add incrementally to dead leaves.

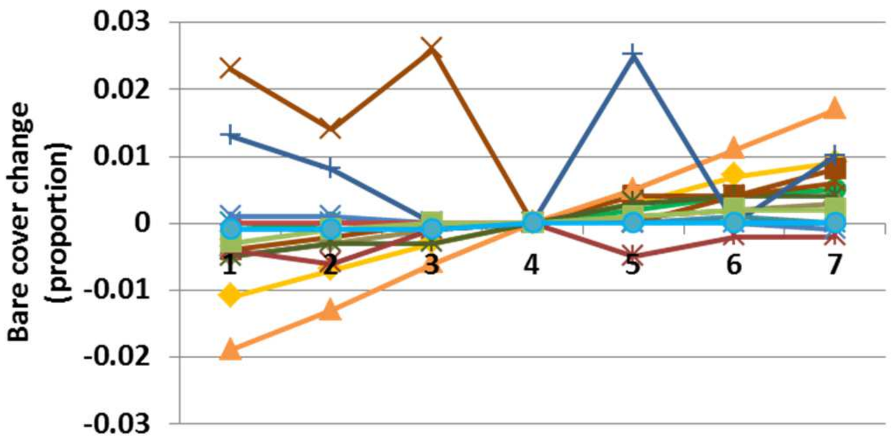
Basis for assignment: The value was inferred, but required further research to assign better values.

Baseline values
0.2, 0.2, 0.2 in all units

Sensitivity values:
1 – 0.05, 0.05, 0.05
2 – 0.10, 0.10, 0.10
3 – 0.15, 0.15, 0.15
4 – 0.20, 0.20, 0.20
5 – 0.25, 0.25, 0.25
6 – 0.30, 0.30, 0.30
7 – 0.35, 0.35, 0.35







Interpretation: Changed in G-Range output in response to changes in the proportion of plants that were drought deciduous were moderate. Plant-available water changed up to 0.28 cm (above), and annual evapotranspiration changed in an opposite manner, up to 4.3 cm. Soil organic carbon changed up to 115 g m-2, in the polar unit (top). Changes in facet cover were small in response to changes in proportions of drought deciduous plants. Trees changed less than 0.5%, and shrubs less than 0.8%. Herb cover changed up to 3.3%. These changed less to mixed patterns of change in bare ground left).

Conclusion: The parameter captures an ecosystem process of secondary importance, but it can be important in some ecosystems.

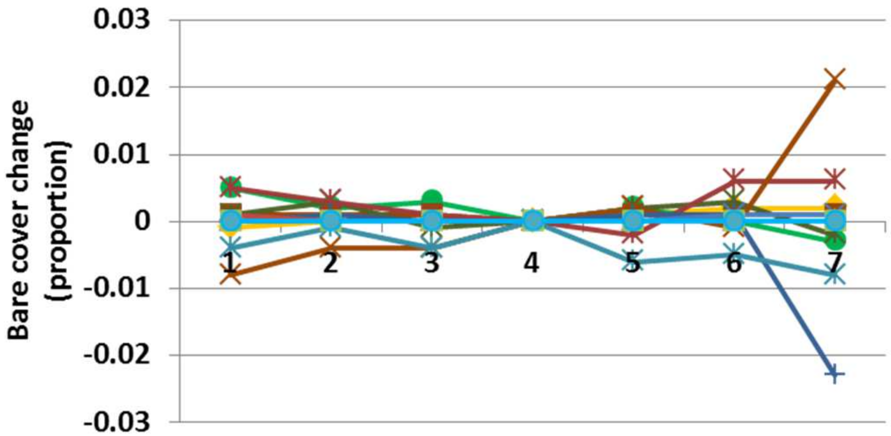
49. Fraction woody leaf nitrogen translocated

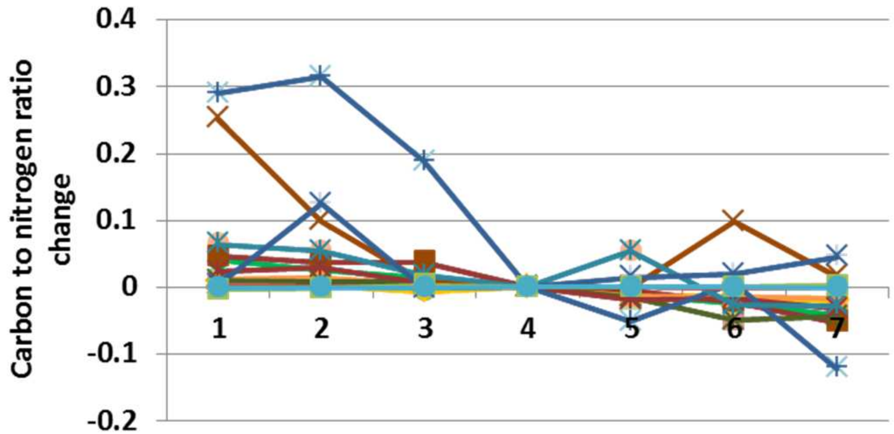
Purpose: The variable fraction_woody_leaf_n_translocated describes the proportion of leaf nitrogen that is translocated to other plant parts prior to the death of deciduous leaves. Woody plants have evolved to withdraw some nitrogen from leaves prior to their senescence.

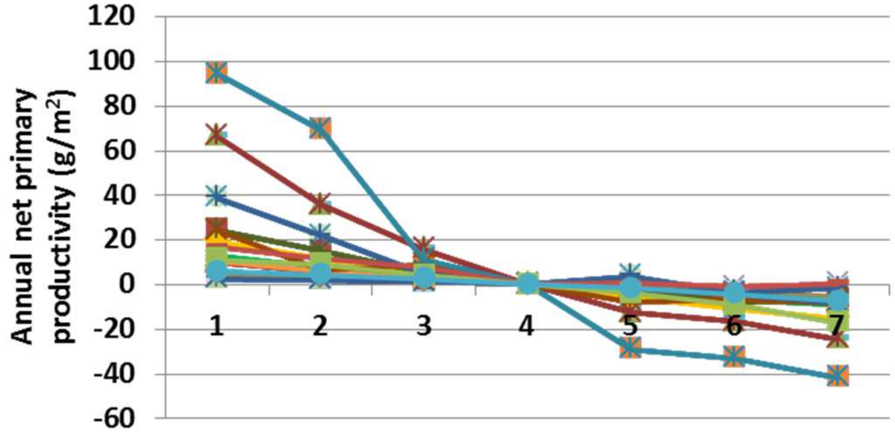
Basis for assignment: The value was assigned based on the variable FORRTF in example files distributed with the Century model.

Baseline values
0.3 in all units

Sensitivity values:
1 – 0.15
2 – 0.20
3 – 0.25
4 – 0.30
5 – 0.35
6 – 0.40
7 – 0.45







Interpretation: Changes in evapotranspiration were small, up to 0.15 cm, and soil temperature, plant-available water, and decomposition coefficients were essentially unchanged. Soil organic carbon changed up to 90 g m-2, and the carbon to nitrogen ratio (the only metric tested directly associated with nitrogen) changed up to 0.315 (top). Annual net primary productivity changed up to 94 g m-2 (above). Changing the fraction nitrogen translocated did not change facet cover very much, such as bare ground less than 2.3%, with herb cover changing opposite. Shrub and tree cover were unchanged.

Conclusion: The parameter captures an effect from an important adaptation in plants, and will be retained.

50a. Leaf death rate - Herbs

Purpose: The variable set leaf_death_rate provides one value per facet that quantifies leaf death rate per month.

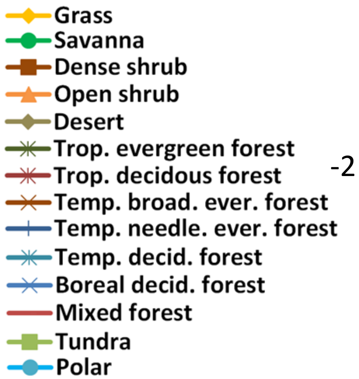
Basis for assignment: The value was inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

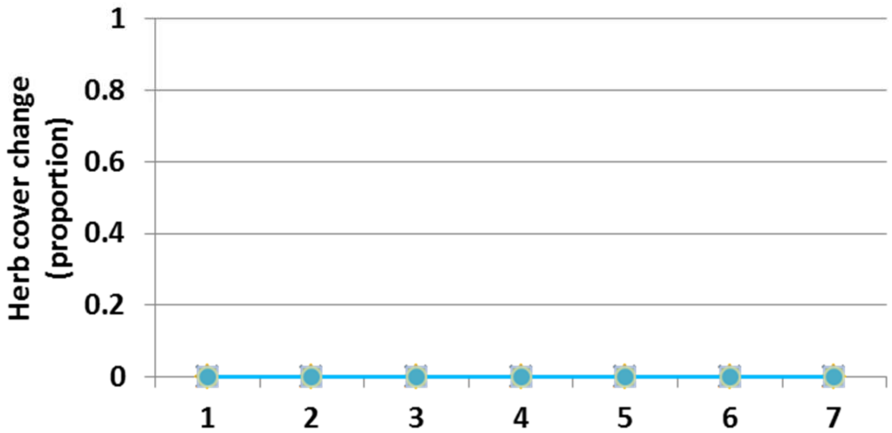
Baseline values

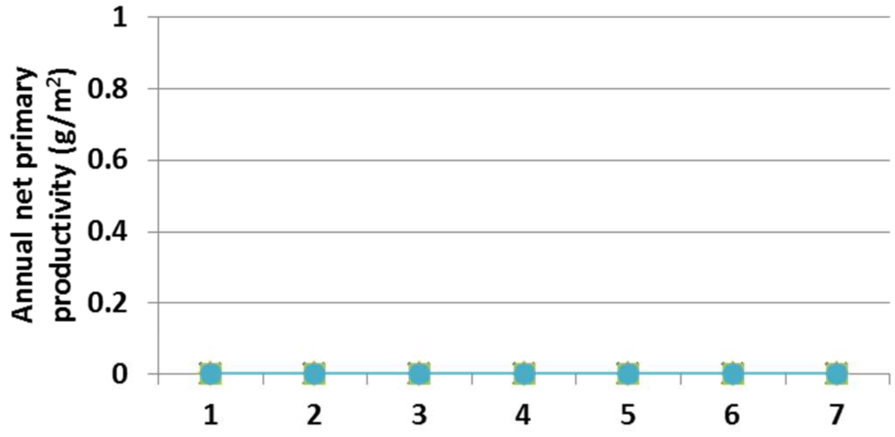
Various values were used, with example entries being:
0.035, 0.035, 0.035
0.036, 0.032, 0.032
0.068, 0.064, 0.065

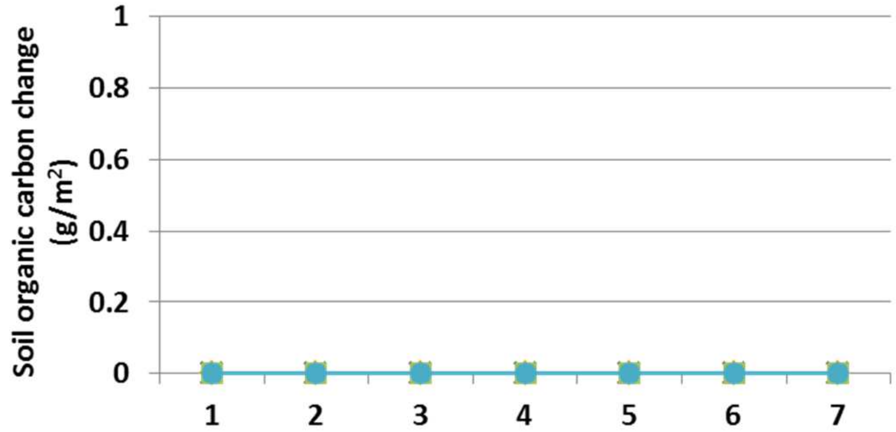
Sensitivity values:

(herb values only changed)
1 – 0.02
2 – 0.03
3 – 0.04
4 – 0.05
5 – 0.06
6 – 0.07
7 – 0.08









Interpretation: There were no changed in response to changes in herbaceous leaf death rate. The parameter was not incorporated in the herbaceous component of the model, and that is correct. The parameter is not used here. Instead, the variable set shoot_death_rate controls mortality.

Conclusion: The parameter is required to represent leaf death, and so will be retained. However, it will be made clear to users that the herbaceous value is not used.

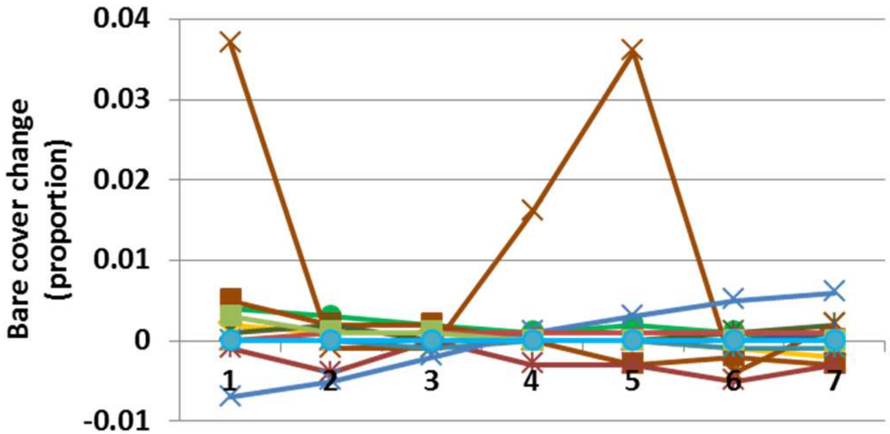
50b. Leaf death rate - Shrubs

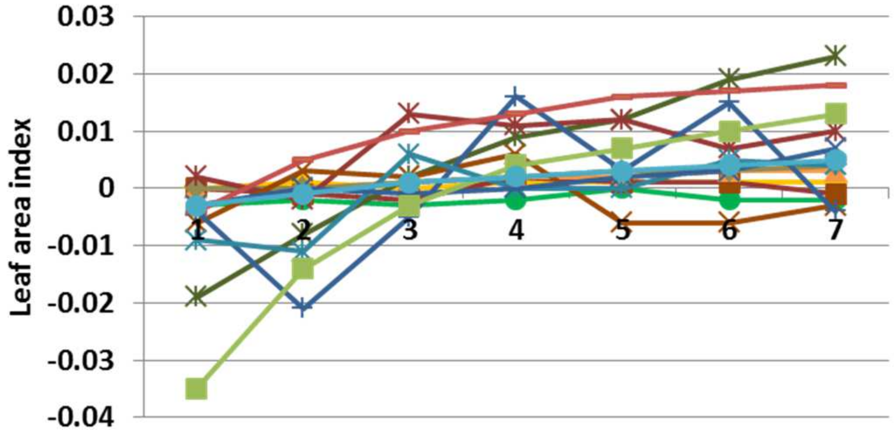
Purpose: The variable set leaf_death_rate provides one value per facet that quantifies leaf death rate per month.

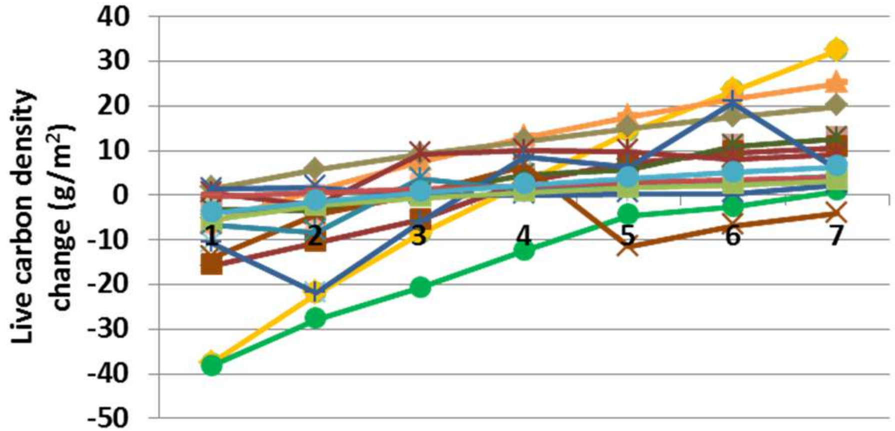
Basis for assignment: The value was inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

Baseline values
Various values were used, with example entries being:
0.035, 0.035, 0.035
0.036, 0.032, 0.032
0.068, 0.064, 0.065

Sensitivity values:
(shrub values only changed)
1 – 0.02
2 – 0.03
3 – 0.04
4 – 0.05
5 – 0.06
6 – 0.07
7 – 0.08







Interpretation: Changes in annual evapotranspiration were up to 0.11 cm, and soil temperature just a fraction of degree. Soil organic carbon changed up to 80 g m^{-2}, and carbon to nitrogen ratio changes up to 0.1. Net primary productivity changed little, less than 11 g m^{-2}, and leaf area index 0.035 (top). Live carbon density changed almost 40 g m^{-2}. Changes in facet cover were small, with bare ground changing up to 3.7%. Herbs changed in an opposite pattern, with shrubs and trees essentially unchanged.

