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Developing and optimizing shrub parameters representing sagebrush (*Artemisia* spp.) ecosystems in the northern Great Basin using the Ecosystem Demography (EDv2.2) model

Karun Pandit et al.

Correspondence to: Karun Pandit (karunpandit@gmail.com)

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Table S1. Shrub (sagebrush) PFT parameters used to initialize ED2.

S.N.	Description of parameter	Value used for sagebrush PFT	Parameter name used in EDv2.2	Reasoning / References
1	DBH-leaf allometry intercept [kgC/plant]	2.582×10^{-6}	b1Bl_small	Based on our allometry equation
2	DBH-leaf allometry slope	2.746	b2Bl_small	Based on our allometry equation
3	DBH-stem allometry intercept [kg/plant]	5.709×10^{-8}	b1Bs_small	Based on our allometry equation
4	DBH-stem allometry slope	4.149	b2Bs_small	Based on our allometry equation
5	DBH-canopy area allometry intercept [m2 canopy / m2 ground]	6.35×10^{-5}	b1Ca	Based on our allometry equation
6	DBH-canopy allometry slope	2.18	b2Ca	Based on our allometry equation
7	Coefficient used to compute the crown length, which is then used to find the height of the bottom of the crown	1	b1Cl	Since shrub crown is close to ground set to 1 (Poorter et al., 2006)
8	Coefficient used to compute the crown length, which is then used to find the height of the bottom of the crown	1	b2Cl	Since shrub crown is close to ground set to 1 (Poorter et al., 2006)
9	DBH-height allometry intercept (m)	4.7562	b1Ht	Based on our allometry equation
10	DBH-height allometry slope	-0.002594	b2Ht	Based on our allometry equation
11	Root depth from DBH intercept (m)	-3.0, if allom = 0, -1.75, if allom >0	b1Rd	Based on Sturges (1977) and Tabler (1964)
12	Root depth from DBH slope	0.15, if allom =0, 0.10, if allom >0	b2Rd	Based on Sturges (1977) and Tabler (1964)
13	DBH-volume intercept	2.035×10^{-5}	b1Vol	Based on allometry equation
14	DBH-volume slope	2.314	b2Vol	Based on allometry equation
15	Wood area index intercept	0.0192 * 0.5	b1WAI	Adopted default for broadleaf in EDv2.2
16	Wood area index slope	1.4648	b2WAI	Value of broadleaf divided by 1.43 based on Ahrends et al. 2009
17	Factor indicating degree of clumpiness of leaves and shoots ranging between 0 and 1	0.84	clumping_factor	We used default for hardwood PFTs in EDv2.2

18	Intercept of the Ball/Berry stomatal conductance relationship [µmol/m^2/s]	1000	cuticular_cond	We used default in EDv2.2 for conifer PFTs
19	The transpiration control in gsw	0.016	D0	Default for all other PFTs in EDv2.2
20	Dark respiration factor (gamma). The rate of dark (i.e., leaf) respiration. Dimensionless because it is relative to Vm0.	0.0145	dark_respiration_factor	Default for most of the PFTs in EDv2.2
21	Fraction of litter that goes into labile (fast) carbon pool.	0.79	f_labile	Default for trees in EDv2.2
22	Fire survivorship fraction for trees with heights greater than treefall_hite_threshold	0	fire_s_gtht	Default for all PFTs in EDv2.2
23	Fire survivorship fraction for trees with heights less than treefall_hite_threshold	0	fire_s_ltht	Default for all PFTs in EDv2.2
24	Mortality due to frost. Determines how rapidly trees die if it is too cold for them [1/years]	3	frost_mort	Default for all PFTs in EDv2.2
25	Growth respiration factor, used in growth respiration = (growth_resp_factor) * (P - Rl - Rr)	0.333	growth_resp_factor	Based on Paembonan et al. 1992
26	Maximum height of an individual [m]	2.5	hgt_max	Based on field observation
27	Minimum height of an individual [m]	0.25	hgt_min	Based on field observation
28	Reference height for diameter/height allometry [m]	0	hgt_ref	Used only for trees.
29	Fraction of vertical branches (range from -1 to 1)	0.5	horiz_branch	Set to make random arrangement of branches
30	Initial plant density in a near-bare-ground run [plant/m²]	0.1	init_density	same as trees
31	Emissivity on thermal infrared	9.70×10^{-1}	leaf_emiss_tir	Hipps, 1989; default for conifers in EDv2.2
32	Leaf reflectance in near infrared spectrum (NIR)	5.77×10^{-1}	leaf_reflect_nir	Based on Qi et al. 2014
33	Leaf reflectance in visible spectrum (PAR)	3.0×10^{-1}	leaf_reflect_vis	Based on Qi et al. 2014
34	Leaf transmittance in infrared spectrum (NIR)	2.48×10^{-1}	leaf_trans_nir	Default for trees in EDv2.2
35	Leaf transmittance in visible spectrum (PAR)	1.6×10^{-1}	leaf_trans_vis	Default for trees in EDv2.2
36	Leaf turn over rate (the inverse of leaf life span) [1/year]	1	leaf_turnover_rate	Based on Miller and Shultz, 1987
37	Leaf width [m]	0.05	leaf_width	Default for conifers in EDv2.2

