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Supplement of

Modeling the effects of alternative crop–livestock management scenarios on important ecosystem services for smallholder farming from a landscape perspective

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Supplementary tables and figures referenced in the publication.

Table S1. APSIM evaluations specific to aspects relevant to our study. Full references are included in the reference list of the main manuscript.

Topic	Reference
Cowpea	Ncube et al. (2009); Sennhenn et al. (2017)
Groundnut	Hoffmann et al. (2018b)
Maize	Rurinda et al. (2015)
Mucuna	Robertson et al. (2005)
Pearl millet	Akponikpè et al. (2010)
Soybean	Mabapa et al. (2010)
Phosphorus limitations	Delve et al. (2009)
Crop responses to manure application	Probert et al. (2005)
Intercropping systems in southern Africa	Chimonyo et al. (2016)
Residual effects in rotation	Masikati et al. (2014); Ncube et al. (2009); Robertson et al. (2005)

Table S2. Average annual per-hectare values and standard deviation across hectares for the years with lowest (left value) and highest (right value) mean value. a) average annual grass biomass demand per hectare; b) average number of days a hectare was frequented by grazers; c) grass biomass removed by grazers on a grazing day; d) annual grazed grass biomass per hectare. GL: grassland; WL: woodland; RO: rangeland-only scenario; RC: rangeland+cropland scenario.

Site/Area	GL hectares RO	GL hectares RC	WL hectares RO	WL hectares RC
		a) Annual biomass demand [t ha^{-1} yr^{-1}]		
Selwana	0.29±0.12 to 0.34±0.13	0.07±0.09 to 0.19±0.11	0.10±0.04 to 0.11±0.05	0.03±0.03 to 0.07±0.03
Gabaza A1	0.47±0.16 to 0.63±0.16	0.18±0.10 to 0.33±0.11	0.18±0.08 to 0.24±0.09	0.08±0.04 to 0.13±0.06
Gabaza A2	0.52±0.17 to 0.57±0.17	0.22±0.11 to 0.34±0.09	0.19±0.07 to 0.22±0.06	0.08±0.05 to 0.14±0.04
Gabaza A3	0.52±0.16 to 0.60±0.18	0.20±0.14 to 0.34±0.14	0.18±0.7 to 0.22±0.07	0.06±0.05 to 0.12±0.04
Gabaza A4	0.50±0.15 to 0.59±0.23	0.13±0.13 to 0.31±0.10	0.17±0.07 to 0.21±0.08	0.05±0.05 to 0.11±0.04
		b) Grazing days [ha^{-1} yr^{-1}]		
Selwana	8.3±2.6 to 9.2±3.1	2.1±2.1 tp 5.5±1.5	8.2±3.3 to 9.3±3.1	2.3±1.9 to 5.6±1.5
Gabaza A1	7.4±1.9 to 10.6±1.0	2.9±1.2 to 5.8±1.3	7.5±2.0 to 10.5±1.5	3.0±1.3 to 5.6±1.3
Gabaza A2	11.8±3.2 to 13.9±3.2	5.0±2.0 to 8.0±2.1	11.3±2.9 to 13.7±3.1	5.5±2.3 to 8.1±2.4
Gabaza A3	11.9±3.1 to 13.9±3.2	5.2±2.3 to 8.1±2.3	11.8±3.5 to 13.9±3.1	4.9±2.5 to 7.5±2.2
Gabaza A4	11.1±3.9 to 13.2±3.3	2.6±2.3 to 7.4±1.7	12.0±3.5 to 13.5±3.8	3.1±2.2 to 7.4±2.0
		c) Daily removed biomass [kg ha^{-1} day^{-1}]		
Selwana	29.5±24.3 to 36.7±28.8	29.8±27.3 to 34.2±25.7	11.2±9.1 to 12.4±9.8	10.9±10.7 to 13.0±8.4
Gabaza A1	38.7±28.7 to 73.8±49.1	44.7±28.3 to 64.4 ±39.4	18.7±12.9 to 28.5±19.9	20.5±16.2 to 32.6±15.0
Gabaza A2	31.2±29.1 to 45.6±36.0	37.6±27.0 to 43.7±37.2	13.5±11.9 to 17.4±13.2	13.3±11.9 to 16.9±10.3
Gabaza A3	38.0±30.5 to 44.5±27.9	30.4±25.5 to 45.4±26.4	13.9±11.7 to 17.0±14.2	12.4±9.9 to 18.1±8.8
Gabaza A4	31.0±28.1 to 42.5±38.2	29.6±30.8 to 46.2±26.5	12.4±10.9 to 16.3±13.1	12.5±13.2 to 16.5±10.6
		d) Annual removed biomass [t ha^{-1} yr^{-1}]		
Selwana	0.26±0.11 to 0.34±0.13	0.07±0.08 to 0.18±0.06	0.10±0.04 to 0.11±0.05	0.03±0.3 to 0.07±0.02
Gabaza A1	0.37±0.19 to 0.63±0.16	0.18±0.10 to 0.33±0.11	0.18±0.08 to 0.24±0.09	0.08±0.04 to 0.13±0.06
Gabaza A2	0.39±0.17 to 0.57±0.17	0.22±0.12 to 0.33±0.09	0.17±0.06 to 0.22±0.06	0.08±0.05 to 0.14±0.04
Gabaza A3	0.46±0.19 to 0.60±0.18	0.19±0.11 to 0.32±0.12	0.18±0.06 to 0.22±0.07	0.06±0.05 to 0.12±0.03
Gabaza A4	0.38±0.17 to 0.53±0.22	0.11±0.17 to 0.30±1.0	0.15±0.06 to 0.20±0.07	0.05±0.04 to 0.10±0.05

Table S3. Mean and standard deviation of annual grass layer GPP across simulated hectares for the years with lowest (left value) and highest (right value) mean value. GL: grassland; WL: woodland; CO: control scenario; RO: rangeland-only scenario; RC: rangeland+cropland scenario.

Site/Area	GL hectares CO	GL hectares RO	GL hectares RC
Selwana	3.13±1.45 to 11.18±4.09	3.11±1.38 to 11.05±4.07	3.14±1.68 to 8.18±2.55
Gabaza A1	3.58±2.24 to 15.79±6.53	3.36±1.92 to 15.78±6.55	2.97±4.41 to 8.93±3.90
Gabaza A2	3.71±1.89 to 13.58±4.39	4.06±2.14 to 13.65±4.52	3.91±2.71 to 8.20±3.36
Gabaza A3	3.56±1.88 to 14.25±3.74	3.64±1.88 to 14.21±3.77	3.59±3.13 to 8.37±3.92
Gabaza A4	3.95±2.32 to 14.54±5.18	3.88±2.35 to 14.48±5.26	3.98±3.38 to 8.79±3.84
Site/Area	WL hectares CO	WL hectares RO	WL hectares RC
Selwana	1.15±0.60 to 3.64±1.71	1.15±0.52 to 3.66±1.67	1.12±1.40 to 2.75±1.41
Gabaza A1	1.52±0.58 to 4.70±1.63	1.69±0.58 to 4.70±1.63	1.55±1.31 to 4.05±1.00
Gabaza A2	1.45±0.56 to 4.44 to 1.30	1.51±0.62 to 4.42±1.29	1.52±0.86 to 3.83±0.87
Gabaza A3	1.30±0.65 to 4.16±1.60	1.41±0.60 to 4.19±1.60	1.31±0.99 to 3.45±0.97
Gabaza A4	1.47±0.73 to 4.34±1.69	1.48±0.56 to 4.38±1.69	1.48±1.29 to 3.68±1.09

Table S4. Mean and standard deviation of grass layer NPP across simulated hectares for the years with lowest (left value) and highest (right value) mean value. GL: grassland; WL: woodland; CO: control scenario; RO: rangeland-only scenario; RC: rangeland+cropland scenario.