Conclusion: The parameter is required to represent leaf death, and so will be retained.

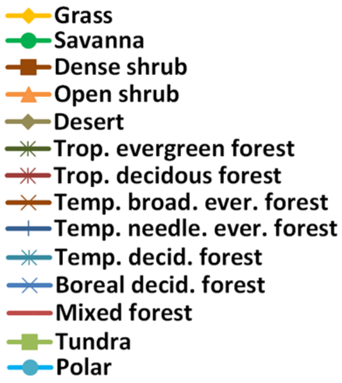
50c. Leaf death rate - Trees

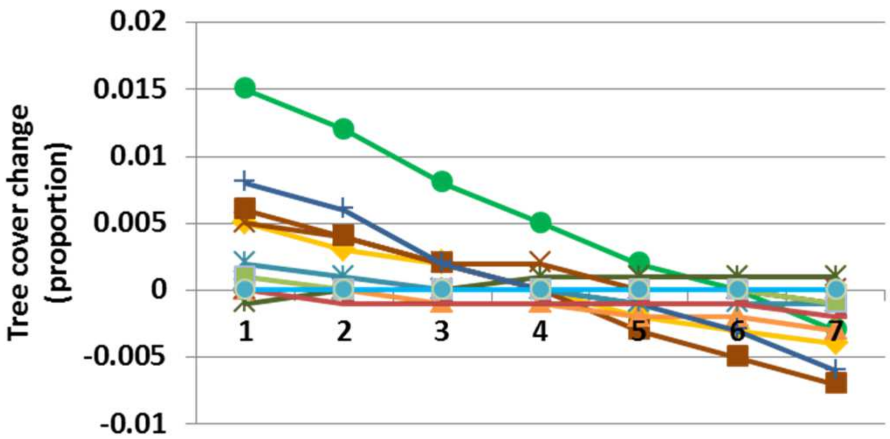
Purpose: The variable set leaf_death_rate provides one value per facet that quantifies leaf death rate per month.

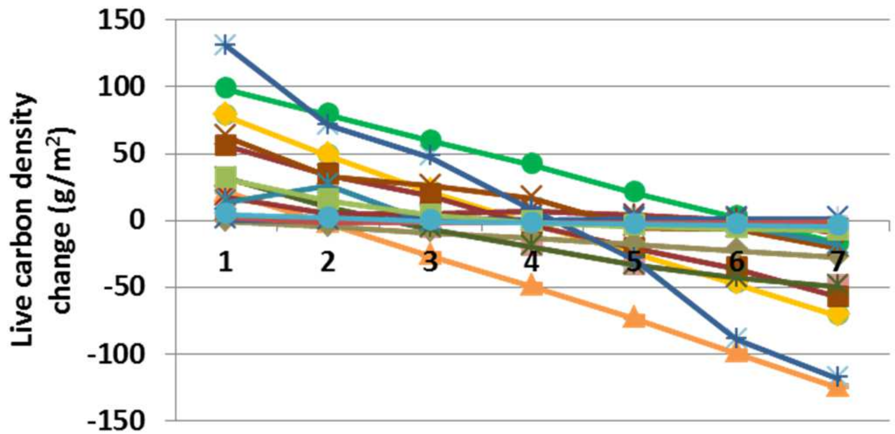
Basis for assignment: The value was inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

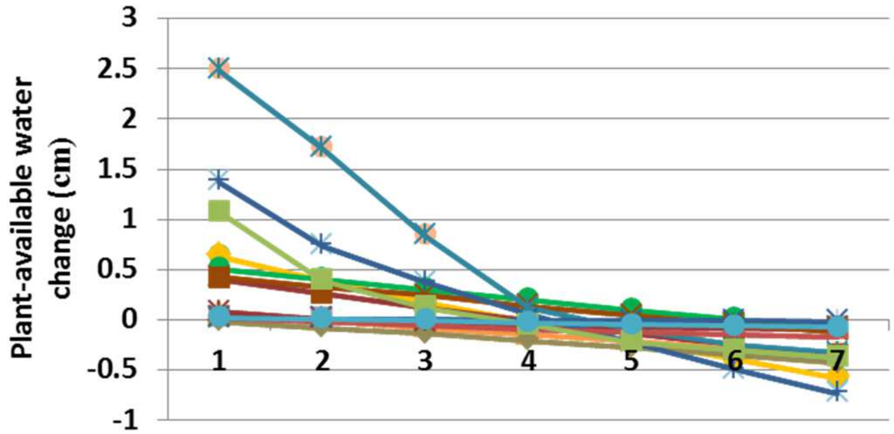
Baseline values
Various values were used, with example entries being:
0.035, 0.035, 0.035
0.036, 0.032, 0.032
0.068, 0.064, 0.065

Sensitivity values:
(tree values only changed)
1 – 0.02
2 – 0.03
3 – 0.04
4 – 0.05
5 – 0.06
6 – 0.07
7 – 0.08









Interpretation: Changes in annual evapotranspiration were less than 20 cm, except for tropical evergreen forest, which increased up to 50 cm at high leaf death rates. Soil temperature changed up to 0.15 degree. Plant-available water changed up to 2.5 cm (above), and decomposition coefficients changed up to 0.026 in a pattern similar to live carbon density changes (top), which changed up to 130 g m^{-2}. Net primary productivity changed up to 52 g m^{-2}. Modest changes in facet cover occurred, such as a 1.5% change in trees (left), and a 2% change in shrubs and herbs.

Conclusion: The parameter is required to represent leaf death, and so will be retained.

51a. Fine root death rate - Herbs

Purpose: The variable set fine_root_death_rate provides one value per facet that quantifies leaf death rate per month.

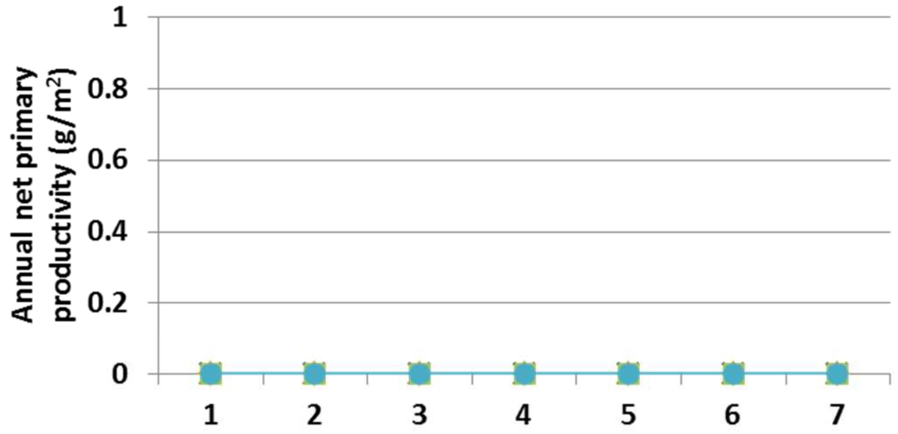
Basis for assignment: The values were inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

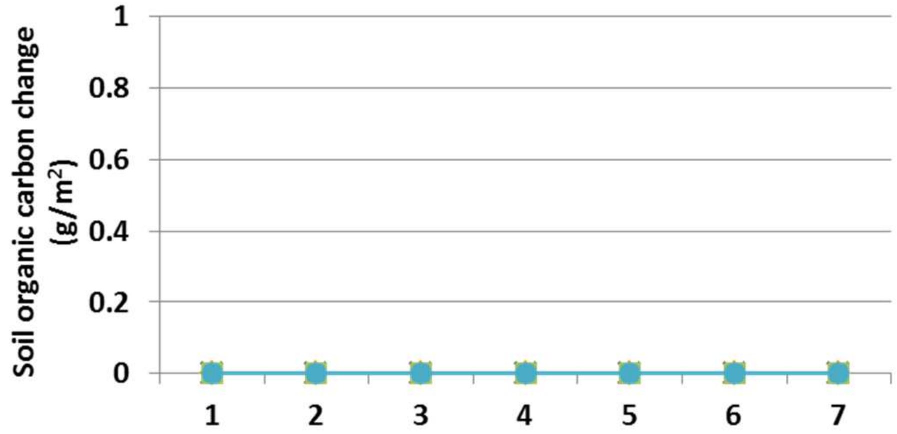
Baseline values

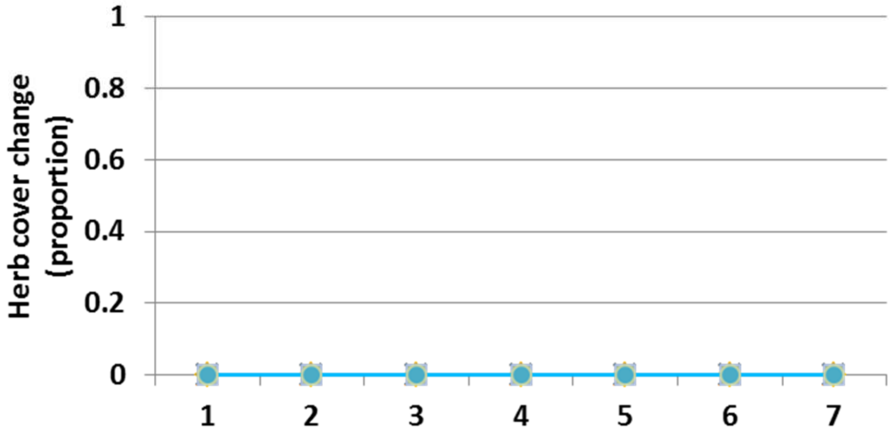
Various values were used, with example entries being:
0.043, 0.043, 0.043
0.055, 0.054, 0.054
0.152, 0.149, 0.149

Sensitivity values:

(herb values only changed)
1 – 0.05
2 – 0.07
3 – 0.09
4 – 0.11
5 – 0.13
6 – 0.15
7 – 0.17







Interpretation: Fine root death rate is not controlled by this variable in herbs. There was no change in any output associated with the change in sensitivity. This is correct. Maximum_root_death_rate influences fine root death rate in herbs.

Conclusion: The parameter is required to represent fine root death, and so will be retained. Users will be informed that the herbaceous parameter is not used.

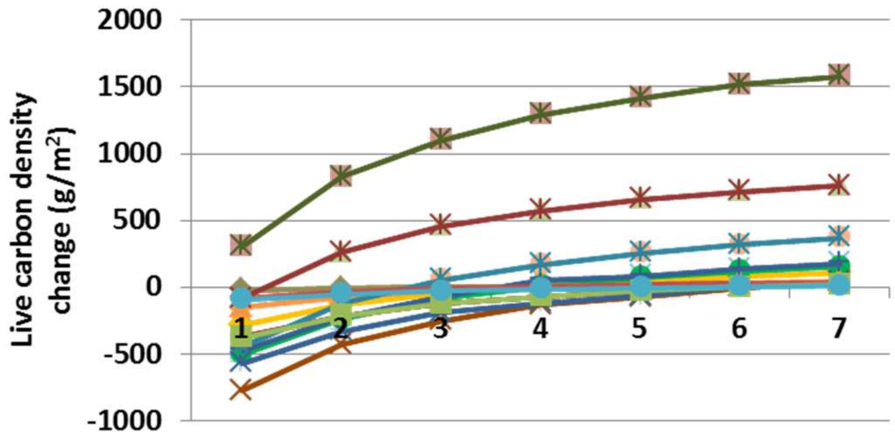
51b. Fine root death rate - Shrubs

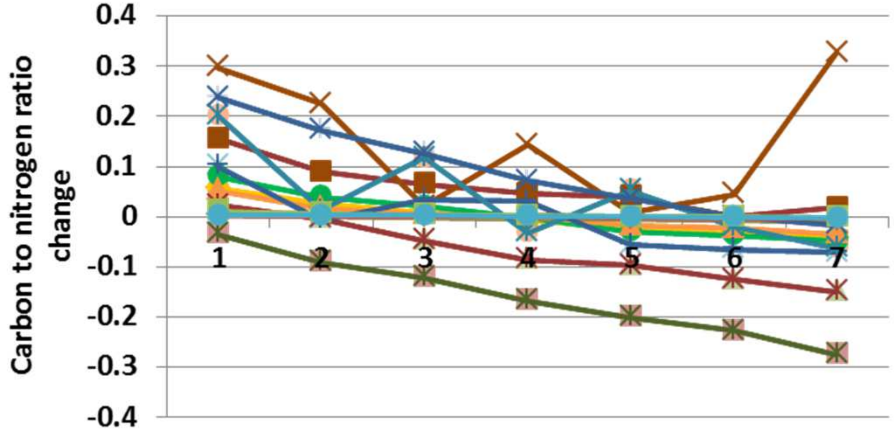
Purpose: The variable set fine_root_death_rate provides one value per facet that quantifies leaf death rate per month.

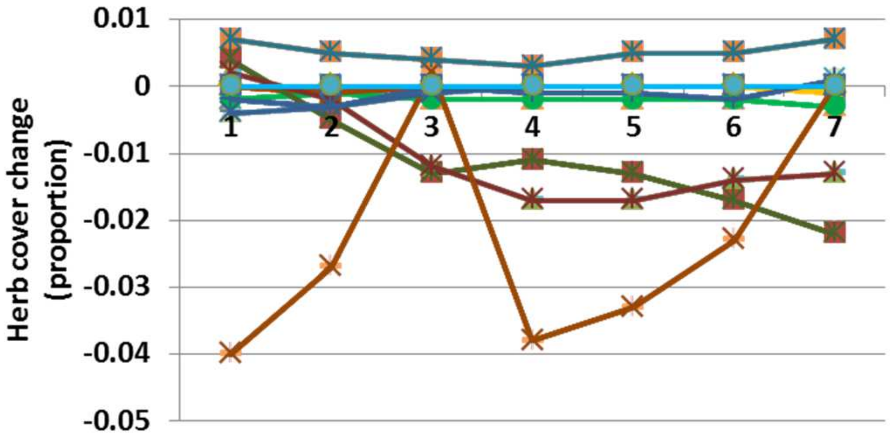
Basis for assignment: The values were inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

Baseline values
Various values were used, with example entries being:
0.043, 0.043, 0.043
0.055, 0.054, 0.054
0.152, 0.149, 0.149

Sensitivity values:
(shrub values only changed)
1 – 0.05
2 – 0.07
3 – 0.09
4 – 0.11
5 – 0.13
6 – 0.15
7 – 0.17







Interpretation: Changes in fine root death rate in shrubs caused up to 0.26 cm in annual evapotranspiration. Soil temperature, plant-available soil water, and decomposition coefficients were essentially unchanged. Soil organic carbon changed up to 185 g m^{-2}, and annual net primary production changed up to 20 g m^{-2}. Live carbon density changed up to 1600 g m^{-2} (top), and carbon to nitrogen ratio up to 0.33. Herbaceous cover mostly declined, up to 4% (left), and shrubs and tree facet cover were essentially unchanged.

Conclusion: The parameter is required to represent fine root death, and so will be retained.