38	Adjustment to mortality due to low carbon balance for grasses and tropical plants	0	mort0	Default for temperate trees in EDv2.2
39	Parameter controlling the time scale at which plants die out of carbon suffer mortality [1/years]	1	mort1	Default for temperate trees in EDv2.2
40	Parameter used in calculation of mortality rates due to negative C balance	20	mort2	Default for temperate trees in EDv2.2
41	Controls the density-independent mortality rate due to ageing [1/years]	0.001	mort3	Lower value chosen compared to grasses (0.066, from EDv2.2) and temperate trees (0.002 to 0.006) (Medvigy et al. 2009)
42	Fraction of seed dispersal that is grid cell wide	0.325	nonlocal_dispersal	Set this similar to old growth temperate tree in EDv2.2
43	Leaf orientation, 0=leaves are randomly oriented; 1=all leaves are perfectly horizontal; 2=all leaves are perfectly vertical.	0	orient_factor	We used default value for trees in EDv2.2
44	Phenology, 0=evergreen; 1=drought deciduous; 2=cold deciduous; 3=light controlled; 4=drought deciduous based on 10 day average	0	phenology	Based on expert opinion
45	Minimum temperature below which mortality rapidly increases	-80	plant_min_temp	Default form other PFTs EDv2.2
46	Ratio between fine roots and leaves [kg fine roots/kg leaves]	3.2	q-ratio	Poorter et al. 2012, Cleary et al. 2010
47	Efficiency of using PAR to fix CO2 [mol_CO2/Einstein]	0.08	quantum_efficiency	We used default for all C3 plants in EDv2.2
48	Fraction of (positive) carbon balance devoted to reproduction	0.3	r_fract	Default from EDv2.2, as other PFTs
49	Minimum height plants need to attain before allocating reproduction	0.25	repro_min_h	Field observation / Expert opinion
50	Wood density [g/cm³].	0	rho	Not used for Sagebrush PFT
51	Factor denoting contribution of roots to respiration [umol_CO2/kg_fine_roots/second]	0.28	root_respiration_factor	Default for all PFTs in EDv2.2
52	Fine root turnover rate (the inverse of fine root life span) [1/year]	0.33	root_turnover_rate	Inferred from different studies; 0.16-0.54 (Li et al. 2009); 0.34 (Gill and Jackson 2000)