Site/Area	GL hectares CO	GL hectares RO	GL hectares RC
Selwana	1.24±0.46 to 6.02±2.25	1.26±0.44 to 5.97±2.26	1.34±0.87 to 4.33±0.73
Gabaza A1	1.65±1.19 to 8.71±3.79	1.58±0.97 to 8.77±3.79	1.78±2.16 to 4.78±2.42
Gabaza A2	1.53±0.82 to 7.35±2.58	1.68±0.89 to 7.44±2.65	1.50±1.89 to 4.45±1.95
Gabaza A3	1.44±0.64 to 7.79±2.32	1.53±0.65 to 7.82±2.37	1.52±1.89 to 4.60±2.38
Gabaza A4	1.52±1.05 to 7.92±3.16	1.60±1.03 to 7.91±3.21	1.58±2.10 to 4.75±2.28
Site/Area	WL hectares CO	WL hectares RO	WL hectares RC
Selwana	0.40±0.26 to 1.94±0.93	0.42±0.21 to 1.97±0.91	0.41±0.76 to 1.47±0.73
Gabaza A1	0.55±0.24 to 2.59±0.91	0.67±0.24 to 2.62±0.90	0.58±0.72 to 2.20±0.58
Gabaza A2	0.55±0.27 to 2.44±0.75	0.63±0.27 to 2.45±0.74	0.60±0.58 to 2.09±0.49
Gabaza A3	0.48±0.25 to 2.28±0.88	0.54±0.26 to 2.32±0.88	0.51±0.67 to 1.89±0.55
Gabaza A4	0.55±0.27 to 2.39±0.94	0.56±0.26 to 2.42±0.94	0.56±0.69 to 2.01±0.61

Table S5. Average and standard deviations of annual grass layer GPP per unit living biomass across simulated hectares for the years with lowest (left value) and highest (right value) mean value. GL: grassland; WL: woodland; CO.: control scenario; RO: rangeland-only scenario; RC: cropland+rangeland scenario.

Site/Area	GL hectares CO	GL hectares RO	GL hectares RC
Selwana	8.42±0.77 to 12.53 ±0.69	8.42±0.64 to 12.94 ±0.84	8.33±1.41 to 12.75±0.68
Gabaza A1	7.37±0.99 to 12.82±0.78	7.77±1.40 to 13.52±1.35	7.59±1.11 to 12.44±1.29
Gabaza A2	7.38±0.98 to 12.37±1.41	7.53±1.10 to 12.93±1.49	7.56±1.19 to 12.30±1.11
Gabaza A3	7.37±1.03 to 12.69±0.95	7.49±1.11 to 12.72±1.23	7.36±1.24 to 13.01±1.22
Gabaza A4	7.32±0.84 to 12.66±1.17	7.55±1.15 to 13.23±1.25	7.44±1.22 to 13.01±1.22
Site/Area	WL hectares CO	WL hectares RO / WL hectares RC	
Selwana	8.51±0.50 to 12.31±0.75	8.74±0.64 to 12.73±0.99	8.67±1.13 to 12.44±0.59
Gabaza A1	8.17±0.54 to 12.49±0.97	8.22±0.53 to 12.40±0.99	8.13±0.85 to 12.35±0.46
Gabaza A2	8.22±0.51 to 12.33±0.85	8.37±0.55 to 13.06±1.00	8.22±0.54 to 12.23±0.54
Gabaza A3	8.18±0.66 to 12.53±0.96	8.09±0.60 to 12.37±0.95	8.22±1.01 to 12.67±0.71
Gabaza A4	8.23±0.63 to 12.28±0.78	8.52±0.82 to 13.32±1.44	8.44±0.69 to 12.66±0.76

Table S6. Average and standard deviations of annual grass layer NPP per unit living biomass across simulated hectares for the years with lowest (left value) and highest (right value) mean value. GL: grassland; WL: woodland; CO: control scenario; RO: rangeland-only scenario; RC: rangeland+cropland scenario.

Site/Area	GL hectares CO	GL hectares RO	GL hectares RC
Selwana	2.85±0.89 to 6.74±0.63	3.19±3.25 to 7.19±0.57	3.11±0.68 to 6.88±2.77
Gabaza A1	2.94±0.67 to 7.48±0.68	2.98±0.78 to 7.98±1.05	3.00±1.18 to 7.13±1.00
Gabaza A2	2.62±0.74 to 6.90±0.96	2.53±2.31 to 7.39±1.31	2.62±0.78 to 6.96±1.16
Gabaza A3	2.27±2.73 to 7.16±1.08	2.64±1.73 to 7.31±1.30	2.51±0.73 to 7.35±1.08
Gabaza A4	2.39±1.00 to 7.23±1.05	2.60±1.39 to 7.59±1.07	2.49±0.70 to 7.38±3.01
Site/Area	WL hectares CO	WL hectares RO	WL hectares RC
Selwana	3.37±0.75 to 6.55±1.96	3.67±0.75 to 7.09±0.73	3.58±0.64 to 6.80±0.75
Gabaza A1	3.23±0.77 to 7.25±0.73	3.62±0.64 to 7.29±0.76	3.20±0.52 to 7-16±1.44
Gabaza A2	3.51±0.67 to 7.20±0.71	3.72±0.64 to 7.70±0.80	2.97±0.39 to 7.10±1.81
Gabaza A3	3.35±0.81 to 7.21±1.10	3.49±0.78 to 7.21±0.68	3.44±0.45 to 7.48±0.78
Gabaza A4	3.48±0.73 to 7.14±0.67	3.75±0.82 to 7.87±0.86	3.64±0.47 to 7.47±0.79

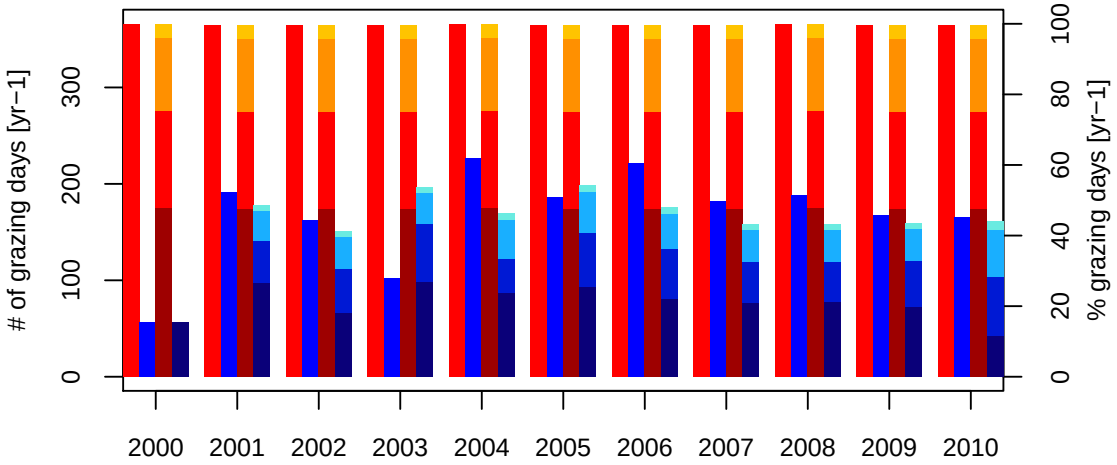

Figure S1. Total number of days spent on rangeland in each year (left y-axis) and as proportion of the number of days within a year (right y-axis). Red color hues indicate RO-scenario, blue color hues RC-scenario. The left two bars for each year are for Selwana, the right two bars for Gabaza with sub-divisioning according to sub-areas.