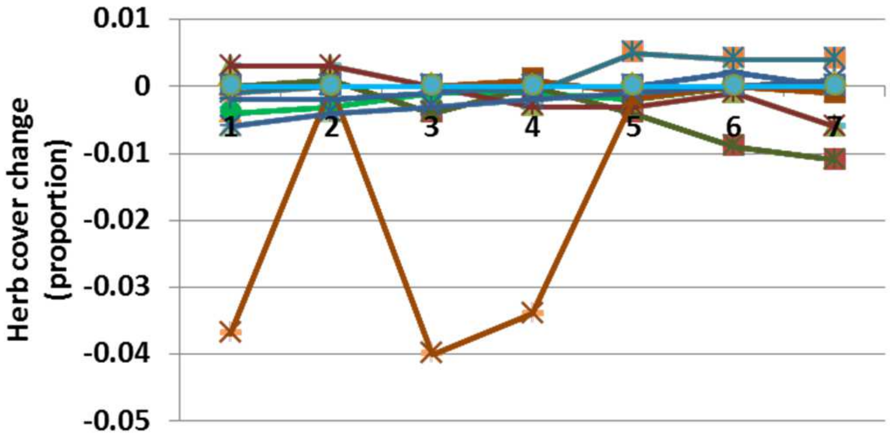
51c. Fine root death rate - Trees

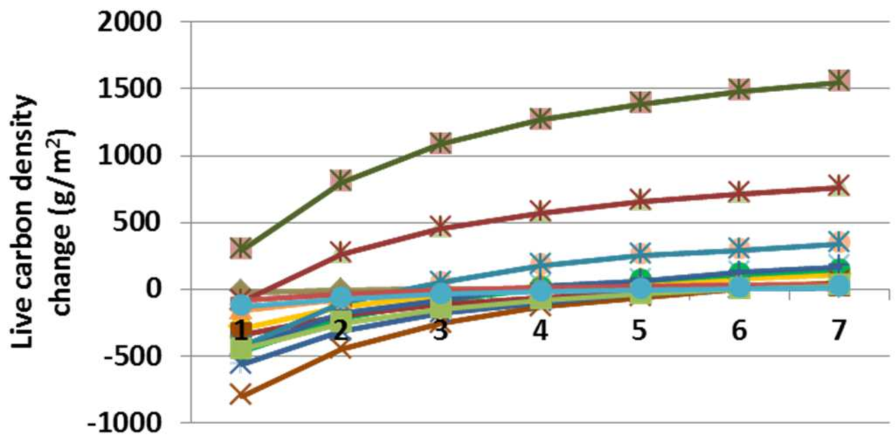
Purpose: The variable set fine_root_death_rate provides one value per facet that quantifies leaf death rate per month.

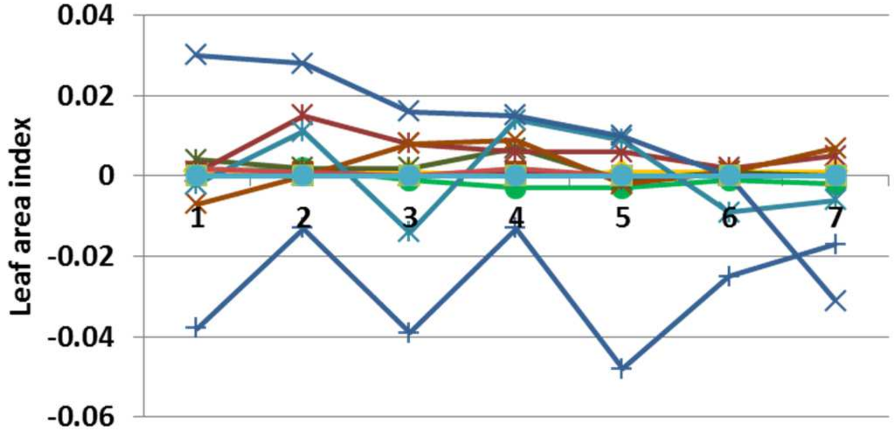
Basis for assignment: The values were inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

Baseline values
Various values were used, with example entries being:
0.043, 0.043, 0.043
0.055, 0.054, 0.054
0.152, 0.149, 0.149

Sensitivity values:
(tree values only changed)
1 – 0.05
2 – 0.07
3 – 0.09
4 – 0.11
5 – 0.13
6 – 0.15
7 – 0.17







Interpretation: Changes were small or showed no difference in annual evapotranspiration, soil temperature, plant-available water, and decomposition coefficients. Soil organic carbon changed up to 173 g m^{-2}, and live carbon density up to 1549 g m^{-2} (top). Carbon to nitrogen ratio changed up to 0.31, and net primary productivity changed little, less than 20 g m^{-2}. Leaf area index changed up to 0.048. Herbaceous cover changed up to 4% when fine root death rate in trees was changed, and shrub and tree facet cover were essentially unchanged.

Conclusion: The parameter is required to represent fine root death, and so will be retained.

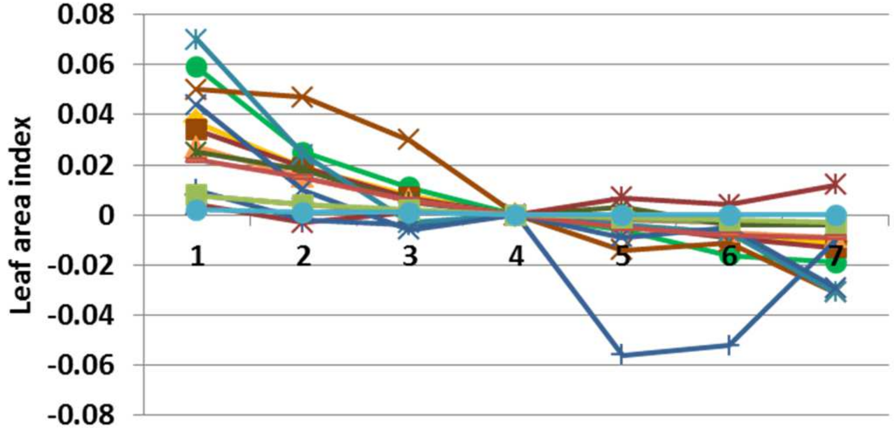
52a. Fine branch death rate - Shrubs

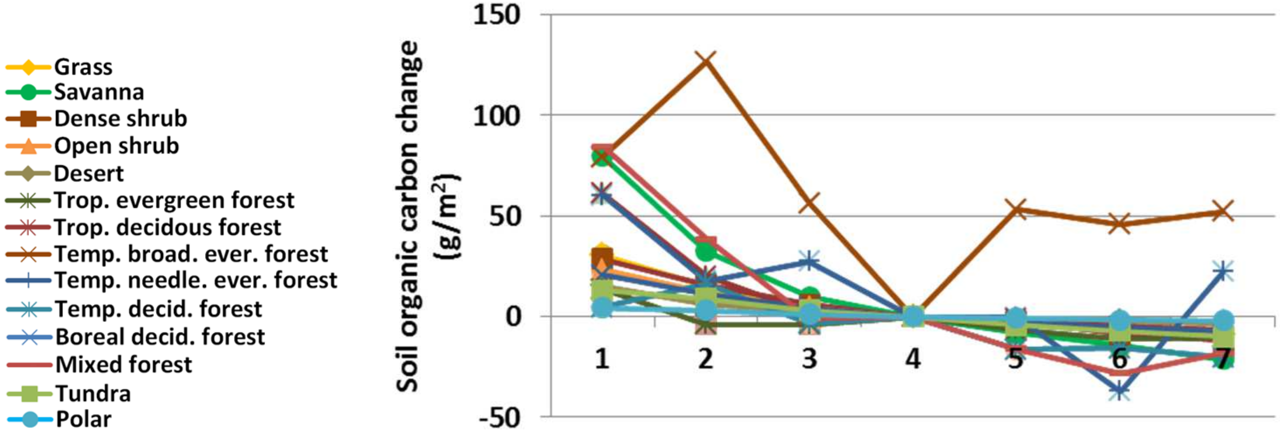
Purpose: The variable set fine_branch_death_rate provides one value per facet that quantifies leaf death rate per month. A placeholder is used for herbs, but they have no fine branches, and so that value is not used.

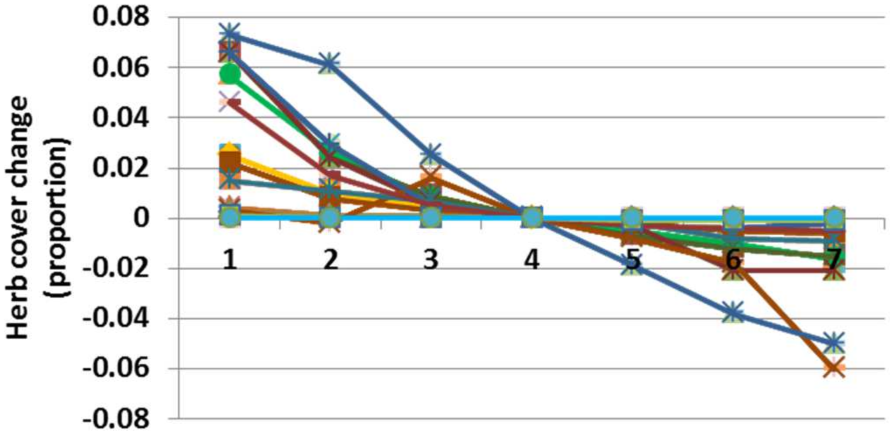
Basis for assignment: The value was inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

Baseline values
0.0, 0.008, 0.008

Sensitivity values:
(shrubs values only changed)
1 – 0.002
2 – 0.004
3 – 0.006
4 – 0.008
5 – 0.010
6 – 0.012
7 – 0.014







Interpretation: Changes with fine branch death rate differences included a 0.63 cm change in annual evapotranspiration, and small changes in soil temperature and plant-available water. Soil organic carbon changed up to 127 g m-2 (above), and live carbon density declined 193 g m-2 in tropical evergreen forest. Annual net primary productivity changed up to 29 g m-2, and leaf area index up to 0.07.. Herbaceous cover changed up to 7.3% in response to changes in fine branch death rate in shrubs (left), and shrub and trees were essentially unchanged; bare ground changed opposite herbs.

Conclusion: The parameter is required to represent fine branch death, and so will be retained.

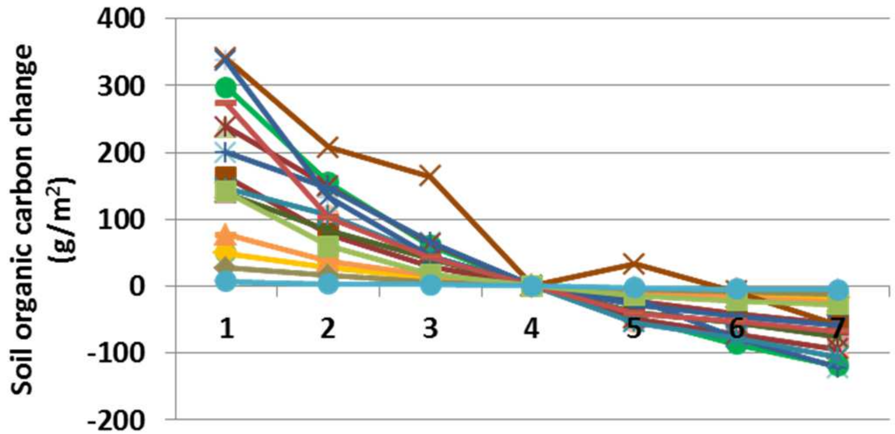
52b. Fine branch death rate - Trees

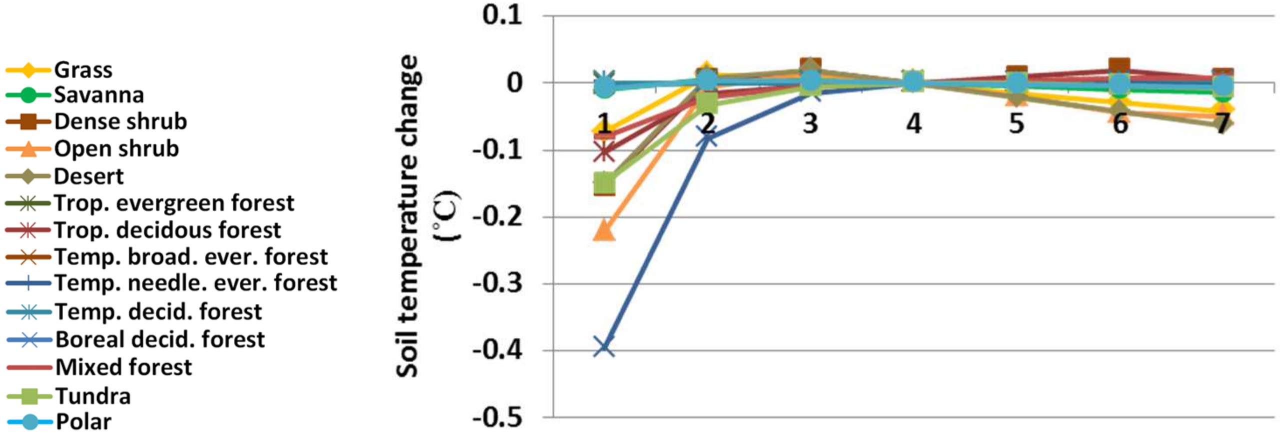
Purpose: The variable set fine_branch_death_rate provides one value per facet that quantifies leaf death rate per month. A placeholder is used for herbs, but they have no fine branches, and so that value is not used.

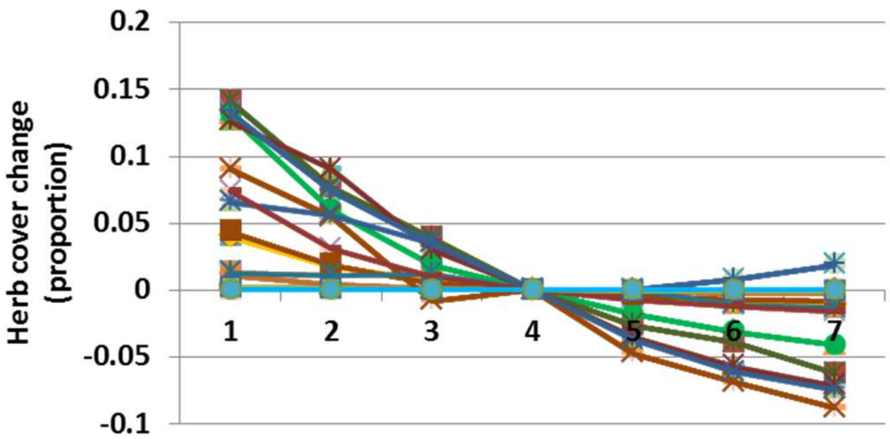
Basis for assignment: The value was inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

Baseline values
0.0, 0.008, 0.008

Sensitivity values:
(shrubs values only changed)
1 – 0.002
2 – 0.004
3 – 0.006
4 – 0.008
5 – 0.010
6 – 0.012
7 – 0.014







Interpretation: Annual evapotranspiration changed, mostly increased, up to 11.8 cm at low levels of find branch death rates. Soil temperature decreased by almost 0.4 degrees (above). Decomposition coefficients changed up to 0.015. Soil organic carbon changed up to 336 g m^{-2} (top), and carbon to nitrogen ratio changed up to 1.5, in a pattern similar to soil organic carbon. Annual net primary productivity changed up to 42.2 g m^{-2}, and leaf area index by 0.14. Herbaceous cover changed up to 14% with changes to the fine branch death rate in trees. Shrubs and trees changed little.

Conclusion: The parameter is required to represent fine branch death, and so will be retained.

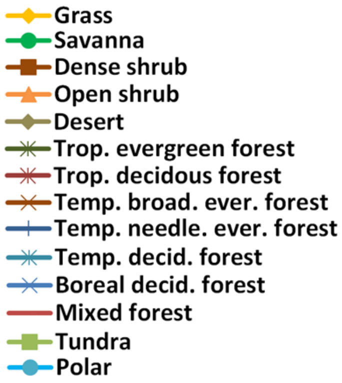
53a. Coarse branch death rate - Shrubs

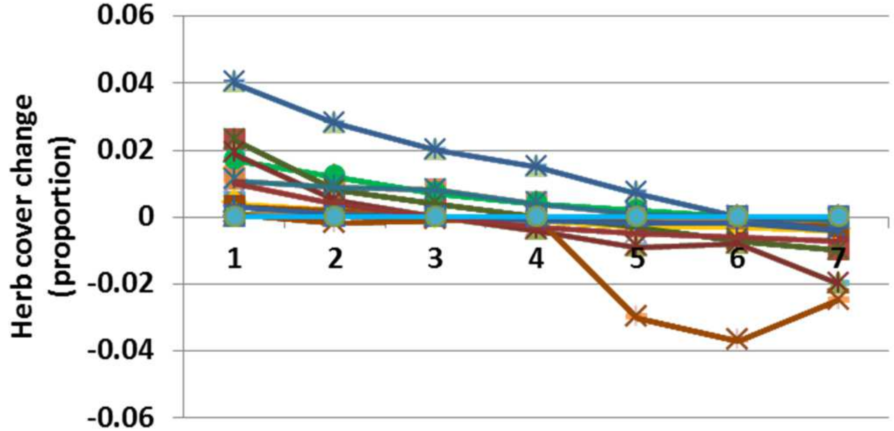
Purpose: The variable set coarse_branch_death_rate provides one value per facet that quantifies coarse branch death rate per month. A placeholder is used for herbs, but they have no coarse branches, and so that value is not used.