53	Fraction of seedlings that suffer mortality without becoming a recruit	0.95	seedling_mortality	Default value in EDv2.2
54	Specific leaf area [m² leaf / kg C]	4.5	SLA	Based on Olsoy et al (2016)
55	Storage fraction	0	st_fract	Default from EDv2.2, as other PFTs
56	Slope of the Ball/Berry stomatal conductance-photosynthesis relationship, aka M factor.	7	stomatal_slope	Default in EDv2.2 for temperate and conifers
57	Turnover rate of plant storage pools [1/year]	0.6243	storage_turnover_rate	Same as for other hardwood PFTs (Medvigy et al, 2009)
58	Survivorship fraction for trees with heights greater than treefall height threshold. Used in management/disturbance strategies.	0	treefall_s_gtht	Default in EDv2.2
59	Survivorship fraction for trees with heights less than treefall height threshold. Used in management/disturbance strategies.	0.1	treefall_s_ltht	Default in EDv2.2
60	Temperature above which leaf metabolic activity begins to rapidly decline [°C]	45	Vm_high_temp	We used default for C3 plants in EDv2.2
61	Temperature below which leaf metabolic activity begins to rapidly decline [°C]	4.7137	Vm_low_temp	We used default for C3 plants in EDv2.2
62	Maximum photosynthetic capacity at a 15°C reference temperature [µmol/m2/s]	16.5	Vm0	Based on average of range cited in Comstock & Ehlenger (1992)
63	Water dry ratio for leaves	2.5	wat_dry_ratio_grn	Default from EDv2.2
64	Water conductance (m2/s/kgC root)	1.9 X 10-5	water_conductance	We used default for trees in EDv2.2
65	Emissivity on thermal infrared	9.00×10^{-1}	wood_emiss_tir	Default value for trees in EDv2.2
66	Wood reflectance in near infrared spectrum (NIR)	2.50×10^{-1}	wood_reflect_nir	Default for all other PFTs in EDv2.2
67	Wood reflectance in visible spectrum (PAR)	1.10×10^{-1}	wood_reflect_vis	Default for woody PFTs in EDv2.2
68	Wood transmittance in infrared spectrum (NIR)	1.00×10^{-1}	wood_trans_nir	Default for trees in EDv2.2
69	Wood transmittance in visible spectrum (PAR)	1.00×10^{-1}	wood_trans_vis	Default for trees in EDv2.2

Figure S1. Relationship between predicted and observed sagebrush height; (a) fitted line for observed vs predicted sagebrush height, (b) standardized residuals. Data provided by Qi et al., (2018).

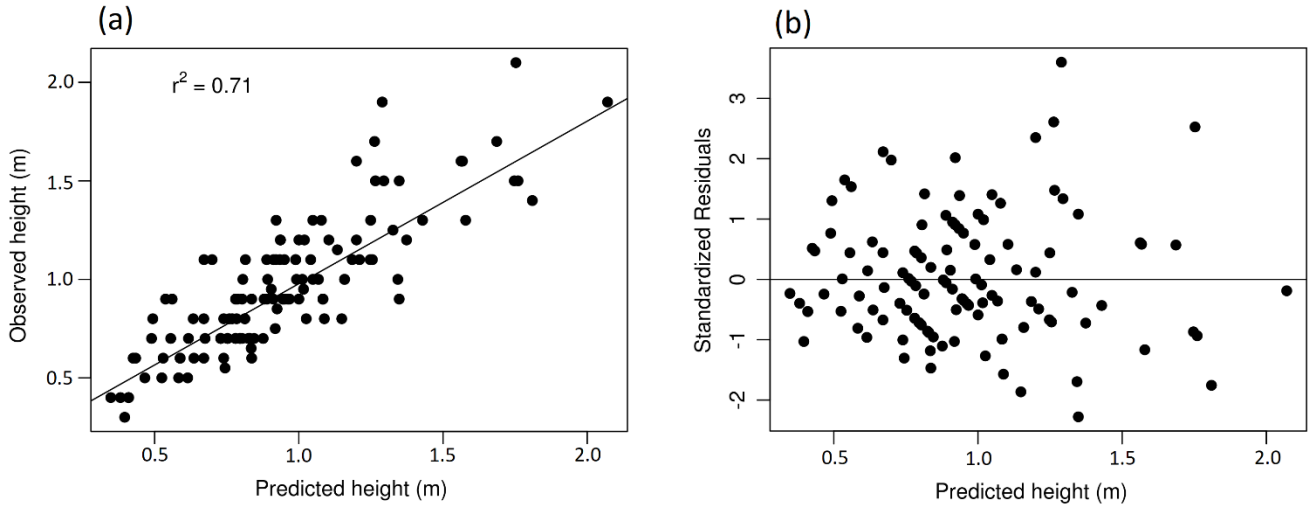

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Table S2. Predicted GPP, Bias, Standard Deviation, NSE (Nash-Sutcliffe efficiency), and RMSE of ten best simulations (based on final year of simulation) for LS and WBS sites based on GPP observations from respective sites.