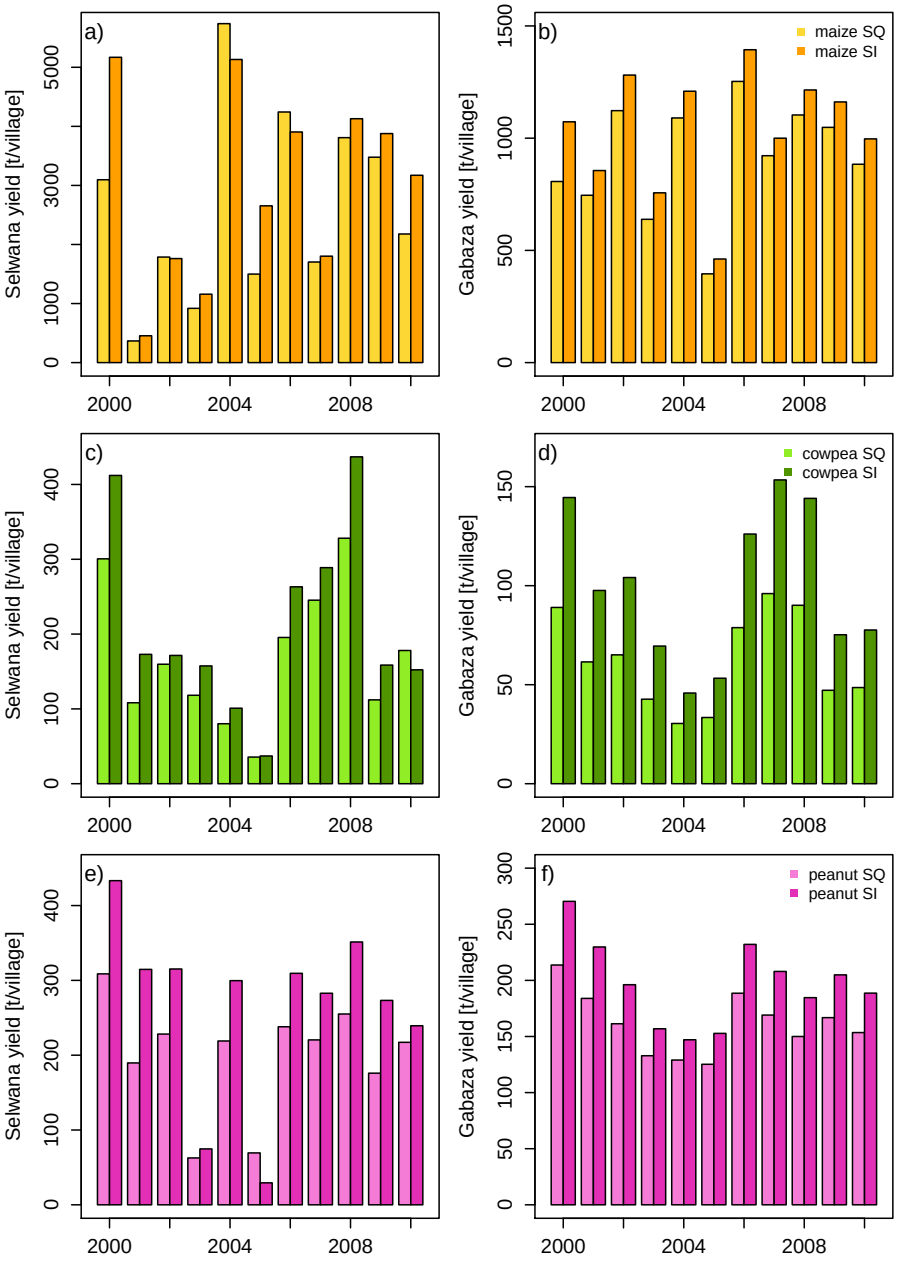

Figure S2. Total yields per village for the three crops maize (panel a, b), cowpea (panel c, d) and peanut (panel e, f) under SQ and SI cropland management.

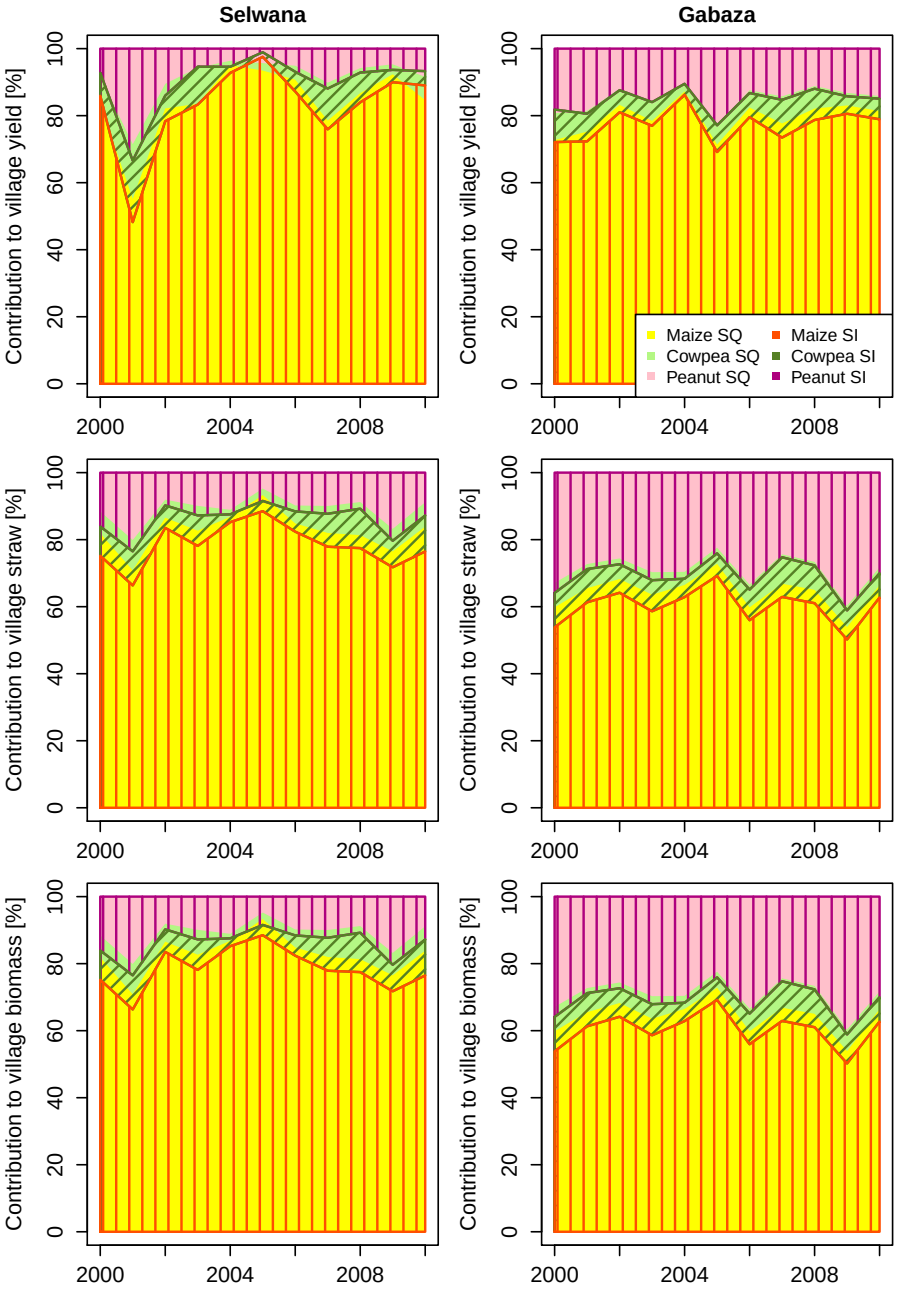

Figure S3. Relative contribution of each crop type to the village total yield, quantity of straw, and total crop biomass (yield+straw). The left column shows the time series for Selwana, the right column the time series for Gabaza. Solid colors indicate contributions to the village-totals for the SQ-scenario, the hatched colors show the contributions in case of the SI-scenario.