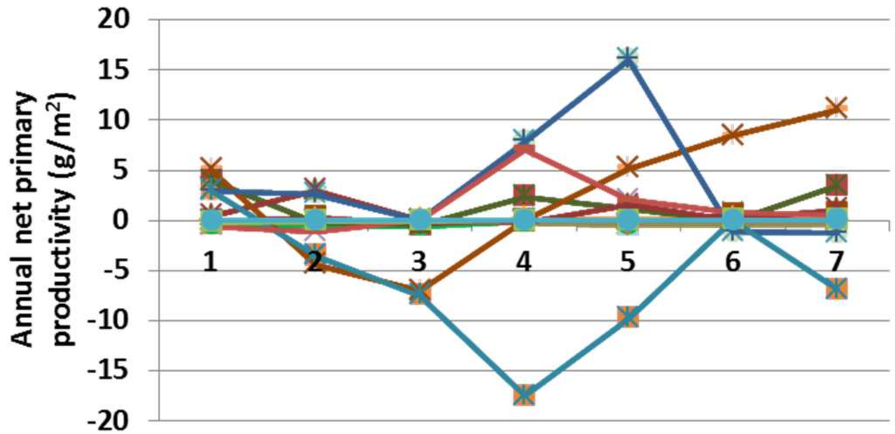
Basis for assignment: The value was inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

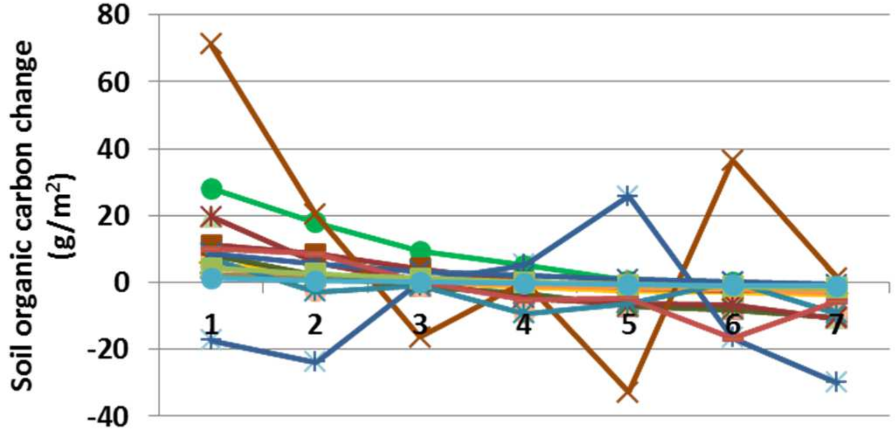
Baseline values
Various values, but most are like:
0.0, 0.004, 0.004
0.0, 0.005, 0.005

Sensitivity values:
(shrubs values only changed)
1 – 0.002
2 – 0.003
3 – 0.004
4 – 0.005
5 – 0.006
6 – 0.007
7 – 0.008









Interpretation: Changes with coarse branch death rate caused only small changes in responses. Annual evapotranspiration changed less than 0.15 cm, and plant-available water less than 0.03 cm. Soil organic carbon changed up to 72 g m^{-2} (above), and annual net primary productivity changed less than 20 g m^{-2}. Live carbon density changed up to 35 g m^{-2}. In relation to changes in coarse branch death rate, herbaceous cover changed up to 4% (left), and shrubs and trees changed very little.

Conclusion: The parameter is required to represent coarse branch death, and so will be retained.

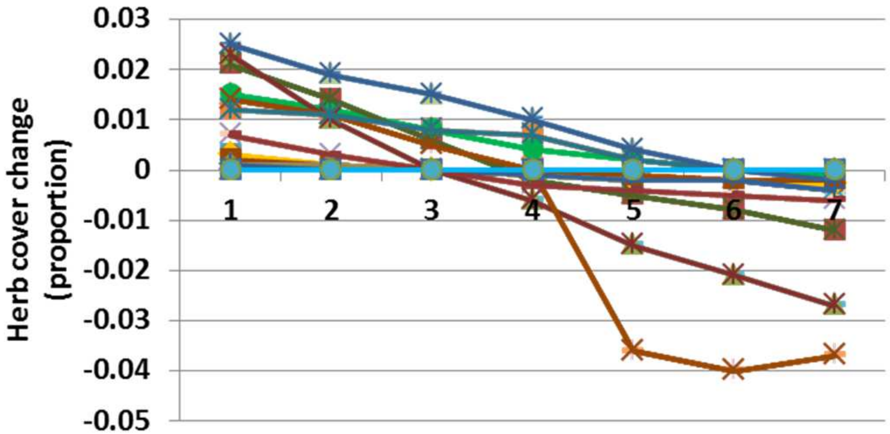
53b. Coarse branch death rate - Trees

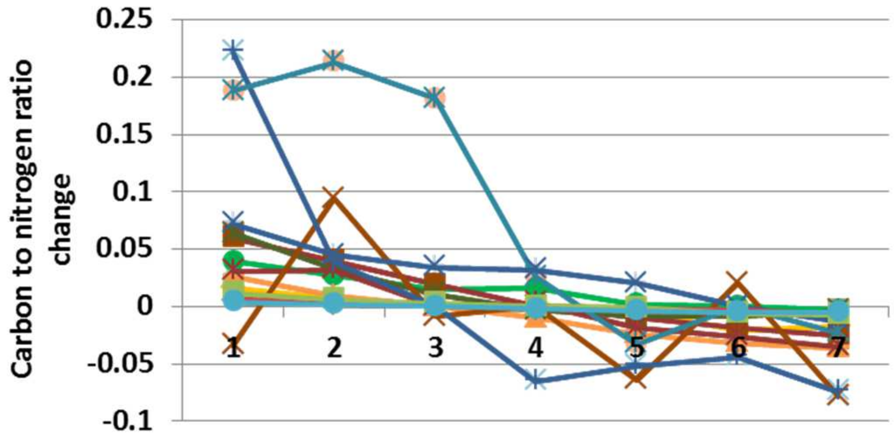
Purpose: The variable set coarse_branch_death_rate provides one value per facet that quantifies coarse branch death rate per month. A placeholder is used for herbs, but they have no coarse branches, and so that value is not used.

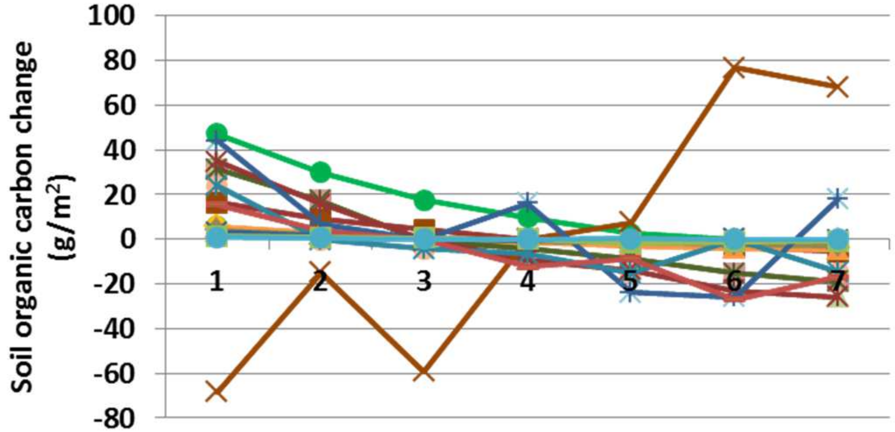
Basis for assignment: The value was inferred, but informed by similar variables in example Savanna applications. Values were adjusted to improve model fit.

Baseline values
Various values, but most are like:
0.0, 0.004, 0.004
0.0, 0.007, 0.007

Sensitivity values:
(shrubs values only changed)
1 – 0.002
2 – 0.003
3 – 0.004
4 – 0.005
5 – 0.006
6 – 0.007
7 – 0.008







Interpretation: Changes annual evapotranspiration and soil temperature were small, and decomposition coefficients were essentially unchanged. Changes in soil organic carbon (above) were mostly small, except for temperate broadleaf evergreen forest. Carbon to nitrogen ratio changed up to 0.22(top). Annual net primary productivity changed up to 22.3 g m^{-2}. Changes in coarse branch death rates caused small changes in herbaceous facet cover (left), up to 4%. Shrub and tree cover changed very little, and as expected, bare ground cover changed in a pattern opposite to herbs.

Conclusion: The parameter is required to represent coarse branch death, and so will be retained.

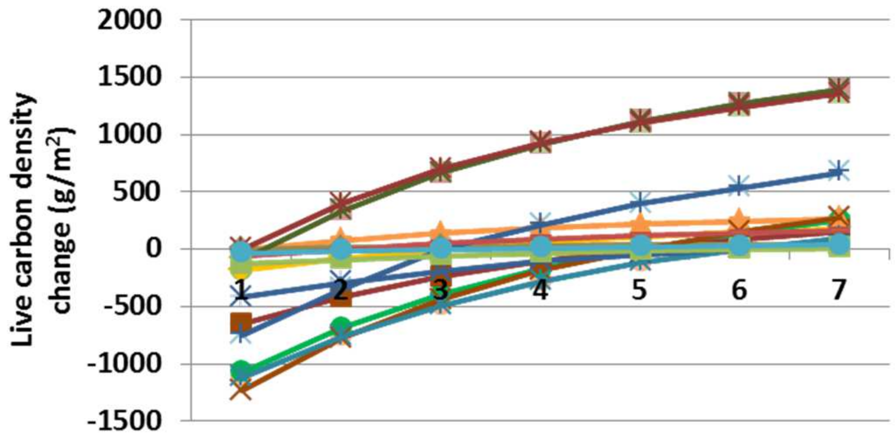
54a. Coarse root death rate - Shrubs

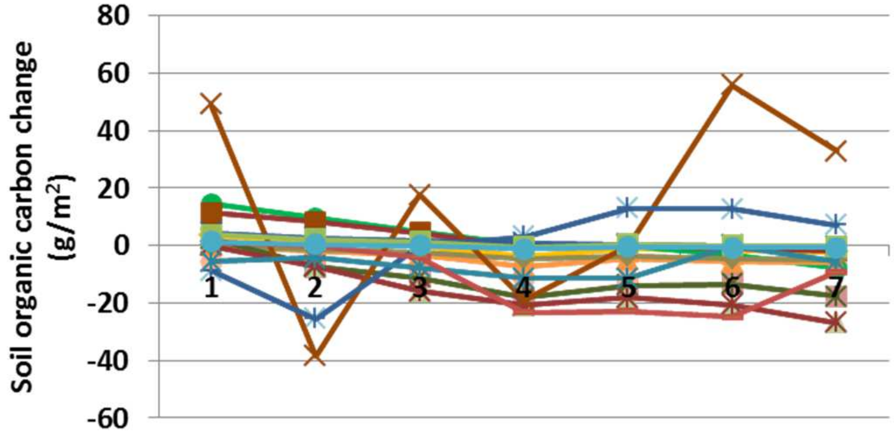
Purpose: The variable set coarse_root_death_rate provides one value per facet that quantifies coarse root death rate per month. A placeholder is used for herbs, but they have no coarse roots, and so that value is not used.

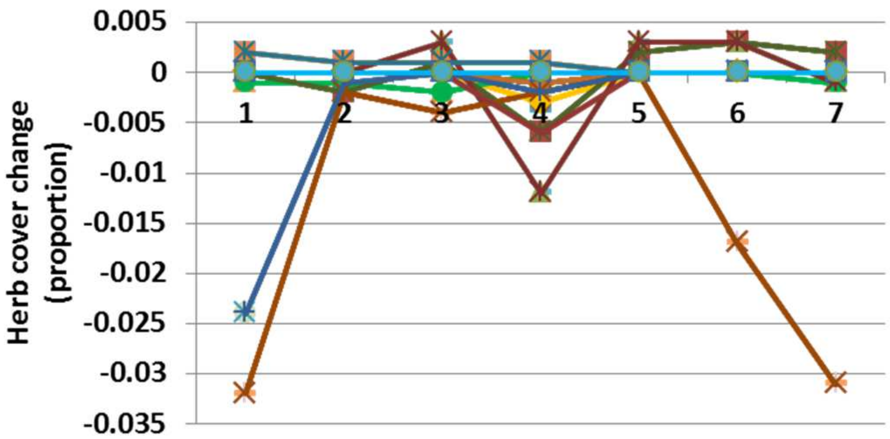
Basis for assignment: The value was inferred, but informed by variables in example Savanna applications, then adjusted.

Baseline values
Various values, but most are like:
0.0, 0.006, 0.005
0.0, 0.008, 0.008

Sensitivity values:
(shrubs values only changed)
1 – 0.004
2 – 0.005
3 – 0.006
4 – 0.007
5 – 0.008
6 – 0.009
7 – 0.010







Interpretation: Changes with secondary responses such as evapotranspiration, soil temperature, plant-available water, and decomposition coefficients were small. Annual net primary productivity changed up to 18 g m^{-2}, and leaf area index by less than 0.06. Soil organic carbon changed up to 58 g m^{-2} (above), and live carbon density changed up to 1356 g m-2. Carbon to nitrogen ratios changed up to 0.1. Changes in coarse root death rates led to up to 3.3% changes in herbaceous facet cover (left), and very small changes in shrub and tree cover.

Conclusion: The parameter is required to represent coarse root death, and so will be retained.

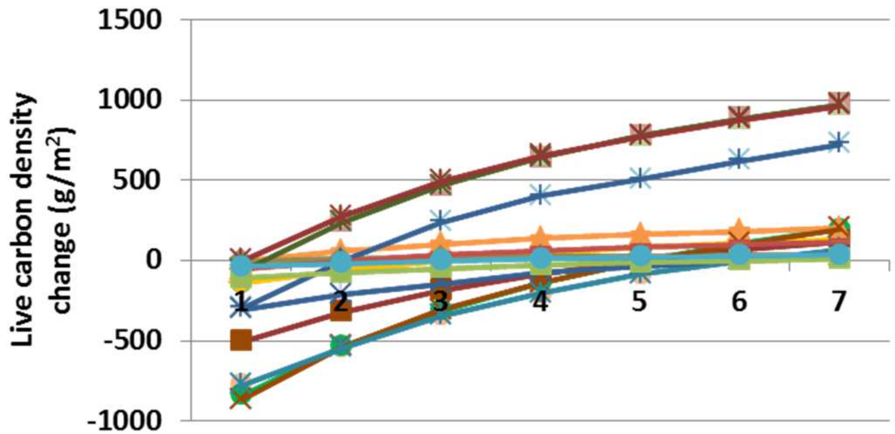
54b. Coarse root death rate - Trees

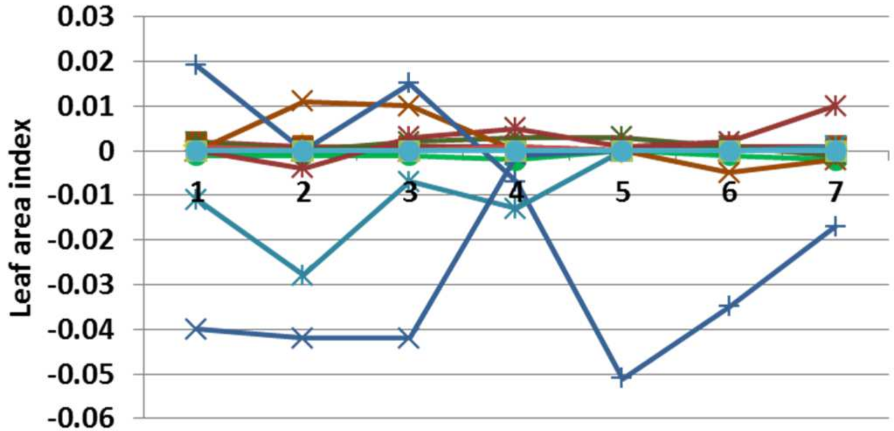
Purpose: The variable set coarse_root_death_rate provides one value per facet that quantifies coarse root death rate per month. A placeholder is used for herbs, but they have no coarse roots, and so that value is not used.