a. Ten best simulations for LS site

S.N.	V_{m0} ($\mu molm^{-2}s^{-1}$)	SLA (m^2kg^{-1})	Stomatal slope	Fine root turnover rate (a^{-1})	Q-ratio	Calibration					Validation				
						Estimated mean annual GPP ($kgC/m^2/yr$)	Bias ($kgC/m^2/yr$)	St Dev ($kgC/m^2/yr$)	NSE	RMSE ($kgC/m^2/yr$)	Estimated mean annual GPP ($kgC/m^2/yr$)	Bias ($kgC/m^2/yr$)	St Dev ($kgC/m^2/yr$)	NSE	RMSE ($kgC/m^2/yr$)
1	19	7.5	9	0.22	3.2	0.476	-0.137	0.211	0.277	0.456	0.298	-0.252	0.312	0.069	0.554
2	19	7.5	9	0.11	1.8	0.425	-0.188	0.217	0.273	0.457	0.255	-0.295	0.274	0.032	0.565
4	19	7.5	9	0.22	1.8	0.425	-0.188	0.212	0.271	0.458	0.252	-0.298	0.267	0.035	0.564
3	16.5	9	10	0.33	3.2	0.401	-0.212	0.232	0.270	0.458	0.243	-0.307	0.27	-0.014	0.579
5	19	7.5	9	0.11	3.2	0.423	-0.191	0.211	0.266	0.459	0.256	-0.294	0.275	0.025	0.567
6	21.5	7.5	10	0.33	0.4	0.386	-0.227	0.252	0.251	0.464	0.241	-0.309	0.268	-0.016	0.579
7	21.5	9	7	0.11	3.2	0.520	-0.093	0.222	0.249	0.464	0.306	-0.244	0.338	0.073	0.549
8	19	9	8	0.22	3.2	0.414	-0.199	0.194	0.234	0.469	0.254	-0.296	0.271	0.034	0.565
9	16.5	9	8	0.11	0.4	0.448	-0.165	0.183	0.230	0.470	0.278	-0.272	0.235	0.065	0.555
10	19	7.5	8	0.11	0.4	0.440	-0.173	0.184	0.216	0.475	0.279	-0.271	0.228	0.052	0.559
Mean	19	8.1	8.7	0.19	2.08	0.438	-0.172	0.203	0.281	0.455	0.272	-0.278	0.269	0.053	0.559

Note: we used Nash-Sutcliffe Efficiency (NSE) skill score (Nash and Sutcliffe, 1970) to rank the results from simulations using equation below,

$$NSE = 1 - \frac{\sum_{i=1}^{n} (O_i - P_i)^2}{\sum_{i=1}^{n} (O_i - \underline{O})^2},$$

where, where, O_i is observation, P_i is predicted value, $\underline{O}$ is mean of observation, and *n* is number of observations