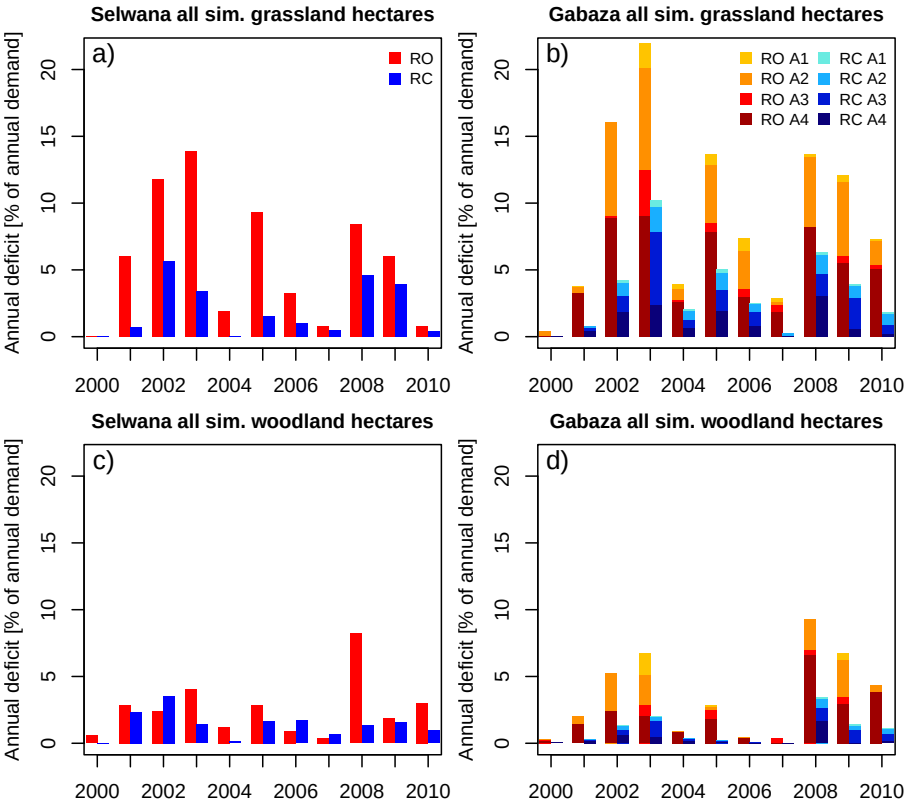

Figure S4. Annual deficit across all simulated hectares per site relative to annual demand across all simulated hectares per site. Panel a) shows relative deficits across all simulated grassland hectares at Selwana, panel b) shows relative deficits for grassland hectares at Gabaza. Panels c) and d) show relative deficits across all woodland hectares for Selwana and Gabaza, respectively. Subdivisions of bars in panel b) and d) indicate the relative contribution of each sub-area to the site-scale annual deficit.

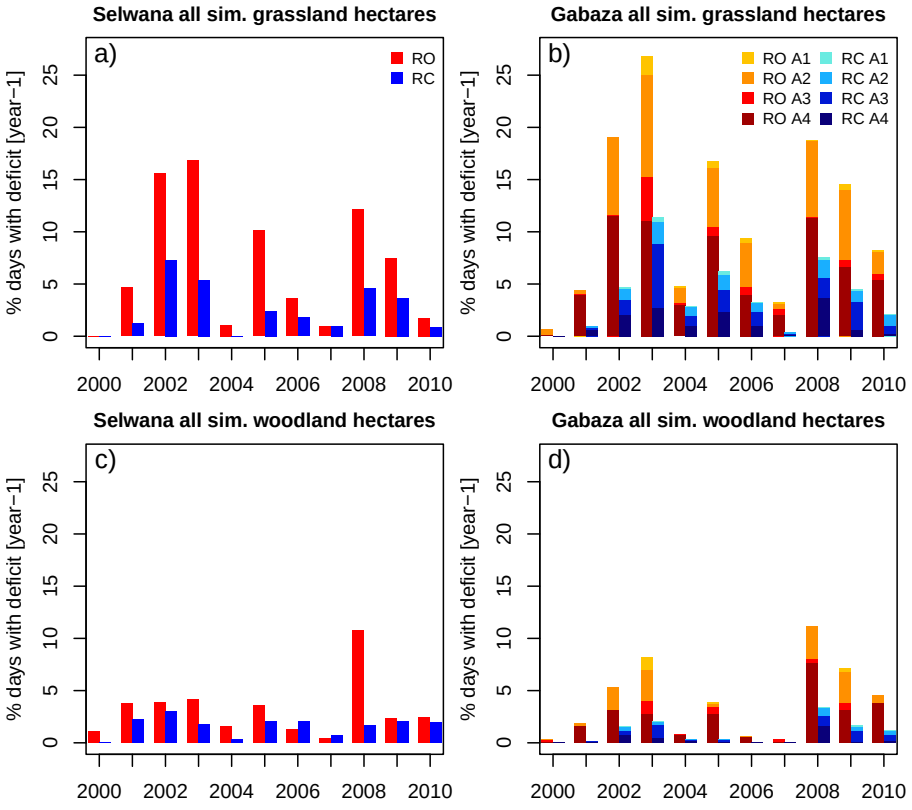

Figure S5. Percentage of grazing days integrated across all simulated hectares that had a deficit, relative to the total grazing days within a year. Panel a) shows percentage of grazing days with deficit across all simulated grassland hectares for Selwana, panel b) shows percentage of days with deficit across all grassland hectares for Gabaza. Panel c) and d) show the same for woodland hectares, respectively. Subdivisions of bars in panel b) and d) indicate the relative contribution of each sub-area to the site-scale percentage.

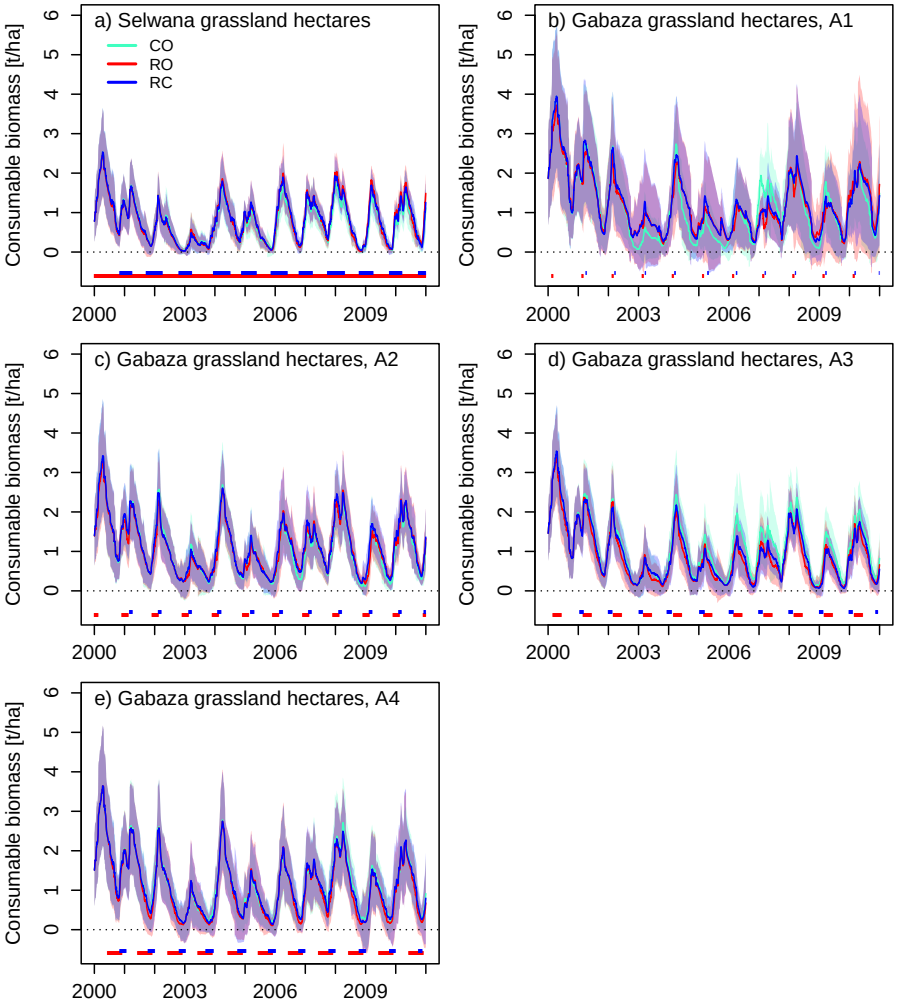

Figure S6. Temporal dynamics of average consumable grass biomass on simulated grassland hectares (living grass leaf biomass + dead standing grass leaf biomass + reproductive biomass, reduced by the minimum amount per hectare that is not available to grazers, i.e., 0.3 t/h for living and dead grass biomass, respectively, and 0.1 t/ha of reproductive biomass) that had no fire in either of the three scenarios up to the day under consideration. Differences between scenarios are therefore exclusively due to the grazing regime. Lines denote the mean across all simulated hectares, shaded areas show the standard deviation. Horizontal red and blue lines at the bottom indicate timelines of animal presence on rangeland during the RO- and RC-scenario, respectively.