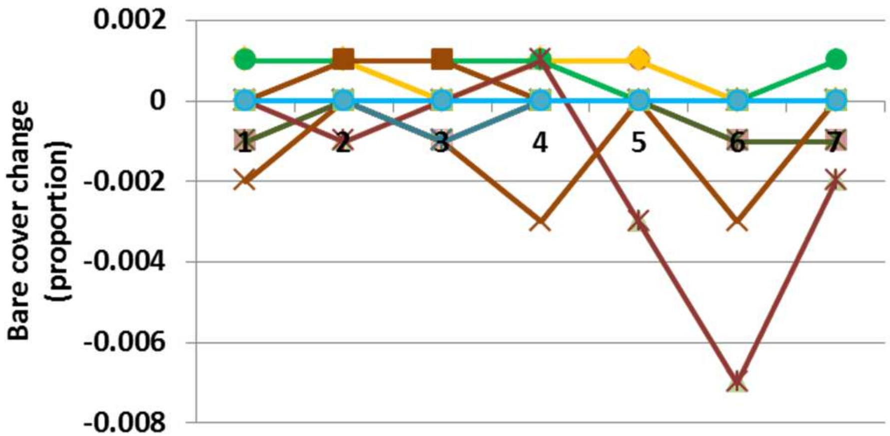
Basis for assignment: The value was inferred, but informed by variables in example Savanna applications, then adjusted.

Baseline values
Various values, but most are like:
0.0, 0.006, 0.005
0.0, 0.008, 0.008

Sensitivity values:
(tree values only changed)
1 – 0.004
2 – 0.005
3 – 0.006
4 – 0.007
5 – 0.008
6 – 0.009
7 – 0.010







Interpretation: Live carbon density was the only large-scale change in response to differences in coarse root death rate (top), with changes up to 1000 g m^{-2}. Leaf area index changed up to 0.05 (above). Annual net primary productivity changed up to 16 g m^{-2}, and carbon to nitrogen ratio changed up to 0.26. Other variables such as soil temperature and plant-available water changed little. None of the facet covers changed notably in response to changes in coarse root death rate, do the degree that bare ground cover changed less than 1% (left).

Conclusion: The parameter is required to represent coarse root death, and so will be retained.

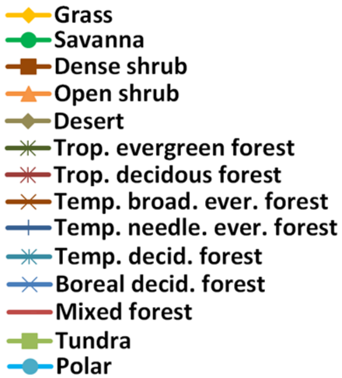
55. Fraction carbon grazed returned

Purpose: The variable set fraction_carbon_grazed_returned describes the portion of carbon that is grazed that is returned to the system as feces.

Basis for assignment: The value was assigned based on GRET/GFCRET, which is part of the example files distributed with the Century model.

Baseline values
0.3 for all units

Sensitivity values:
1 – 0.15
2 – 0.20
3 – 0.25
4 – 0.30
5 – 0.35
6 – 0.40
7 – 0.45



Interpretation: Results for the fraction carbon grazed returned are not available due to technical difficulties. We suspect that changes in the fraction of carbon that is returned would yield relatively small changes to model output.

Conclusion: The parameter captures a known component of ecosystem processes, the return of carbon to the system from herbivores.

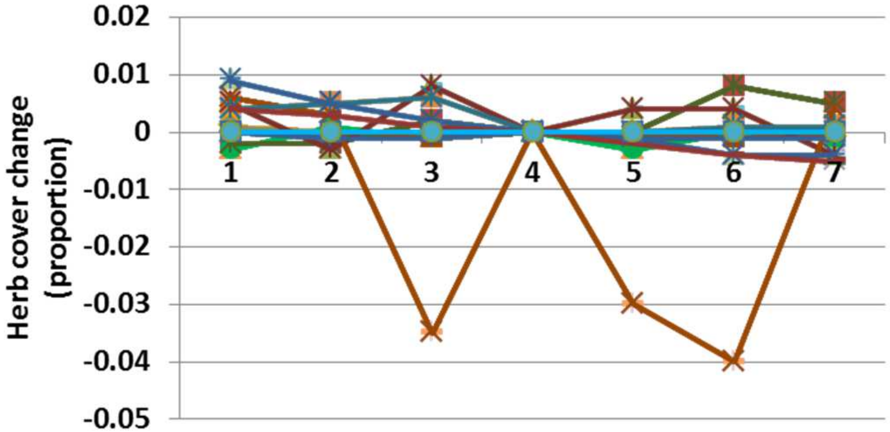
56. Fraction excreted nitrogen in feces

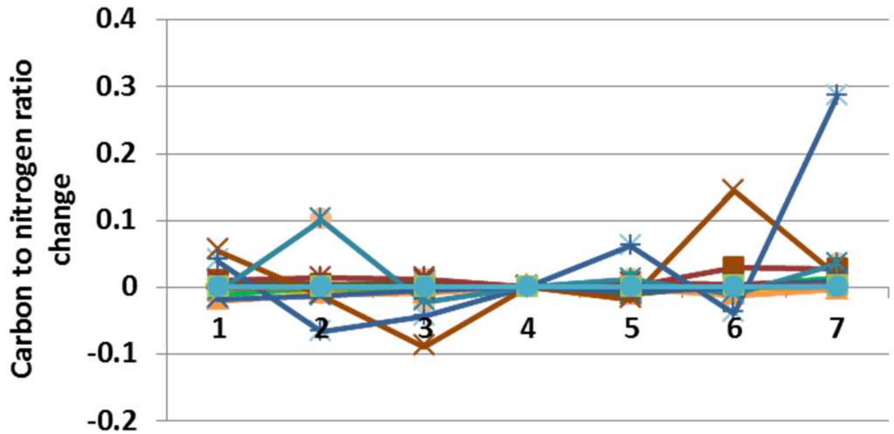
Purpose: The variable fraction_excreted_n_to_feces defines the fraction of nitrogen that is in feces. The remainder is in urine and may be volatilized.

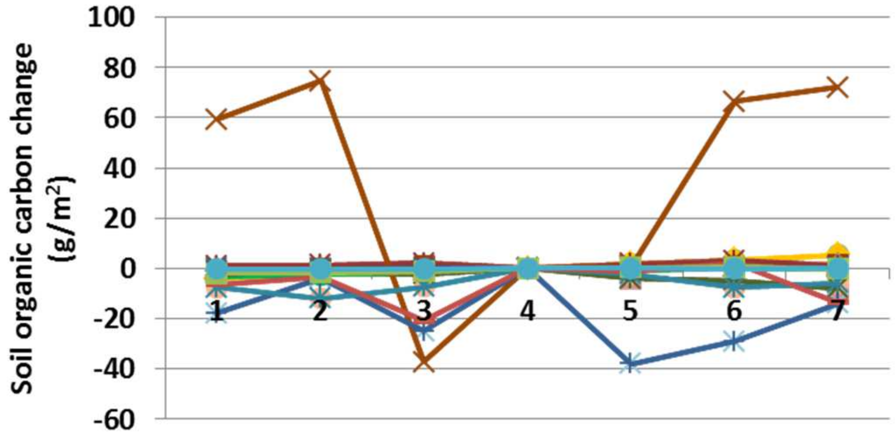
Basis for assignment: The value was assigned based on the variable FACESFR in example applications of the Savanna model.

Baseline values
0.5 for all units

Sensitivity values:
1 – 0.35
2 – 0.40
3 – 0.45
4 – 0.50
5 – 0.55
6 – 0.60
7 – 0.65







Interpretation: Changes in secondary results from G-Range, such as annual evapotranspiration, plant-available water, decomposition coefficients, and soil temperature, were very small. Carbon to nitrogen ratio changed up to 0.29 (top), and soil organic carbon changed up to 75 $g\ m^{-2}$ (above). Live carbon density changed 49 $g\ m^{-2}$, and annual net primary productivity less than 20 $g\ m^{-2}$. Changes in the fraction of excreted nitrogen in feces caused small changes, up to 4%, in herbaceous facet cover (left). Shrubs and trees were essentially unchanged.

Conclusion: The parameter represents an important relationship in ecosystems with large herbivores, and will be retained.

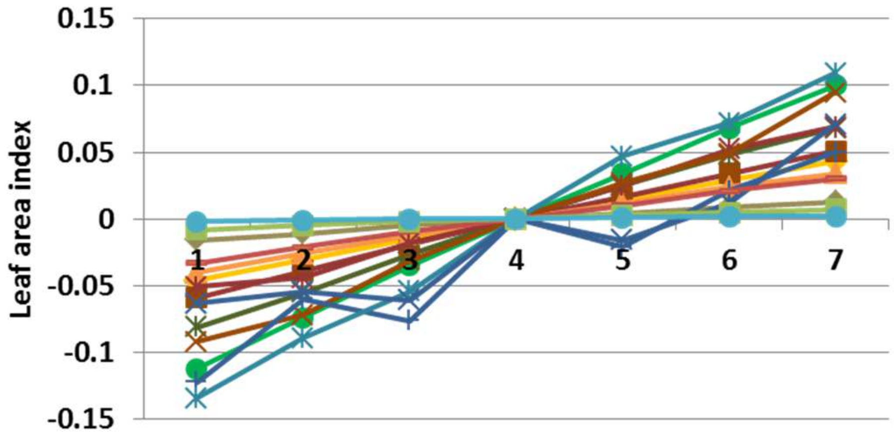
57. Fraction grazed by facet

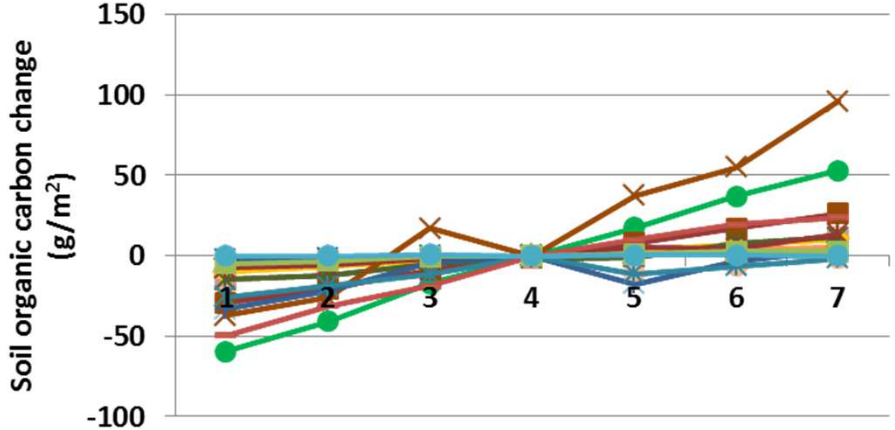
Purpose: The variable fraction_grazed_by_facet defines the distribution of grazing across the different facets. The values should sum to 1.

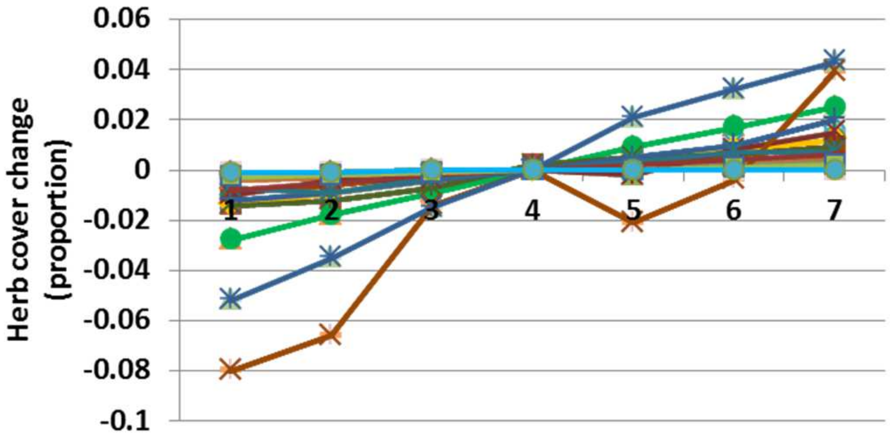
Basis for assignment: The values were inferred based upon typical diets of livestock.

Baseline values
0.8, 0.25, 0.10 for unit 1 (which is incorrect, it should sum to 1)
0.8, 0.15, 0.05 for units 2 to 15

Sensitivity values:
1 – 0.65, 0.27, 0.08
2 – 0.70, 0.23, 0.07
3 – 0.75, 0.19, 0.06
4 – 0.80, 0.15, 0.05
5 – 0.85, 0.11, 0.04
6 – 0.90, 0.07, 0.03
7 – 0.95, 0.03, 0.02







Interpretation: Changes in secondary responses from G-Range, such as decomposition coefficients, plant-available water, soil water, and annual evapotranspiration were small. Soil organic carbon changed up to 96 g m^{-2}, and carbon to nitrogen ratio changed up to 0.15. Live carbon density changed up to 100 g m^{-2}, in a pattern similar to the responses shown. Changes to the fraction grazed by facet changed herbaceous facet cover but up to 8%, and may be in a direction opposite than expected. Shrub and tree cover changed little.

Conclusion: The distribution of grazing must be defined, given the logic of the model. More careful assignment of the values would be helpful.

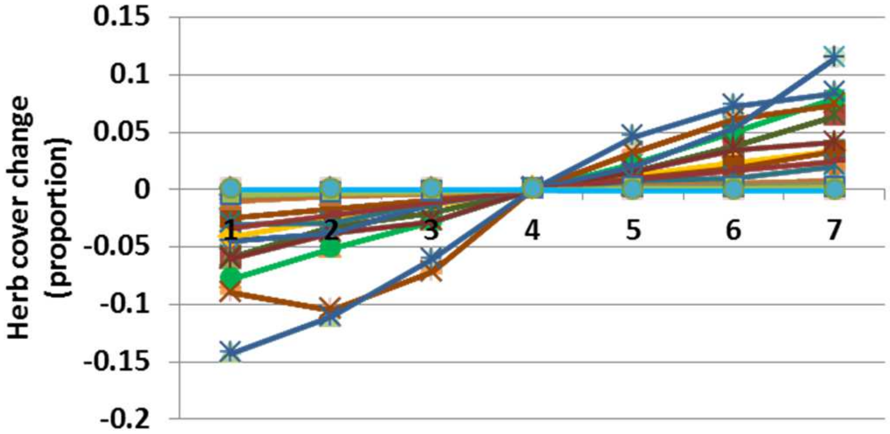
58. Fraction grazed

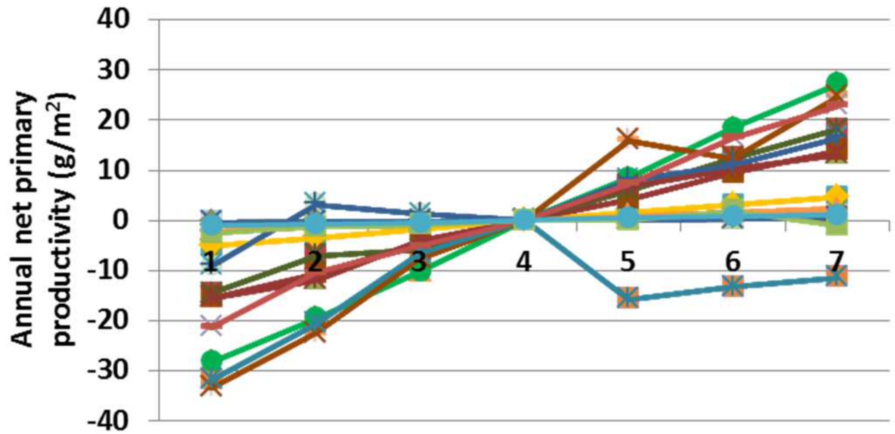
Purpose: The variable fraction_grazed defines the annual proportion of plant material that is grazed.