b. Ten best simulations for WBS site

S.N.	V_{m0} ($\mu molm^{-2}s^{-1}$)	SLA (m^2kg^{-1})	Stomatal slope	Fine root turnover rate (a^{-1})	Q-ratio	Calibration					Validation				
						Estimated mean annual GPP ($kgC/m^2/yr$)	Bias ($kgC/m^2/yr$)	St Dev ($kgC/m^2/yr$)	NSE	RMSE ($kgC/m^2/yr$)	Estimated mean annual GPP ($kgC/m^2/yr$)	Bias ($kgC/m^2/yr$)	St Dev ($kgC/m^2/yr$)	NSE	RMSE ($kgC/m^2/yr$)
1	19	7.5	9	0.33	1.8	0.321	-0.028	0.195	0.452	0.213	0.208	-0.252	0.246	0.079	0.411
2	19	7.5	9	0.22	0.4	0.32	-0.029	0.213	0.446	0.214	0.201	-0.259	0.233	0.06	0.415
4	19	9	9	0.22	0.4	0.328	-0.021	0.206	0.441	0.213	0.171	-0.289	0.211	-0.028	0.434
3	19	9	10	0.33	0.4	0.303	-0.046	0.209	0.439	0.216	0.176	-0.284	0.195	-0.011	0.429
5	19	7.5	9	0.11	3.2	0.321	-0.028	0.203	0.435	0.217	0.204	-0.256	0.238	0.046	0.418
6	16.5	7.5	9	0.22	1.8	0.321	-0.028	0.169	0.426	0.218	0.193	-0.267	0.214	0.020	0.423
7	19	7.5	9	0.11	1.8	0.311	-0.038	0.229	0.425	0.218	0.203	-0.257	0.24	0.069	0.413
8	19	7.5	9	0.22	3.2	0.312	-0.037	0.174	0.411	0.221	0.199	-0.261	0.223	0.022	0.423
9	16.5	9	9	0.22	1.8	0.333	-0.016	0.237	0.408	0.222	0.199	-0.261	0.226	0.045	0.418
10	16.5	9	9	0.33	3.2	0.319	-0.03	0.174	0.405	0.222	0.200	-0.26	0.223	0.019	0.424
Mean	18.25	8.1	9.1	0.23	1.8	0.319	-0.03	0.197	0.429	0.217	0.195	-0.265	0.224	0.036	0.420

Figure S2. Mean monthly GPP estimation from the ten best simulations (based on NSE) for each of EC stations; (a) LS and (b) WBS, for 15 years.