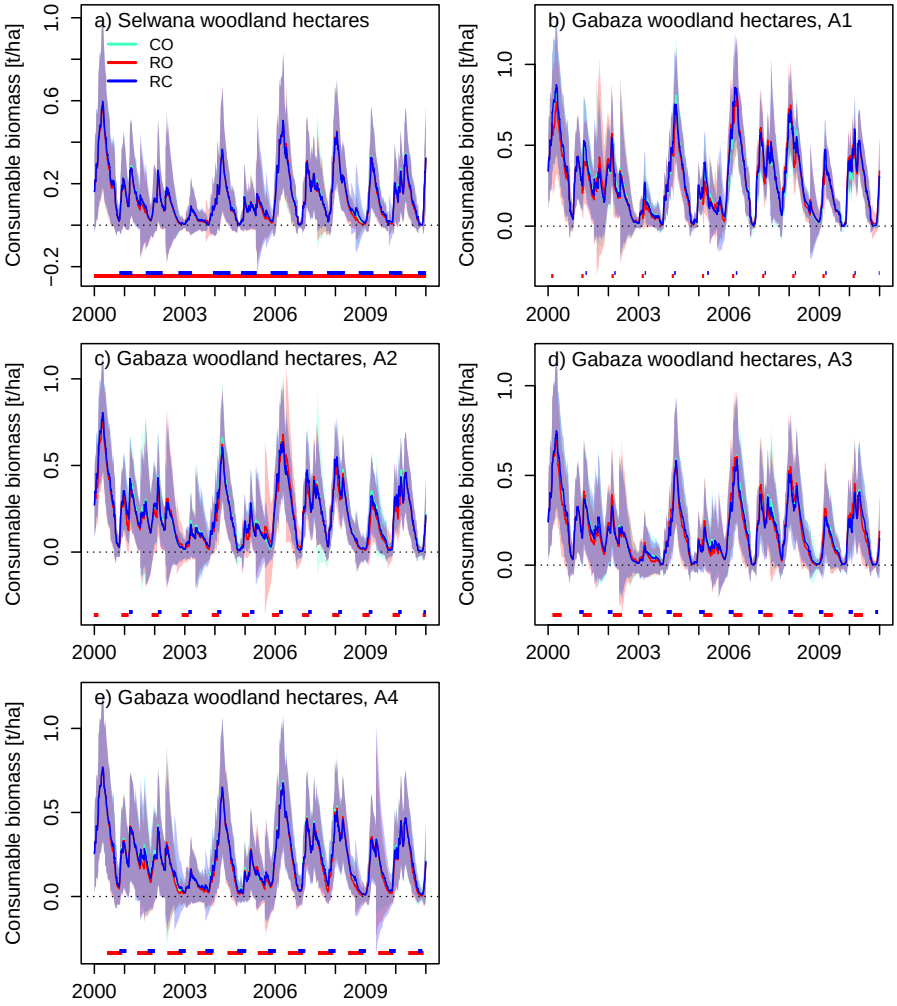

Figure S7. Temporal dynamics of average consumable grass biomass on simulated woodland hectares (living grass leaf biomass + dead standing grass leaf biomass + reproductive biomass, reduced by the minimum amount per hectare that is not available to grazers, i.e., 0.3 t/h for living and dead grass biomass, respectively, and 0.1 t/ha of reproductive biomass) that had no fire in either of the three scenarios up to the day under consideration. Differences between scenarios are therefore exclusively due to the grazing regime. Lines denote the mean across all simulated hectares, shaded areas show the standard deviation. Horizontal red and blue lines at the bottom indicate timelines of animal presence on rangeland during the RO- and RC-scenario, respectively.

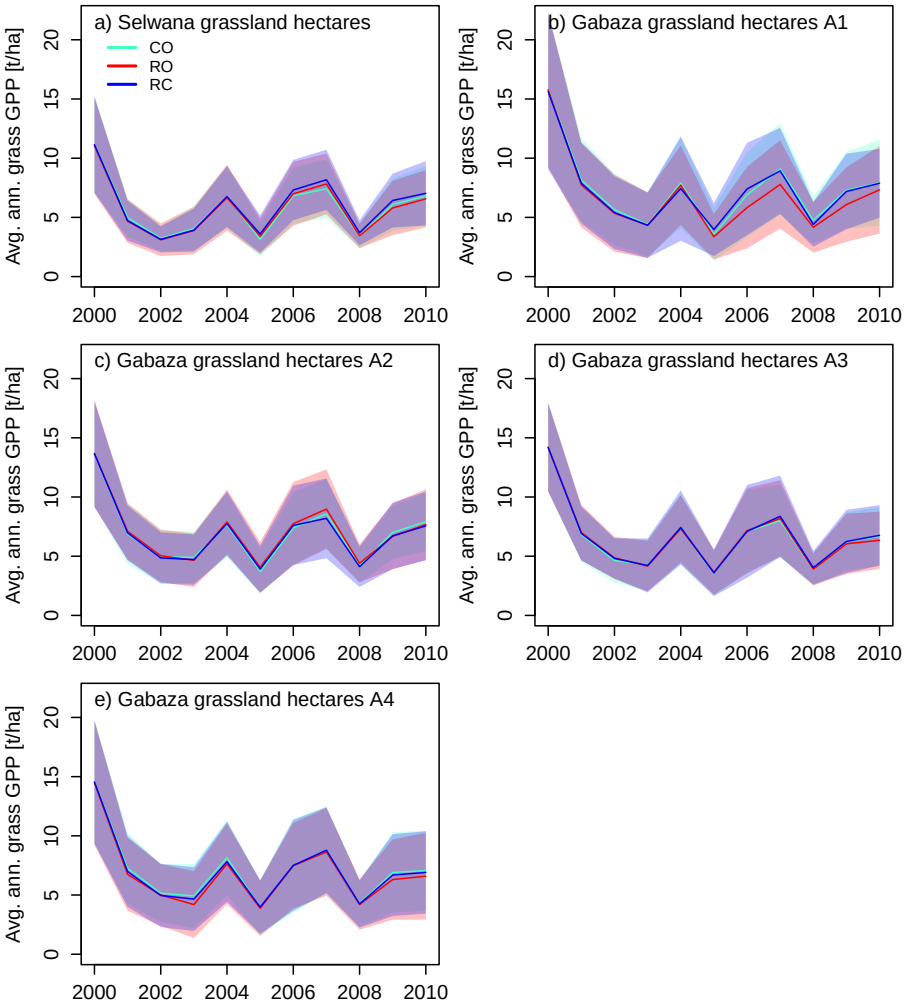

Figure S8. Average per-hectare annual grass layer GPP across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Differences between annual mean values between both grazing scenarios and control were all statistically non-significant (two-sided t-test, $p<0.05$).