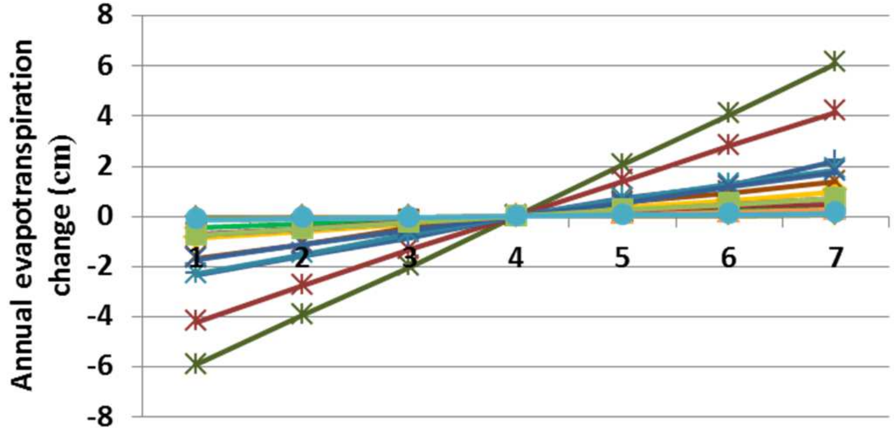
Basis for assignment: The value was assigned based on FLGREM, which is a component in the example files distributed with the Century model, but also in line with typical offtake values for livestock.

Baseline values
0.35 for all units

Sensitivity values:
1 – 0.20
2 – 0.25
3 – 0.30
4 – 0.35
5 – 0.40
6 – 0.45
7 – 0.50







Interpretation: Changes in the fraction of productivity grazed were significant, such as for annual evapotranspiration (above). Soil temperature changed up to one degree in a direction opposite to evapotranspiration. Annual net primary productivity changed up to 33 g m^{-2}. It appears compensatory vegetation production is occurring. Live carbon density changed up to 340 g m^{-2}, and leaf area index changed up to 0.42. Herbaceous facet cover changed up to 14% in response to changed fraction grazed, in a pattern that may be opposite than expected. Shrubs and trees changed little.

Conclusion: The proportion offtake by livestock or wildlife is a critical variable defined for examples, and must be retained.

Future Steps

This sensitivity analysis is part of a joint approach to assessing G-Range. Here extensive tests were conducted in a *spatial* way, but for a single year. Complementary analyses by Dr. Sircely are using specific sites where field data provide an ability to make detailed comparisons through *time*. With results of from these sensitivities and the site-specific analyses to refer to, we are well placed to adjust the G-Range application. Specifically, we will:

- Correct coding errors that have been identified by the results of sensitivity analyses. No changes were made to the G-Range model coding during these analyses, so as to preserve a single baseline for comparison;
- Incorporate a fire frequency spatial surface into the application, and edit fire parameters;
- Rebalance and parameterize the G-Range application given what has been learned, jointly (to the degree possible) minimizing deviations from the spatial surfaces and site-specific observations.

We will then release the model to be used by others, train users, and continue in our own work to address research questions and improve G-Range.

Acknowledgement

Our thanks to Dr. Philip Thornton and the International Livestock Research Institute for providing financial support for sensitivity analyses of G-Range. Our continued thanks to the developers of Century, which forms a foundation for G-Range.

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Appendices

Appendix A. Parameters within the landscape unit parameter file (e.g., Land_Units.grg in the base application). The parameters shown are for rangeland cells within a single land cover type. Analogous blocks of parameters would follow those shown for the remaining land cover types in the spatial layer used.

10	// range_type GRASSLAND / STEPPE	The landscape unit identifier
8.00	// prcp_threshold	The amount of precipitation required for there to be runoff (in cm)
0.15	// prcp_threshold_fraction	The fraction of monthly precipitation that is lost as storm runoff (unitless)
0.20	// base_flow_fraction	The fraction of soil water content in the last soil layer lost to base flow (unitless)
0.8, 0.6, 0.4, 0.2	// soil_transpiration_fraction	The fraction of water transpired from each soil layer (unitless)
22.0	// init_soil_c_n_ratio	Initial soil carbon to nitrogen ratio
150.0	// init_lignin_n_ratio	Initial lignin to nitrogen ratio in litter
1200, 500, 800, 3500, 1200, 100, 100, 300, 200, 300	// tree_carbon	Initial tree carbon for each plant part (1-5 = leaf, fine root, fine branch, coarse branch, coarse root) for alive (1) and dead (2) components (gC m^2)
300, 150, 200, 800, 300, 40, 40, 80, 60, 80	// shrub_carbon	Initial shrub carbon for each plant part (1-5 = leaf, fine root, fine branch, coarse branch, coarse root) for alive (1) and dead (2) components (gC m^2)
0.5, 2.0, 8.0	// plant_dimension	Single dimension of square area occupied by plant root mass per facet (1-3 = herb, shrub, tree) (m)
30., 45., 1.0, 2.5	// temperature_production	Effect of temperature on potential production, coefficients shaping a response curve, 1 = optimum temperature, 2 = maximum temperature, 3 = left shape, 4 = right shape (C, C, unitless, unitless)
60.0	// standing_dead_production_halved	Standing dead material plus a portion of structural material that reduces production by half due to physical obstruction (gC m^2)
0.40	// radiation_production_coefficient	Coefficient relating potential aboveground monthly production as a function of solar radiation outside the atmosphere (unitless)
0.40, 0.37, 0.33	// fraction_carbon_to_roots	Fraction of carbon allocated to roots (unitless)
1	// grazing_effect	Grazing effect flag, used to specify 0 through 6 types of plant functional responses to grazing. See documentation for their definitions.
0.8	// effect_of_co2_on_transpiration	The effect of CO2 on transpiration rates (unitless)
2.0, 2.0	// decomp_rate_structural_litter_inverts	Decomposition rate of structural litter in soil layers one and two, due to invertebrates (gC m^2)

0.25	// feces_lignin	Proportion of feces that is lignin (unitless)
0.0200, 0.0012, 0.2600, -0.0015	// lignin_content_fraction_and_precip	Relating precipitation to lignin content in materials, providing a 1) intercept aboveground, 2) slope aboveground, 3) intercept belowground, 4) slope belowground
0.2	// fraction_urine_volatilized	Fraction of urine nitrogen that is volatilized (unitless)
0.05000, 0.00700	// precip_n_deposition	Coefficients shaping a line relating precipitation to nitrogen deposition (intercept and slope)
30.00, 0.0100	// precip_n_symbiotic	Coefficients shaping a line relating precipitation to symbotic nitrogen fixation (intercept and slope)
0.25	// decomp_litter_mix_facets	The degree to which litter mixes between facets within a landscape cell (proportion, from 0 to 1)
0,0, 200,1, 400,2, 700,3, 1200,4, 0,0, 400,1, 800,2, 1000,3, 2000,4, 0,0, 400,1, 800,2, 1000,3, 2000,4	// degree_days_phen	Degree days relating to plant phenology, per facet, and with four pairs of values forming the relationship (degree days per phenology, which is from 0 to 4)
1500, 3000, 3000	// degree_days_reset	Degree days to reset phenology back to zero (degree days)
1.0	// tree_site_potential	Tree site potential, in peak aboveground herbaceous biomass if trees are absent (gB m^2)
0.001	// max_symbiotic_n_fixation_ratio	Maximum symbiotic nitrogen fixation, in gN fixed for gC of new growth
10., 13., 0., 0., 0., 13., 20., 30., 50., 60., 15., 21., 32., 52. 52.	// minimum_c_n_ratio	Minimum carbon to nitrogen ratio of plant biomass, for three facets, five plant parts each (the last three in herbs not used) (unitless)
30., 33., 0., 0., 0., 33., 40., 50., 80., 90., 35., 51., 62., 92. 95.	// maximum_c_n_ratio	Maximum carbon to nitrogen ratio of plant biomass, for three facets, five plant parts each (the last three in herbs not used) (unitless)
6.0	// maximum_leaf_area_index	Maximum leaf area index (unitless)
2000.	// k_leaf_area_index	Large wood mass at which half of the maximum leaf area index is attained (gC m^2)
0.008	// biomass_to_leaf_area_index_factor	Biomass to leaf area index conversion factor (coefficient)
0.020	// annual_fraction_volatilized_n	Annual fraction of nitrogen that is volatized (unitless)
0.10, 0.10, 0.10	// maximum_root_death_rate	Maximum root death rate, per facet (herb, shrub, and tree) (unitless)
0.20, 0.95, 0.20, 150.0	// shoot_death_rate	Shoot death rate due to 1) water stress, 2) phenology, 3) shading according to the carbon concentration in 4.
0.20	// prop_annuals	Proportion of herbaceous plants that are annuals (unitless)
12	// month_to_remove_annuals	Month to kill annual plants if they had not been killed already by phenology or

other reasons (month)

1050.0, 1050.0, 1050.0 // relative_seed_production Relative seed production of plants in each facet (herbs, shrubs, trees) (unitless)

0.67,0.2, 2.9,1.0, 3.0,0.2, 6.0,1.0, 0.2,0.2, 0.4,1.0 // water_effect_on_establish The effect of available water ratio to potential evapotranspiration on plant establishment, per facet (herb, shrub, tree) with two pairs of values defining a linear relationship

100.0,1.0, 600.,0.3, 0.0,1.0, 300.0,0.5, 150.0,1.0, 300.0,0.4 // herb_root_effect_on_establish The effect of herbaceous root biomass on the establishment of plants, per facet (herb, shrub, tree) with two pairs of values defining a linear relationship

300.0,1.0, 1000.0,0.0, 300.0,1.0, 1000.0,0.0, 300.0,1.0, 1000.0,0.0 // litter_effect_on_establish The effect of surface litter biomass on the establishment of plants, per facet (herb, shrub, tree) with two pairs of values defining a linear relationship

0.0,1.0, 0.4,0.1, 0.0,1.0, 0.8,0.1, 0.0,1.0, 0.8,0.1 // woody_cover_effect_on_understory The effect of woody cover on the establishment of plants in understories, per facet (herb, shrub, tree) with two pairs of values defining a linear relationship

0.05, 0.03, 0.01 // nominal_plant_death_rate Nominal plant death rate, per facet (unitless)

2.0,0.0, 0.5,0.6, 1.0,0.0, 0.3,0.3, 0.9,0.0, 0.2,0.3 // water_effect_on_death_rate The effect of available water ratio to potential evapotranspiration on plant death rate, per facet (herb, shrub, tree) with two pairs of values defining a linear relationship

0.0,0.0, 1.0,0.5, 0.0,0.0, 1.0,0.1, 0.0,0.0, 1.0,0.1 // grazing_effect_on_death_rate The effect of grazing frequency on plant death rate, per facet (herb, shrub, tree) with two pairs of values defining a linear relationship

0.0,0.0, 5.0,0.05, 0.0,0.0, 4.0,0.05, 0.0,0.0, 4.0,0.01 // shading_effect_on_death_rate The effect of shading on plant death rate, per facet (herb, shrub, tree) with two pairs of values defining a linear relationship

0.02, 0.05, 0.05 // fall_rate_of_standing_dead The rate standing dead falls to join litter, per facet (herb, shrub, tree) (unitless)

0.10 // death_rate_of_deciduous_leaves The rate of death of deciduous leaves during the period of senescence (unitless)

0.2, 0.2, 0.2 // drought_deciduous The fraction of plants that are drought deciduous, per facet (herb, shrub, tree) (unitless)

0.3 // fraction_woody_leaf_n_translocated The fraction of nitrogen in woody leaves that are translocated back to roots prior to death (unitless)

0.08, 0.03, 0.01 // leaf_death_rate Leave death rate, per facet (herb, shrub, tree) (unitless)

0.03, 0.02, 0.02 // fine_root_death_rate Fine root death rate, per facet (herb, shrub, tree) (unitless)

0.0, 0.005, 0.005 // fine_branch_death_rate Fine branch death rate, per facet (herb, shrub, tree) (unitless)

0.0, 0.003, 0.003 // coarse_branch_death_rate Coarse branch death rate, per facet (herb, shrub, tree) (unitless)

0.0, 0.005, 0.005	// coarse_root_death_rate	Coarse root death rate, per facet (herb, shrub, tree) (unitless)
0.3	// fraction_carbon_grazed_returned	The fraction of carbon that is grazed that is returned through feces or other routes (unitless)
0.5	// fraction_excreted_nitrogen_in_feces	The fraction of excrete nitrogen that is feces; the remainder is urine (unitless)
0.8, 0.15, 0.05	// fraction_grazed_by_facet	The fraction of total grazing that is from each of the facets (herb, shrub, tree), with the total summing to 1.0 (proportion)
0.35	// fraction_grazed	The annual proportion of plant material grazed
0.0	// frequency_of_fire	The probability of fire per year for any given cell within the landscape unit (NOTE SCALE DEPENDENCE, USE DEPENDS ON fire_maps_used), set to 0 for no fire (unitless)
0.0	// fraction_burned	The proportion of a landscape cell that burns, in the case of a fire event (NOTE SCALE DEPENDENCE. USE DEPENDS ON fire_maps_used. ALSO ONE FIRE PER YEAR MAX) (unitless)
6	// burn_month	The month in which patches will be burned, in the case of a fire event (ONE FIRE PER YEAR MAX, USE DEPENDS ON fire_maps_used) (month)
50., 400.	// fuel_vs_intensity	The fuel load as related to low and high intensity fires (g biomass / m2)
0., 1., 0.3, 0.7	// green_vs_intensity	The proportion of aboveground vegetation that is green versus fire intensity (unitless)
0.1,1.0, 0.1,0.2, 0.1,0.2	// fraction_shoots_burned	The proportion of live leaves and shoots removed by a fire event, by facet, for low and high intensity fire (unitless)
0.4,1.0, 0.3,0.9, 0.3,0.9	// fraction_standing_dead_burned	The proportion of standing dead removed by a fire event, by facet, for low and high intensity fire (unitless)
0.2,0.5, 0.0,0.15, 0.0,0.15	// fraction_plants_burned_dead	The proportion of plants that are burned that die, by facet, for low and high intensity fire (unitless)
0.1, 0.5, 0.1, 0.5, 0.1, 0.5	// fraction_litter_burned	The proportion of litter removed by a fire event, by facet, for low and high intensity fire (unitless)
0.06	// fraction_burned_carbon_as_ash	The proportion of carbon in burned aboveground material that is ash, going to structural litter (unitless)
0.08	// fraction_burned_nitrogen_as_ash	The proportion of nitrogen in burned aboveground material that is ash, going to soil mineral nitrogen (unitless)
0.0	// frequency_of_fertilization	The probability of fertlization per year in the landscape unit (USE DEPENDS ON fertilize_maps_used) (unitless)

0.0001	// fraction_fertilized	The proportion of a landscape cell that is fertilized, in the case of a fertilization event (NOTE SCALE DEPENDENCE. USE DEPENDS ON fertilize_maps_used) (unitless)
6	// fertilize_month	The month in which fertilization occurs (one event per year per landscape unit) (month)
3.0	// fertilize_nitrogen_added	Amount of inorganic nitrogen added during a fertilization event (g / m2)
100.0	// fertilize_carbon_added	Amount of carbon added as part of organic matter fertilizer (g / m2)