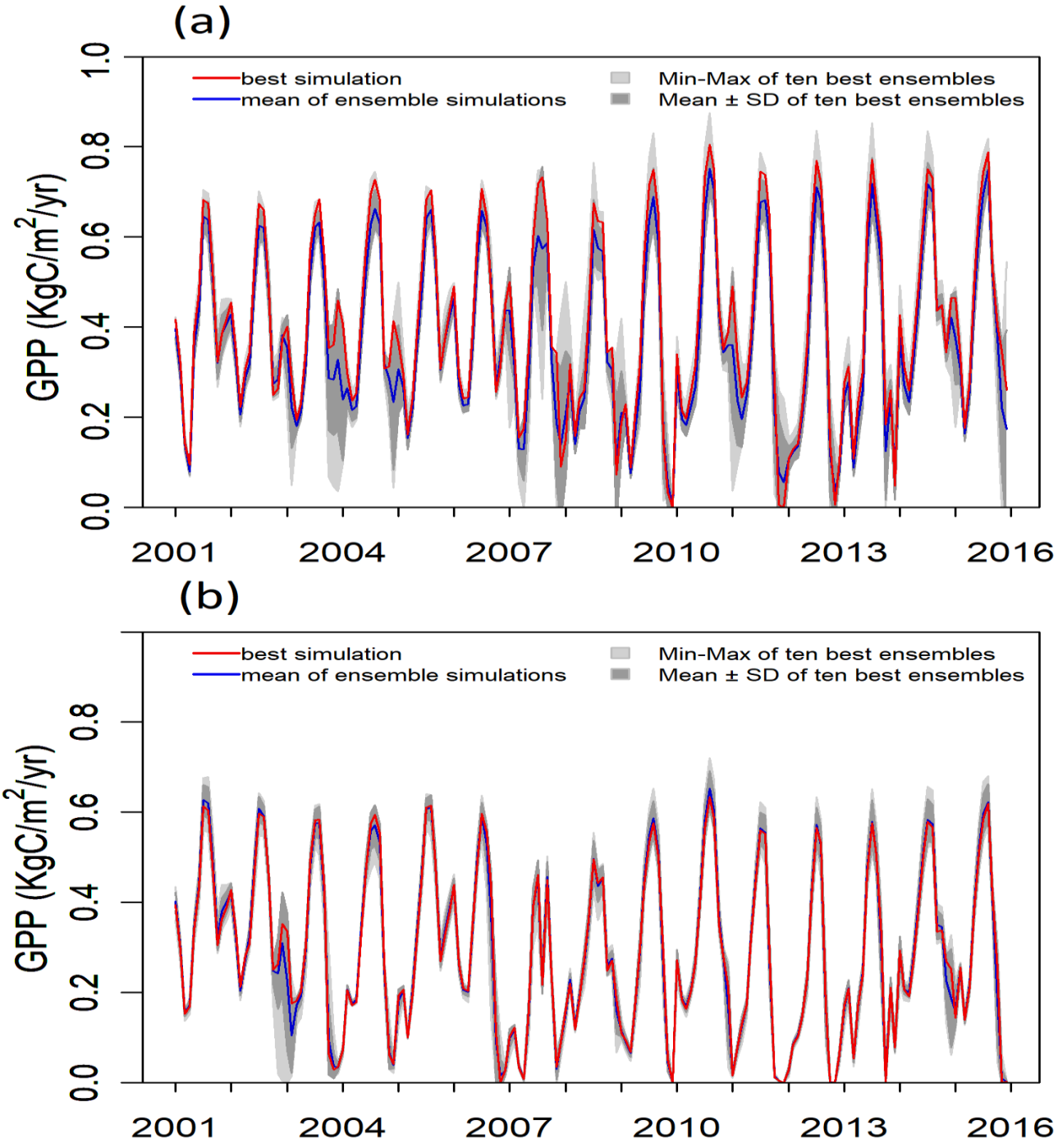
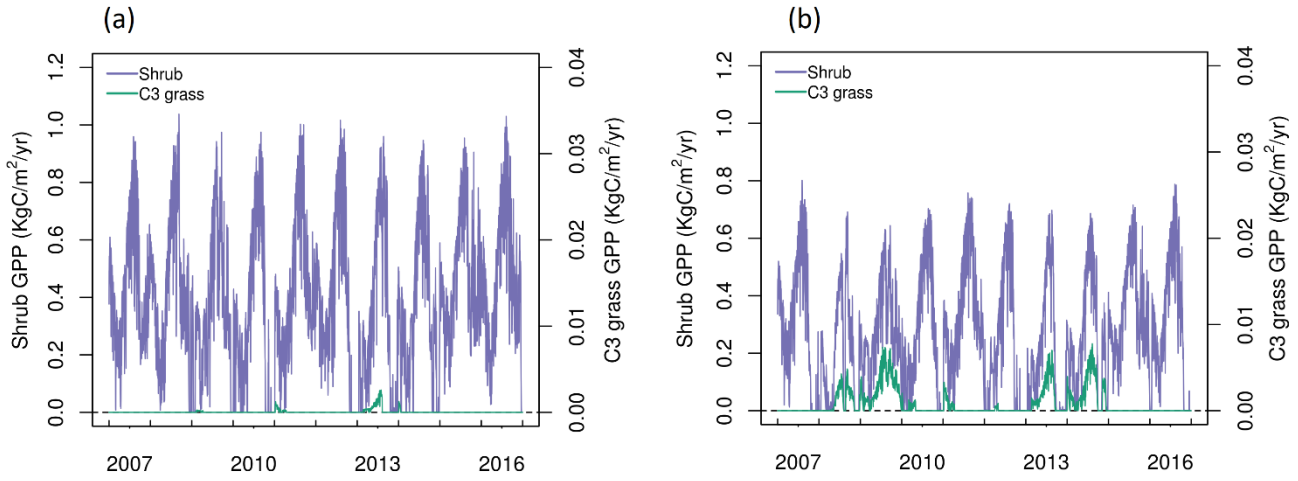


Fig S3. Daily GPP simulated by best cases for (a) LS and (b) WBS sites, dissected into shrub and C3 grass PFTs for final 10 simulation years. C3 grass was plotted at narrower GPP range to make it visible in the figure.



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