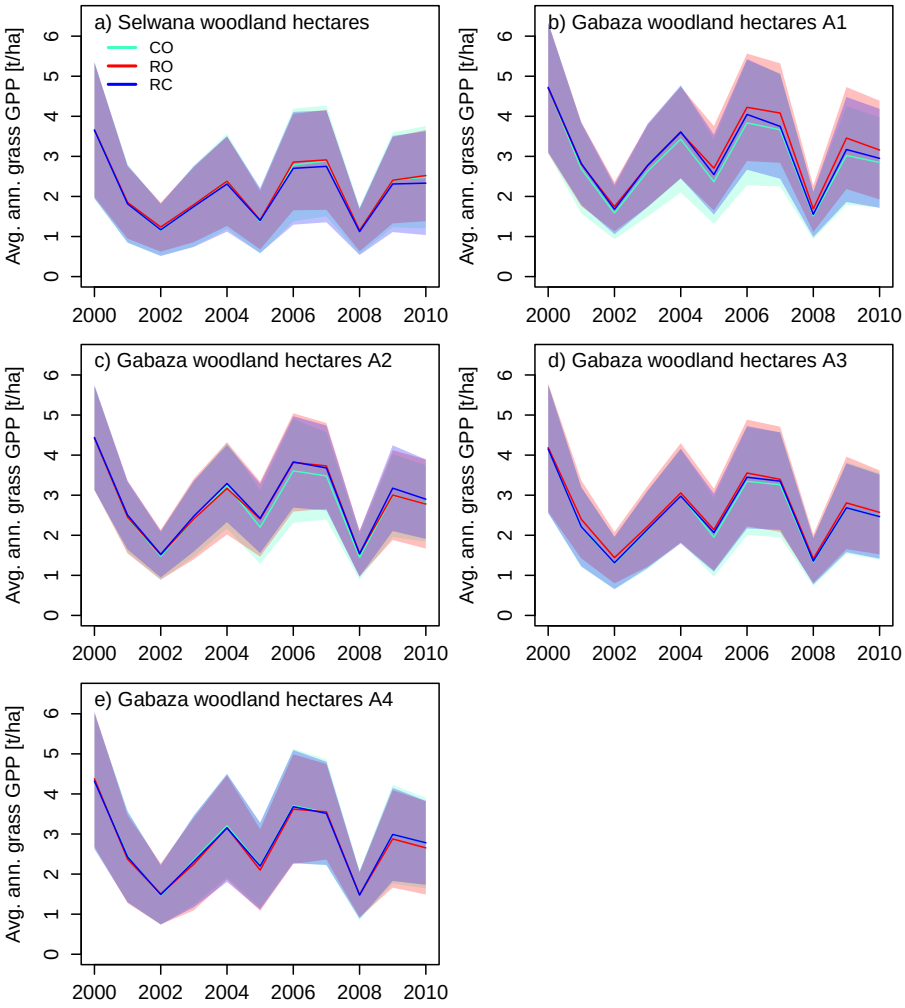

Figure S9. Average per-hectare annual grass layer GPP across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Differences between annual mean values between both grazing scenarios and control were all statistically non-significant (two-sided t-test, $p<0.05$).

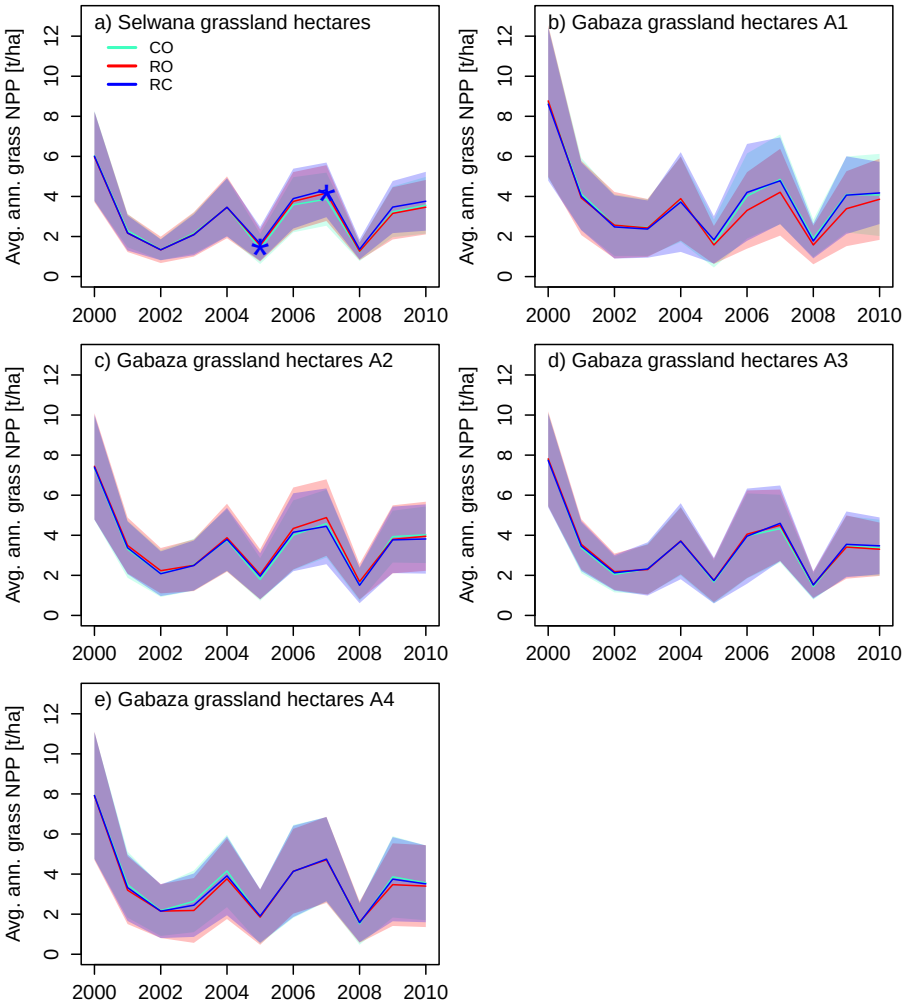

Figure S10. Average per-hectare annual grass layer NPP across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Statistically significant differences between annual mean values between grazing scenario and control (two-sided t-test, $p<0.05$) are marked with a * symbol.

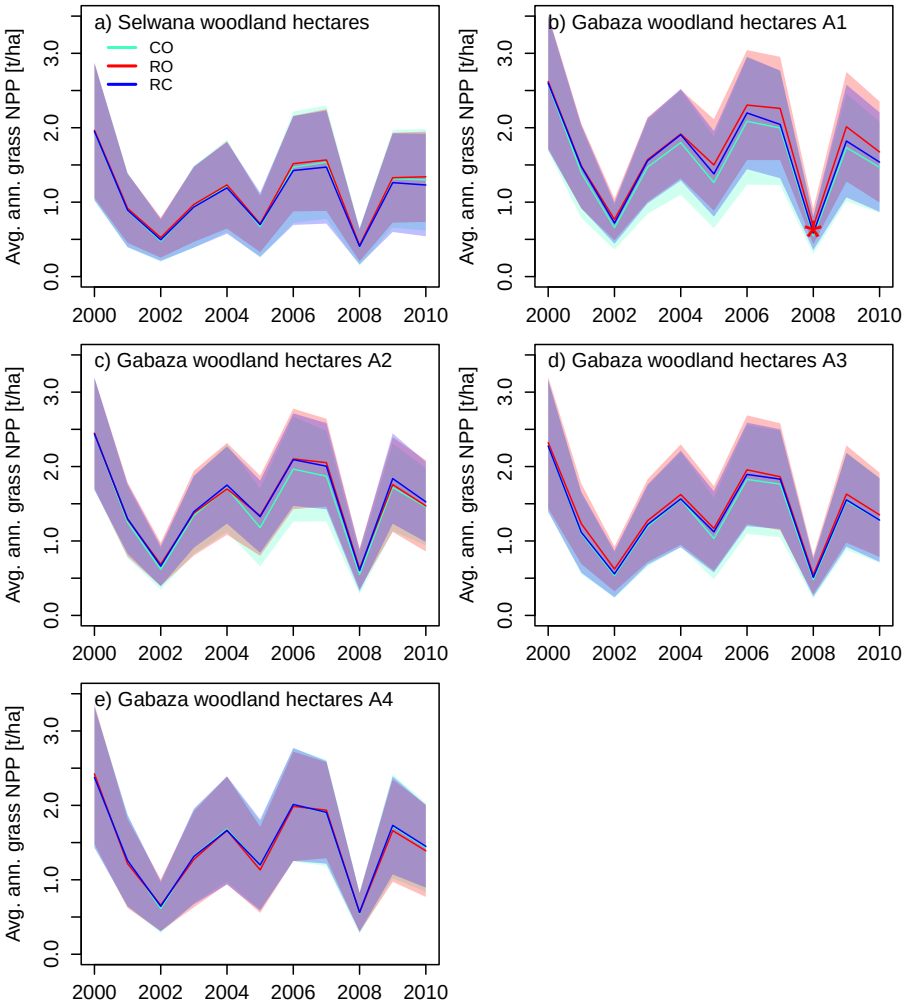

Figure S11. Average per-hectare annual grass layer NPP across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Statistically significant differences between annual mean values between grazing scenario and control (two-sided t-test, $p<0.05$) are marked with a * symbol.