Appendix B. The FIT.AML Arc Macro Language program. The program was used to run a G-Range simulation and create spreadsheets reporting the goodness of fit between observed data layers and the simulated responses. (Note that some lines wrap here, but not in the file itself.)

```
/* An AML that runs G-RANGE, exports selected projects, and compares those to selected existing layers.
/* The goal is for the results to be 15 lines (one per land unit) summarizing the fit of the model and
/* the existing layers.
/*
/* NOTE that all ASC files exported and the working workspace are deleted
/*
/* At 0.5 degree resolution, there are at least 81 cells in each of the biomes.
/* Specifically, zone 3 has 81, zones 4 and 5 have 97, zone 7 has 107, and the remainder have several
/* hundred or more.   So all the fits matter.
/*
/*
/* February 2, 2013 - Changing the percent error estimates
/* February 9, 2013 - A division on the error is still being calculated.   I don't want that.   Changing.
/* March 29, 2013 - An error in LAI calculations, using just the herbaceous layers.   Repaired.
/* May 14, 2013 - Edited to include the other fitting procedure, the one that calculates FACETS.
/*                Now the model runs once, but the two reports are generated.

display 9999 1

w \grange2
&if [exists temp_ws -workspace] &then
   dw temp_ws
   y

w \grange2\fitting
&sys START /WAIT ..\fld_date.bat


w \grange\g_range_bin
&sys cd \GRange\G_Range_Bin
/* GRANGE TURNED ON  ***************************************
/* &echo G-RANGE IS STARTING ...
&sys START /WAIT /NORMAL  \GRange\G_Range_Bin\G_Range.exe
/* echo GRANGE IS TURNED OFF!!!!!!
echo COMPARE ALL UNITS ... COMPARE g C to g C, not g C to g biomass
/* GRANGE TURNED ON  ***************************************

w \grange2\exp_out
&sys cd \GRange2\Exp_Out
/* NOTE that ASC files in this folder are removed
&sys del /Q *.asc

w \grange2
```

```
cw temp_ws

/**********************************************
/* POTENTIAL EVAPOTRANSPIRATION
/**********************************************
/* Comparing potential evapotranspiration (cm/month) against Century PET, which is potential
/*  evapotranspiration (cm/month), so the comparison should be good.
/* REASONABLY CLOSE
/**********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  pot_evap.gof
C:\GRange2\Exp_Out\PET  2004  2006  1

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists pet_%mn% -grid] &then
    kill pet_%mn%
  asciigrid \GRange2\Exp_Out\PET_2006_%mn%_1.asc  pet_%mn%  float
&end

grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists pet_%mn%b -grid] &then
    kill pet_%mn%b
  if (pet_%mn% > -1) pet_%mn%b = pet_%mn% ; endif
&end

&if [exists pet_yr -grid] &then
  kill pet_yr all
pet_yr = pet_01b + pet_02b + pet_03b + pet_04b + pet_05b + pet_06b + pet_07b + pet_08b + pet_09b + pet_10b +
pet_11b + pet_12b

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists pet_out -grid] &then
  kill pet_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   pet_yr - \grange2\century\grds\pet
pet_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )
```

```
quit

w \GRange2
&type Done with Potential Evapotranspiration


/*********************************************
/* PLANT AVAILABLE WATER
/*********************************************
/* Comparing water available to plants for growth (cm) ayer ... to plant available soil water in Century
/* (pah2o) which is in cm, so the comparison should be good.
/* This is leading to a very large bias.  The surfaces are quite close, differing by 100% in the means
/* (relative to other errors, that is close, plus the "observed"
/* surface is for the entire land mass).  But some cells are near 0.  Dividing by the near 0 value yields
/* massive errors, even though they are close.
/* Percent error calculated in the way I am using leads to a bias for small numbers.
/*********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  water_available.gof
C:\GRange2\Exp_Out\H2O  2004  2006  3

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
 &do lyr &list 1 2 3
  &if [exists h2o_%mn%_%lyr% -grid] &then
    kill h2o_%mn%_%lyr%
  asciigrid \GRange2\Exp_Out\H2O_2006_%mn%_%lyr%.asc  H2O_%mn%_%lyr%  float
 &end
&end

grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
 &do lyr &list 1 2 3
  &if [exists h2o_%mn%_%lyr%b -grid] &then
    kill h2o_%mn%_%lyr%b
  if (h2o_%mn%_%lyr% > -1) h2o_%mn%_%lyr%b = h2o_%mn%_%lyr% ; endif
 &end
&end

&if [exists h2o_yr_z -grid] &then
  kill h2o_yr_z all
&if [exists h2o_yr_y -grid] &then
  kill h2o_yr_y all
&if [exists h2o_yr_x -grid] &then
```

```
  kill h2o_yr_x all
&if [exists h2o_yr -grid] &then
  kill h2o_yr all

/* Using only layer one here.   The others get built, but ignored.

h2o_yr_z = h2o_01_1b + h2o_02_1b + h2o_03_1b + h2o_04_1b + h2o_05_1b + h2o_06_1b + h2o_07_1b + h2o_08_1b +
h2o_09_1b + h2o_10_1b + h2o_11_1b + h2o_12_1b
&type Special divisor for Water Availability
h2o_yr = h2o_yr_z / 12.0

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists h2o_out -grid] &then
  kill h2o_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   h2o_yr - \grange2\century\grds\pah2o
h2o_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
&type Done with Plant Available Water


/***********************************************
/* SOIL SURFACE TEMPERATURE
/***********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output
soil_surface_temperature.gof  C:\GRange2\Exp_Out\stemp  2004  2006  1

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists stemp_%mn% -grid] &then
    kill stemp_%mn%
  asciigrid \GRange2\Exp_Out\stemp_2006_%mn%_1.asc  stemp_%mn%  float
&end

grid
```

```
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists stemp_%mn%b -grid] &then
    kill stemp_%mn%b
  if (stemp_%mn% > -250) stemp_%mn%b = stemp_%mn% ; endif
&end

&if [exists stemp_yr -grid] &then
  kill stemp_yr all
/* STEMP_YR is an average
stemp_yr = ( stemp_01b + stemp_02b + stemp_03b + stemp_04b + stemp_05b + stemp_06b + stemp_07b + stemp_08b +
stemp_09b + stemp_10b + stemp_11b + stemp_12b ) / 12.0

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists stemp_out -grid] &then
  kill stemp_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   stemp_yr - \grange2\century\grds\stemp
stemp_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
&type Done with Soil Surface Temperature


/**********************************************
/* SOIL TOTAL CARBON
/**********************************************
/*
/**********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  soil_total_carbon.gof
C:\GRange2\Exp_Out\somtc  2004  2006  1

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists somtc_%mn% -grid] &then
    kill somtc_%mn%
  asciigrid \GRange2\Exp_Out\somtc_2006_%mn%_1.asc  somtc_%mn%  float
&end
```

```
grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists somtc_%mn%b -grid] &then
    kill somtc_%mn%b
  if (somtc_%mn% > -1) somtc_%mn%b = somtc_%mn% ; endif
&end

&if [exists somtc_yr -grid] &then
  kill somtc_yr all
somtc_yr = ( somtc_01b + somtc_02b + somtc_03b + somtc_04b + somtc_05b + somtc_06b + somtc_07b + somtc_08b +
somtc_09b + somtc_10b + somtc_11b + somtc_12b ) / 12.0

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists somtc_out -grid] &then
  kill somtc_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   somtc_yr - \grange2\century\grds\somtc
somtc_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
&type Done with Soil Total Carbon


/**********************************************
/* CARBON_NITROGEN_RATIO
/**********************************************
/* GRANGE produces a BELOW GROUND measure (Layer 2) and a SURFACE measure (Layer 1).   I will use
/* CN_RAT_0_30 with the SOIL layer (LAYER 2)
/* RATIO VERSUS RATIO
/* Using a weighted CN ratio from ISRIC data.  I compared the topsoil that I got with a graphic from the
/* web, and the overall patterns agreed.   Subsoil CN is 92% correlated, so I will use topsoil.  Their means
/* are similar as well.
/**********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  carbon_nitrogen_ratio.gof
C:\GRange2\Exp_Out\cn_rat  2004  2006  2
```

```
w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
 &do lyr &list 2                                                   /* Just using the second layer
  &if [exists cn_rat_%mn%_%lyr% -grid] &then
    kill cn_rat_%mn%_%lyr%
  asciigrid \GRange2\Exp_Out\cn_rat_2006_%mn%_%lyr%.asc  cn_rat_%mn%_%lyr%  float
 &end
&end

grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
 &do lyr &list 2
  &if [exists cn_rat_%mn%_%lyr%b -grid] &then
    kill cn_rat_%mn%_%lyr%b
  if (cn_rat_%mn%_%lyr% > -1) cn_rat_%mn%_%lyr%b = cn_rat_%mn%_%lyr% ; endif
 &end
&end

&if [exists cn_rat_yr -grid] &then
  kill cn_rat_yr all
&if [exists cn_rat_yrz -grid] &then
  kill cn_rat_yrz all

cn_rat_yrz = cn_rat_01_2b + cn_rat_02_2b + cn_rat_03_2b + cn_rat_04_2b + cn_rat_05_2b + cn_rat_06_2b +
cn_rat_07_2b + cn_rat_08_2b + cn_rat_09_2b + cn_rat_10_2b + cn_rat_11_2b + cn_rat_12_2b

/* Not summing here, I want the average of all the layers.
cn_rat_yr = cn_rat_yrz / 12.

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists cn_rat_out -grid] &then
  kill cn_rat_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   cn_rat_yr - \grange2\misc\cn_rat_0_30
cn_rat_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
```

```
&type Done with Carbon Nitrogen Ratio for Soil


/**********************************************
/* NET PRIMARY PRODUCTION
/**********************************************
/*  NOTE that the Century output is g/m2 per month ... no not ANPP, but monthly NPP
/**********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output
total_pot_prod_limited_by_n.gof  C:\GRange2\Exp_Out\tprd  2004  2006  6

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
 &do lyr &list 1 2 3 4 5 6
  &if [exists tprd_%mn%_%lyr% -grid] &then
    kill tprd_%mn%_%lyr%
  asciigrid \GRange2\Exp_Out\tprd_2006_%mn%_%lyr%.asc  tprd_%mn%_%lyr%  float
 &end
&end

grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
 &do lyr &list 1 2 3 4 5 6
  &if [exists tprd_%mn%_%lyr%b -grid] &then
    kill tprd_%mn%_%lyr%b
  if (tprd_%mn%_%lyr% > -1) tprd_%mn%_%lyr%b = tprd_%mn%_%lyr% ; endif
 &end
&end

&if [exists tprd_yr -grid] &then
  kill tprd_yr all
&do lyr &list 1 2 3 4 5 6
  &if [exists tprd_yrz%lyr% -grid] &then
    kill tprd_yrz%lyr% all
&end

setwindow tprd_01_1
setcell tprd_01_1

tprd_yr_y1 = 0.0
tprd_yr_y2 = 0.0
tprd_yr_y3 = 0.0
tprd_yr_y4 = 0.0
```

```
tprd_yr_y5 = 0.0
tprd_yr_y6 = 0.0

&do mn  &list  01 02 03 04 05 06 07 08 09 10 11 12
   tprd_yr_z1 = tprd_yr_y1 + tprd_%mn%_1b
   tprd_yr_z2 = tprd_yr_y2 + tprd_%mn%_2b
   tprd_yr_z3 = tprd_yr_y3 + tprd_%mn%_3b
   tprd_yr_z4 = tprd_yr_y4 + tprd_%mn%_4b
   tprd_yr_z5 = tprd_yr_y5 + tprd_%mn%_5b
   tprd_yr_z6 = tprd_yr_y6 + tprd_%mn%_6b
   kill tprd_yr_y1 all
   kill tprd_yr_y2 all
   kill tprd_yr_y3 all
   kill tprd_yr_y4 all
   kill tprd_yr_y5 all
   kill tprd_yr_y6 all
   rename tprd_yr_z1  tprd_yr_y1
   rename tprd_yr_z2  tprd_yr_y2
   rename tprd_yr_z3  tprd_yr_y3
   rename tprd_yr_z4  tprd_yr_y4
   rename tprd_yr_z5  tprd_yr_y5
   rename tprd_yr_z6  tprd_yr_y6
&end
/* Summing here, I want the total of all the layers.
tprd_yr = ( tprd_yr_y1 +  tprd_yr_y2 +  tprd_yr_y3 +  tprd_yr_y4 +  tprd_yr_y5 +  tprd_yr_y6 ) / 12.0

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists tprd_out -grid] &then
  kill tprd_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   tprd_yr - \grange2\century\grds\npp
tprd_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
&type Done with Net Primary Production


/*********************************************
/* EFFECTS ON DECOMPOSITION
```

```
/*********************************************
/* The comparison is ok.  Both are indices.   This required division to monthly values.
/* The coefficients may not match between CENTURY and G-RANGE.   Here I'm using all three components.
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  all_effects_on_decomp.gof
C:\GRange2\Exp_Out\decomp  2004  2006  1

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists decom_%mn% -grid] &then
    kill decomp_%mn%
  asciigrid \GRange2\Exp_Out\decomp_2006_%mn%_1.asc  decomp_%mn%  float
&end

grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
  &if [exists decomp_%mn%b -grid] &then
    kill decomp_%mn%b
  if (decomp_%mn% > -1) decomp_%mn%b = decomp_%mn% ; endif
&end

&if [exists decomp_yr -grid] &then
  kill decomp_yr all
&if [exists decomp_yr_y -grid] &then
  kill decomp_yr_y all

/* Needs to be a monthly average
decomp_yr = ( decomp_01b + decomp_02b + decomp_03b + decomp_04b + decomp_05b + decomp_06b + decomp_07b +
decomp_08b + decomp_09b + decomp_10b + decomp_11b + decomp_12b ) / 12.0

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists decomp_out -grid] &then
  kill decomp_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   decomp_yr - \grange2\century\grds\adefac
decomp_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit
```

```
w \GRange2
&type Done with All Effects on Decomposition


/*********************************************
/* CARBON DENSITY
/*********************************************
/* A surface in tons carbon / ha for 2000 (Ruesch et al. 2008).  Living biomass above and below ground.
/* Important
/*
w \Grange2\Exporter
&sys cd \GRange2\Exporter
/* Note that aboveground is live biomass, below ground is carbon.
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output
total_aground_live_biomass.gof  C:\GRange2\Exp_Out\talb  2004  2006  3
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  fine_root_carbon.gof
C:\GRange2\Exp_Out\frc   2004  2006  3
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  coarse_root_carbon.gof
C:\GRange2\Exp_Out\crc   2004  2006  3
w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
   /* Total aboveground live biomass in g/m-2
   &do lyr &list 1 2 3
      &if [exists talb_%mn%_%lyr% -grid] &then
        kill talb_%mn%_%lyr% all
      asciigrid \GRange2\Exp_Out\talb_2006_%mn%_%lyr%.asc  talb_%mn%_%lyr%  float
   &end
&end

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
   /* Root carbons  in g/m-2
   &do lyr &list 1 2 3
      &if [exists frc_%mn%_%lyr% -grid] &then
        kill frc_%mn%_%lyr% all
      asciigrid \GRange2\Exp_Out\frc_2006_%mn%_%lyr%.asc  frc_%mn%_%lyr%  float

      /* Coarse roots for herbs will always be 0, but no matter, for simplicity
      &if [exists crc_%mn%_%lyr% -grid] &then
        kill crc_%mn%_%lyr% all
      asciigrid \GRange2\Exp_Out\crc_2006_%mn%_%lyr%.asc  crc_%mn%_%lyr%  float
   &end
&end

grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
```

```
   &do lyr &list 1 2 3
     &if [exists talb_%mn%_%lyr%b -grid] &then
        kill talb_%mn%_%lyr%b
     if (talb_%mn%_%lyr% > -1) talb_%mn%_%lyr%b = talb_%mn%_%lyr% ; endif

     &if [exists frc_%mn%_%lyr%b -grid] &then
        kill frc_%mn%_%lyr%b
     if (frc_%mn%_%lyr% > -1) frc_%mn%_%lyr%b = frc_%mn%_%lyr% ; endif

     &if [exists crc_%mn%_%lyr%b -grid] &then
        kill crc_%mn%_%lyr%b
     if (crc_%mn%_%lyr% > -1) crc_%mn%_%lyr%b = crc_%mn%_%lyr% ; endif
   &end
&end

setwindow talb_01_2b
setcell talb_01_2b

talb_yr_y = 0.0
frc_yr_y = 0.0
crc_yr_y = 0.0

&do mn  &list  01 02 03 04 05 06 07 08 09 10 11 12
  &do lyr &list 1 2 3
     talb_yr_z = talb_yr_y + talb_%mn%_%lyr%b
     kill talb_yr_y all
     rename talb_yr_z  talb_yr_y

     frc_yr_z = frc_yr_y + frc_%mn%_%lyr%b
     kill frc_yr_y all
     rename frc_yr_z  frc_yr_y

     crc_yr_z = crc_yr_y + crc_%mn%_%lyr%b
     kill crc_yr_y all
     rename crc_yr_z  crc_yr_y
  &end
&end

&if [exists talb_yr -grid] &then
  kill talb_yr all
&if [exists frc_yr -grid] &then
  kill frc_yr all
&if [exists crc_yr -grid] &then
  kill crc_yr all

/* Total aboveground live biomass is 12 months, three layers, all summed up.  BUT the three layers should
```

```
/* remain summed, so division by 12.
/* NOTE: CONVERTING to carbon at this point, using the general conversion used in CENTURY, biomass is 2.5
/* times carbon content
/* That could be weighted to use 2.0 for coarse branches, if desirable.
talb_yr = ( talb_yr_y / 12.0 ) * 0.4

/* Fine and coarse root carbon, so 12 months
frc_yr = frc_yr_y / 12.0
crc_yr = crc_yr_y / 12.0

tot_c_yr = talb_yr + frc_yr + crc_yr

/* A metric ton is a million grams. A hectare is 10,000 square meters.   So  1,000,000 / 10,000 =   1 ton
/* per hectare = 100 g / m2 ... so multiply by 100 to get g / m2.

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists totc_out -grid] &then
  kill totc_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   tot_c_yr - ( \grange2\misc\carbon_den * 100.0 )
totc_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
&type Done with Carbon Density


/**********************************************
/* LEAF AREA INDEX
/**********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  leaf_area_index.gof
C:\GRange2\Exp_Out\lai  2004  2006  3

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
   &do lyr &list 1 2 3
      &if [exists lai_%mn%_%lyr% -grid] &then
        kill lai_%mn%_%lyr% all
```

```
        asciigrid \GRange2\Exp_Out\lai_2006_%mn%_%lyr%.asc  lai_%mn%_%lyr%  float
     &end
  &end

  grid

  &do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
     &do lyr &list 1 2 3
       &if [exists lai_%mn%_%lyr%b -grid] &then
          kill lai_%mn%_%lyr%b
       if (lai_%mn%_%lyr% > -1) lai_%mn%_%lyr%b = lai_%mn%_%lyr% ; endif
     &end
  &end

  setwindow lai_01_1b
  setcell lai_01_1b

  lai_yr_y = 0.0

  &do mn  &list  01 02 03 04 05 06 07 08 09 10 11 12
    &do lyr &list  1 2 3
       lai_yr_z = lai_yr_y + lai_%mn%_%lyr%b
       kill lai_yr_y all
       rename lai_yr_z  lai_yr_y
    &end
  &end

  &if [exists lai_yr -grid] &then
    kill lai_yr all
  /* Averaging all the results, so divide by 36 (3 layers, 12 month)
  lai_yr = lai_yr_y / 36.0

  &if [exists tempg -grid] &then
    kill tempg all
  &if [exists tempg99 -grid] &then
    kill tempg99 all
  &if [exists lai_out -grid] &then
    kill lai_out all

  setcell 0.5
  setwindow c:\grange2\misc\rng_sage
  tempg99 =   lai_yr - \grange2\misc\tot_lai
  lai_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

  quit
```

```
w \GRange2
&type Done with Leaf Area Index



/*********************************************
/* ANNUAL EVAPOTRANSPIRATION
/*********************************************
/* Annual evapotranspiration downloaded from Oak Ridge project 10020.  2006 selected and months summed.  MM
/* per year.  G-Range produces CM per year
/* A high resolution global map for reference is at:
/* http://www.arcgis.com/apps/OnePane/main/index.html?appid=48268eba0f414713be00f75ac3289bb4
/* In generally good agreement now.
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output
annual_evapotranspiration.gof  C:\GRange2\Exp_Out\et  2004  2006  1

/* Only the last month is of interest.   This is an accumulation variable
w \Grange2\temp_ws
&if [exists et_12 -grid] &then
   kill et_12 all
asciigrid \GRange2\Exp_Out\et_2006_12_1.asc  et_12  float

grid

&if [exists et_yr -grid] &then
   kill et_yr
/* ET_YR is in CM, ET_ANNUAL is in MM
if (et_12 > -1) et_yr = et_12 * 10.0 ; endif

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists et_out -grid] &then
  kill et_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   et_yr - \grange2\misc\et_annual
et_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
```

```
&type Done with Annual Evapotranspiration


/**********************************************
/* SNOW WATER EQUIVALENT
/**********************************************
/* I'll use 2006 as a basis.  If it was an unusual year, it will be a problem, but the grand patterns should
/* be ok.
/* Snow water equivalent from the NSIDC center in Boulder, R.L. Armstrong.
/* http://nsidc.org/data/docs/daac/nsidc0271_ease_grid_swe_climatology.gd.html
/* A great deal of manipulation to put the data in a usable form (e.g., it was in polar coord.), but I think
/* it is ok.
/* Must bring in snow liquid
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  snow.gof
C:\GRange2\Exp_Out\snowd  2004  2006  1
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  snow_liquid.gof
C:\GRange2\Exp_Out\snowl  2004  2006  1

w \Grange2\temp_ws
&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
      &if [exists snowd_%mn% -grid] &then
        kill snowd_%mn% all
      asciigrid \GRange2\Exp_Out\snowd_2006_%mn%_1.asc  snowd_%mn%  float
      &if [exists snowl_%mn% -grid] &then
        kill snowl_%mn% all
      asciigrid \GRange2\Exp_Out\snowl_2006_%mn%_1.asc  snowl_%mn%  float
&end

grid

&do mn &list 01 02 03 04 05 06 07 08 09 10 11 12
     &if [exists snowd_%mn%b -grid] &then
        kill snowd_%mn%b
     if (snowd_%mn% > -1) snowd_%mn%b = snowd_%mn% ; endif
     &if [exists snowl_%mn%b -grid] &then
        kill snowl_%mn%b
     if (snowl_%mn% > -1) snowl_%mn%b = snowl_%mn% ; endif
&end

setwindow snowd_01b
setcell snowd_01b

snowd_yr_y = 0.0
snowl_yr_y = 0.0
```

```
/* Summing snow, then taking the average across months
&do mn  &list  01 02 03 04 05 06 07 08 09 10 11 12
     snowd_yr_z = snowd_yr_y + snowd_%mn%b
     kill snowd_yr_y all
     rename snowd_yr_z  snowd_yr_y

     snowl_yr_z = snowl_yr_y + snowl_%mn%b
     kill snowl_yr_y all
     rename snowl_yr_z  snowl_yr_y
&end

&if [exists snowd_yr -grid] &then
  kill snowd_yr all
&if [exists snowl_yr -grid] &then
  kill snowl_yr all
/* SNOWD_YR is in CM and SNOW_H2O_EQ is in MM
snowd_yr = snowd_yr_y * 10.0
snowl_yr = snowl_yr_y * 10.0

&if [exists tempg -grid] &then
  kill tempg all
&if [exists tempg99 -grid] &then
  kill tempg99 all
&if [exists snowd_out -grid] &then
  kill snowd_out all

setcell 0.5
setwindow c:\grange2\misc\rng_sage
tempg99 =   ( snowd_yr + snowl_yr ) - \grange2\misc\snow_h2o_eq                  /* Note the addition of the
two layers, snow (in water equiv.) and liquid in snow
snowd_out = zonalmean(\grange2\misc\sage_0p5, tempg99 )

quit

w \GRange2
&type Done with Snow Depth

w \GRange2\temp_ws
&fullscreen &nopaging

&sys del /Q Result.txt

&sys del /Q Avg.txt

grid
```

```
/*****************************************************************************************
&type Note: Values are being multipled by 1000 to avoid truncation of values to integers.   Divide results
by 1000.
/*****************************************************************************************

&if [ exists cn_rat1000 -grid ] &then
  kill cn_rat1000 all
&if [ exists decomp1000 -grid ] &then
  kill decomp1000 all
&if [ exists et1000 -grid ] &then
  kill et1000 all
&if [ exists totc1000 -grid ] &then
  kill totc1000 all
&if [ exists h2o1000 -grid ] &then
  kill h2o1000 all
&if [ exists lai1000 -grid ] &then
  kill lai1000 all
&if [ exists pet1000 -grid ] &then
  kill pet1000 all
&if [ exists snowd1000 -grid ] &then
  kill snowd1000 all
&if [ exists somtc1000 -grid ] &then
  kill somtc1000 all
&if [ exists stemp1000 -grid ] &then
  kill stemp1000 all
&if [ exists tprd1000 -grid ] &then
  kill tprd1000 all

setcell 0.5
setwindow c:\grange2\misc\rng_sage

/* NOTE ... the following uses a SAGE layer that has been trimmed to the current rangeland cells
cn_rat1000 = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, cn_rat_out * 1000. )
) )
decomp1000 = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, decomp_out * 1000. )
) )
et1000     = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, et_out * 1000. ) ) )
totc1000   = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, totc_out * 1000. ) )
)
h2o1000    = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, h2o_out * 1000. ) ) )
lai1000    = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, lai_out * 1000. ) ) )
pet1000    = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, pet_out * 1000. ) ) )
snowd1000  = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, snowd_out * 1000. ) )
)
```

```
somtc1000  = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, somtc_out * 1000. ) ) )
stemp1000  = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, stemp_out * 1000. ) ) )
tprd1000   = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, tprd_out * 1000. ) ) )

&if [ exists cn_rat_obs -grid ] &then
  kill cn_rat_obs all
&if [ exists decomp_obs -grid ] &then
  kill decomp_obs all
&if [ exists et_obs -grid ] &then
  kill et_obs all
&if [ exists totc_obs -grid ] &then
  kill totc_obs all
&if [ exists h2o_obs -grid ] &then
  kill h2o_obs all
&if [ exists lai_obs -grid ] &then
  kill lai_obs all
&if [ exists pet_obs -grid ] &then
  kill pet_obs all
&if [ exists snowd_obs -grid ] &then
  kill snowd_obs all
&if [ exists somtc_obs -grid ] &then
  kill somtc_obs all
&if [ exists stemp_obs -grid ] &then
  kill stemp_obs all
&if [ exists tprd_obs -grid ] &then
  kill tprd_obs all

/* NOTE ... the following uses a SAGE layer that has been trimmed to the current rangeland cells
cn_rat_obs =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage, \grange2\misc\cn_rat_0_30 * 1000. ) ) )
decomp_obs =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage, \grange2\century\grds\adefac * 1000. ) ) )
et_obs     =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage, \grange2\misc\et_annual * 1000. ) ) )
totc_obs   =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage, \grange2\misc\carbon_den * 100. * 1000. ) ) )             /* Special multipler to convert t C /ha to g/m2
h2o_obs    =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage, \grange2\century\grds\pah2o * 1000. ) ) )
lai_obs    =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage, \grange2\misc\tot_lai * 1000. ) ) )
pet_obs    =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage, \grange2\century\grds\pet * 1000. ) ) )
```

```
snowd_obs  =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage,
\grange2\misc\snow_h2o_eq * 1000. ) ) )
somtc_obs  =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage,
\grange2\century\grds\somtc * 1000. ) ) )
stemp_obs  =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage,
\grange2\century\grds\stemp * 1000. ) ) )
tprd_obs   =  combine ( \grange2\misc\rng_sage, int( zonalmean(\grange2\misc\rng_sage,
\grange2\century\grds\npp * 1000. ) ) )

quit

/* Get the current file name, which is based on a time stamp and correlates with the parameters stored in a
folder of the same n
/* This process will permanently associate the name with the output matrix
&sv fileunit = [ open ..\Current.txt openstatus -read ]
&sv line := [ read %fileunit% readstatus ]
&sv line = [ unquote %line% ]
&sv line = [ trim %line% -both ]
&sv closer = [ close %fileunit% ]

tables

select cn_rat1000.vat  ; unload cn_rat1000.txt columnar  temp.fmt  init
select decomp1000.vat  ; unload decomp1000.txt columnar  temp.fmt  init
select et1000.vat  ; unload et1000.txt columnar  temp.fmt  init
select totc1000.vat  ; unload totc1000.txt columnar  temp.fmt  init
select h2o1000.vat  ; unload h2o1000.txt columnar  temp.fmt  init
select lai1000.vat  ; unload lai1000.txt columnar  temp.fmt  init
select pet1000.vat  ; unload pet1000.txt columnar  temp.fmt  init
select snowd1000.vat  ; unload snowd1000.txt columnar  temp.fmt  init
select somtc1000.vat  ; unload somtc1000.txt columnar  temp.fmt  init
select stemp1000.vat  ; unload stemp1000.txt columnar  temp.fmt  init
select tprd1000.vat  ; unload tprd1000.txt columnar  temp.fmt  init

select cn_rat_obs.vat  ; unload cn_rat_obs.txt columnar  temp.fmt  init
select decomp_obs.vat  ; unload decomp_obs.txt columnar  temp.fmt  init
select et_obs.vat  ; unload et_obs.txt columnar  temp.fmt  init
select totc_obs.vat  ; unload totc_obs.txt columnar  temp.fmt  init
select h2o_obs.vat  ; unload h2o_obs.txt columnar  temp.fmt  init
select lai_obs.vat  ; unload lai_obs.txt columnar  temp.fmt  init
select pet_obs.vat  ; unload pet_obs.txt columnar  temp.fmt  init
select snowd_obs.vat  ; unload snowd_obs.txt columnar  temp.fmt  init
select somtc_obs.vat  ; unload somtc_obs.txt columnar  temp.fmt  init
select stemp_obs.vat  ; unload stemp_obs.txt columnar  temp.fmt  init
select tprd_obs.vat  ; unload tprd_obs.txt columnar  temp.fmt  init
```

```
quit

/* Need a single-line file to save the file name
&sys echo %line% > fit.txt

/* Divider all the results by 1000
&sys START /WAIT /NORMAL C:\GRange2\Divisor

&sys copy Results.txt  C:\GRange2\fitting\%line%\Result.txt

/*****************************
/*****************************
/* At this point in the TEMP_WS workspace.  Now incorporating the FACET materials.
/*****************************
/*****************************

/**********************************************
/* FACET COVER
/**********************************************
/* Comparing FACET change in cover through time.
/**********************************************
w \Grange2\Exporter
&sys cd \GRange2\Exporter
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  facet_cover.gof
C:\GRange2\Exp_Out\fac  1957  2006  3
&sys START /WAIT /NORMAL  \GRange2\Exporter\export_file C:\GRange\G_Range\Output  bare_cover.gof
C:\GRange2\Exp_Out\bare  1957  2006  1

w \Grange2\temp_ws
 &do lyr &list 1 2 3
  &do yr &list 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
    &if [exists fac_%yr%_%lyr% -grid] &then
      kill fac_%yr%_%lyr%
    asciigrid \GRange2\Exp_Out\fac_%yr%_01_%lyr%.asc  fac_%yr%_%lyr%  float
  &end
 &end

 &do yr &list 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
   &if [exists bare_%yr%_1 -grid] &then
     kill bare_%yr%_1
   asciigrid \GRange2\Exp_Out\bare_%yr%_01_1.asc  bare_%yr%_1  float
 &end

grid

&do lyr &list 1 2 3
```

```
 &do yr &list 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
   &if [exists fac_%yr%_%lyr%b -grid] &then
    kill fac_%yr%_%lyr%b all
   if (fac_%yr%_%lyr% > -1) fac_%yr%_%lyr%b = fac_%yr%_%lyr% ; endif
 &end
&end

 &do yr &list 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
   &if [exists bare_%yr%_1b -grid] &then
    kill bare_%yr%_1%b all
   if (bare_%yr%_1 > -1) bare_%yr%_1b = bare_%yr%_1 ; endif

   &if [exists fac_%yr%_c -grid] &then
    kill fac_%yr%_c all
   fac_%yr%_c = combine ( \grange2\misc\rng_sage, int(  zonalmean(\grange2\misc\rng_sage, fac_%yr%_1b *
1000. ) ), int(  zonalmean(\grange2\misc\rng_sage, fac_%yr%_2b * 1000. ) ), int(
zonalmean(\grange2\misc\rng_sage, fac_%yr%_3b * 1000. ) ),  int(  zonalmean(\grange2\misc\rng_sage,
bare_%yr%_1b * 1000. ) ) )

 &end

quit

/*****************************************************************************************
&type Note: Values are being multipled by 1000 to avoid truncation of values to integers.   Divide results
by 1000.
/*****************************************************************************************

setcell 0.5
setwindow c:\grange2\misc\rng_sage

/* Get the current file name, which is based on a time stamp and correlates with the parameters stored in a
folder of the same n
/* This process will permanently associate the name with the output matrix
&sv fileunit = [ open ..\Current.txt openstatus -read ]
&sv line := [ read %fileunit% readstatus ]
&sv line = [ unquote %line% ]
&sv line = [ trim %line% -both ]
&sv closer = [ close %fileunit% ]

tables

 &do yr &list 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005
    select fac_%yr%_c.vat  ; unload fac_%yr%_c.txt columnar  temp.fmt  init
 &end
```

```
quit

/* Divider all the results by 1000
&sys START /WAIT /NORMAL C:\GRange2\DivisorFacet

&sys copy Results.txt  C:\GRange2\fitting\%line%\Result_Fac.txt

w \GRange2

&type Done with Everything for Simulation %line%
```