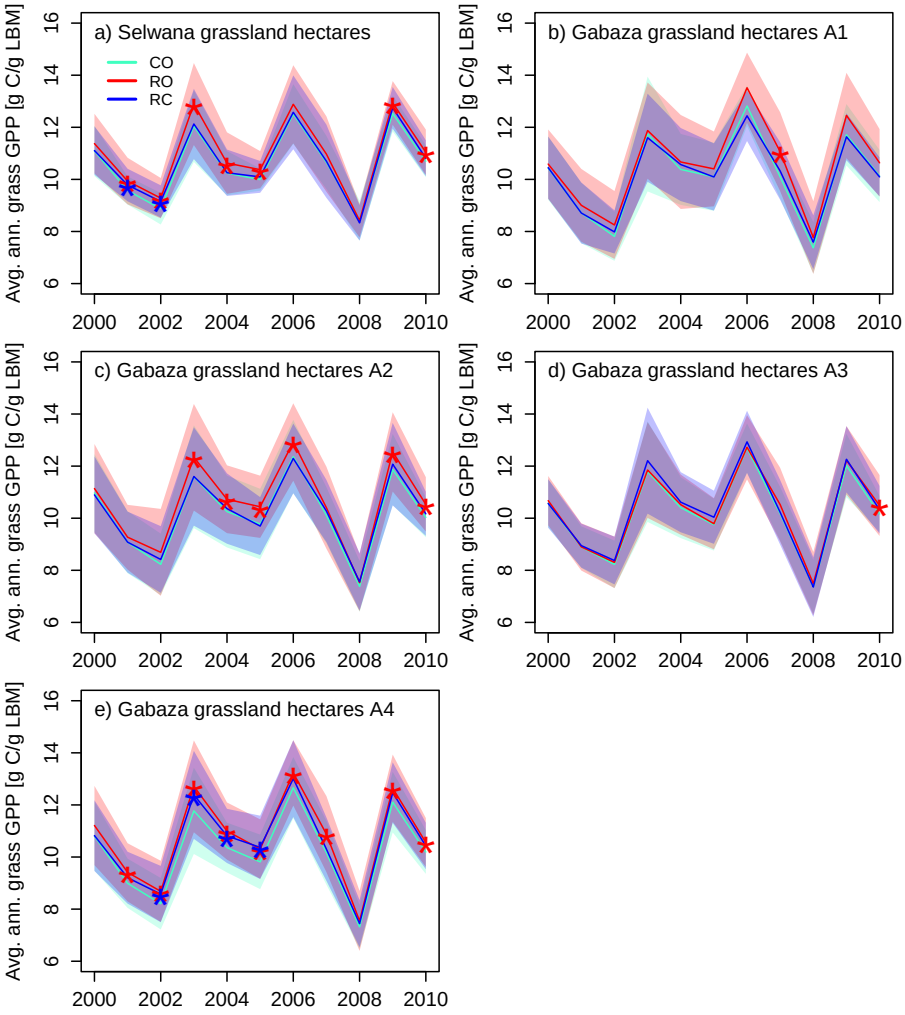

Figure S12. Average annual grass layer GPP per unit living grass biomass across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Statistically significant differences between annual mean values of grazing scenarios and control (two-sided t-test, $p<0.05$) are marked with a * symbol.

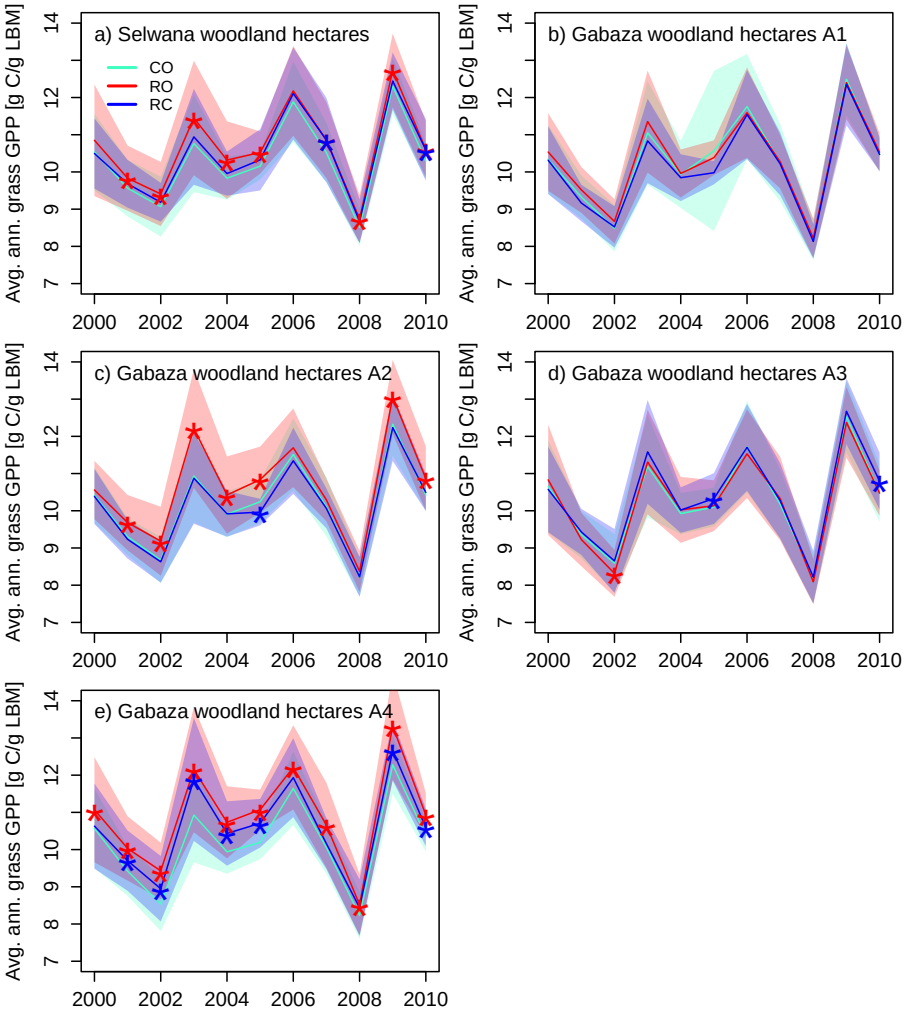

Figure S13. Average annual grass layer GPP per unit living grass biomass across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Statistically significant differences between annual mean values of grazing scenarios and control (two-sided t-test, $p<0.05$) are marked with a * symbol.

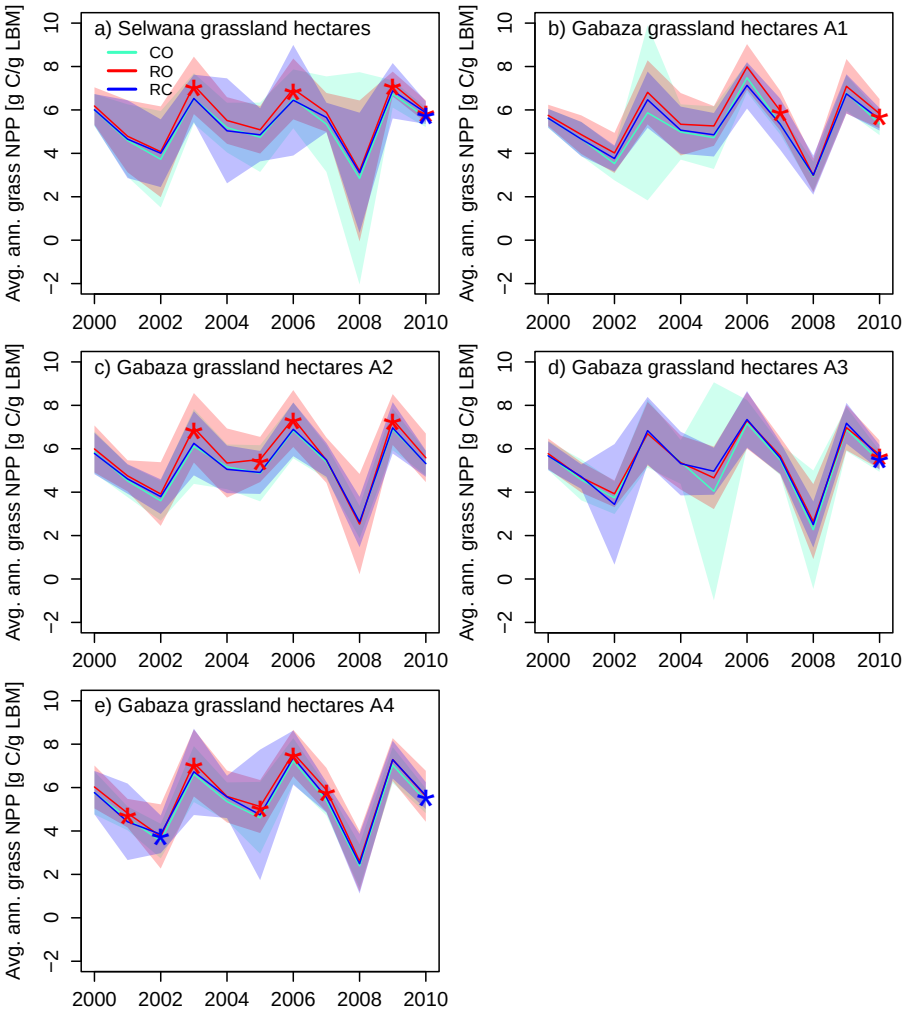

Figure S14. Average annual grass layer NPP per unit living grass biomass across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Statistically significant differences between annual mean values of grazing scenarios and control (two-sided t-test, $p<0.05$) are marked with a * symbol.

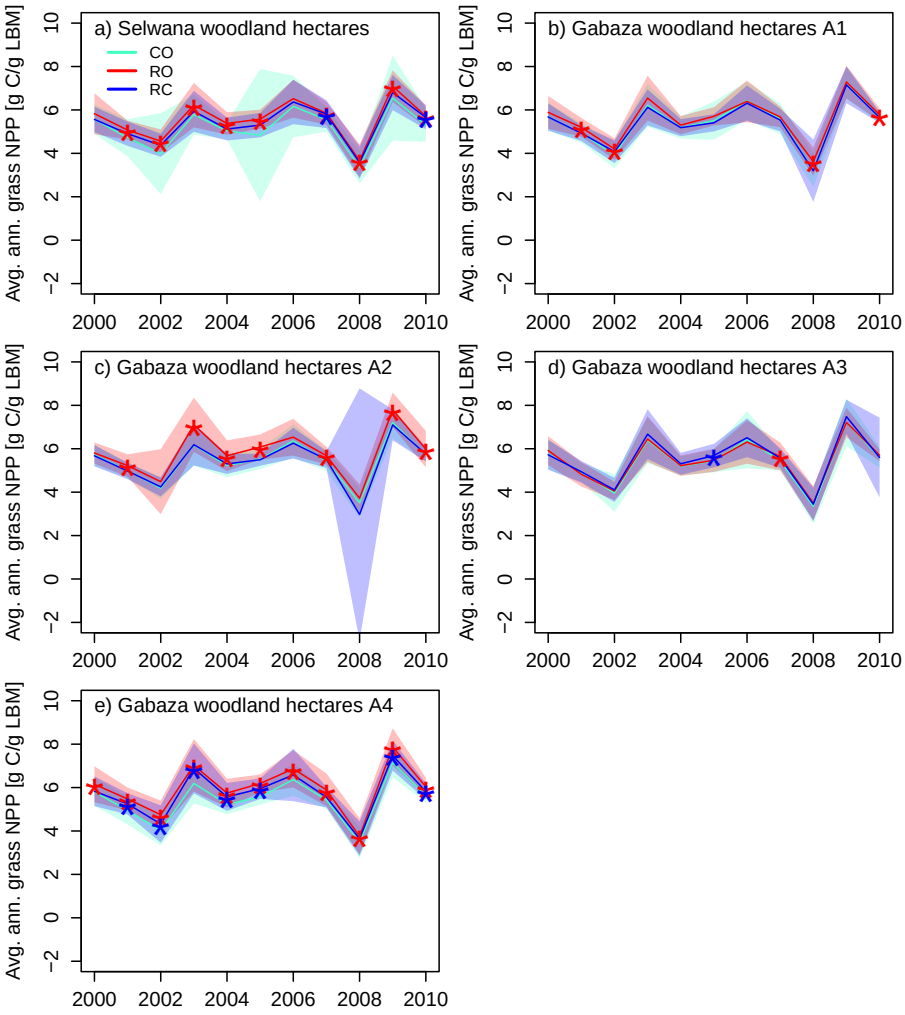

Figure S15. Average annual grass layer NPP per unit living grass biomass across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Statistically significant differences between annual mean values of grazing scenarios and control (two-sided t-test, $p<0.05$) are marked with a * symbol.

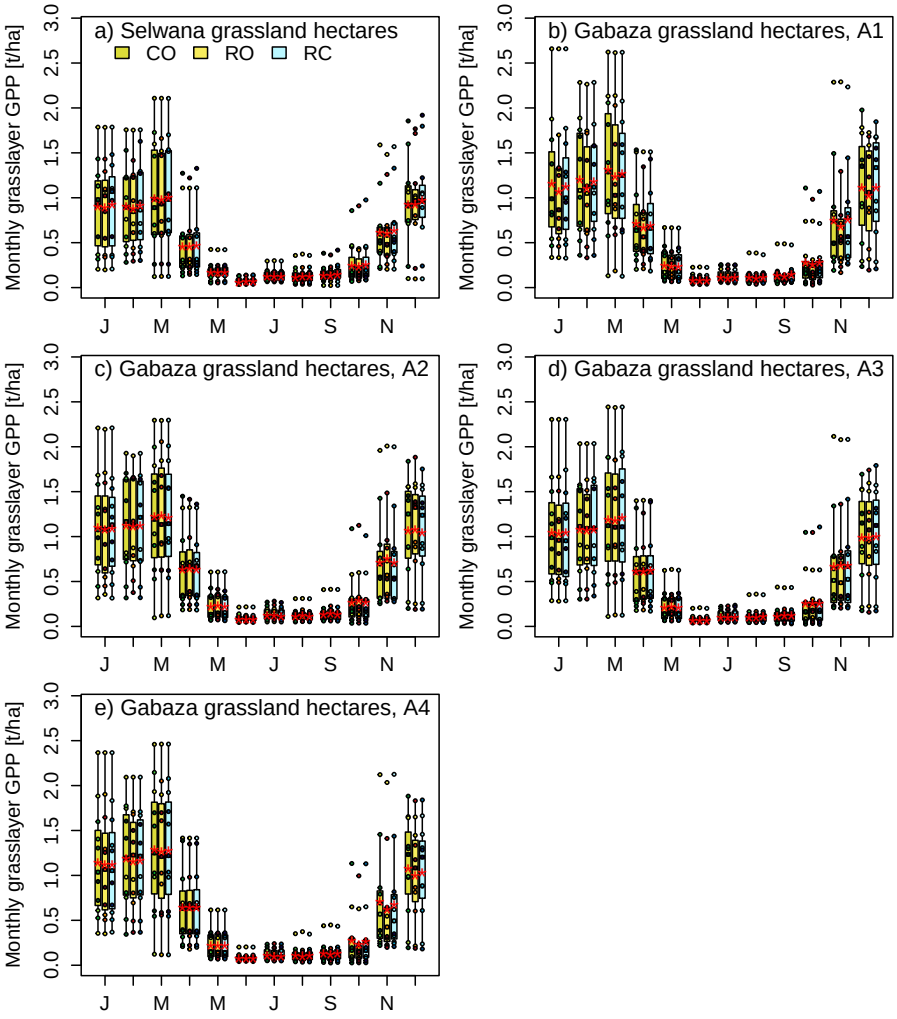

Figure S16. Monthly grass layer GPP per hectare across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years.

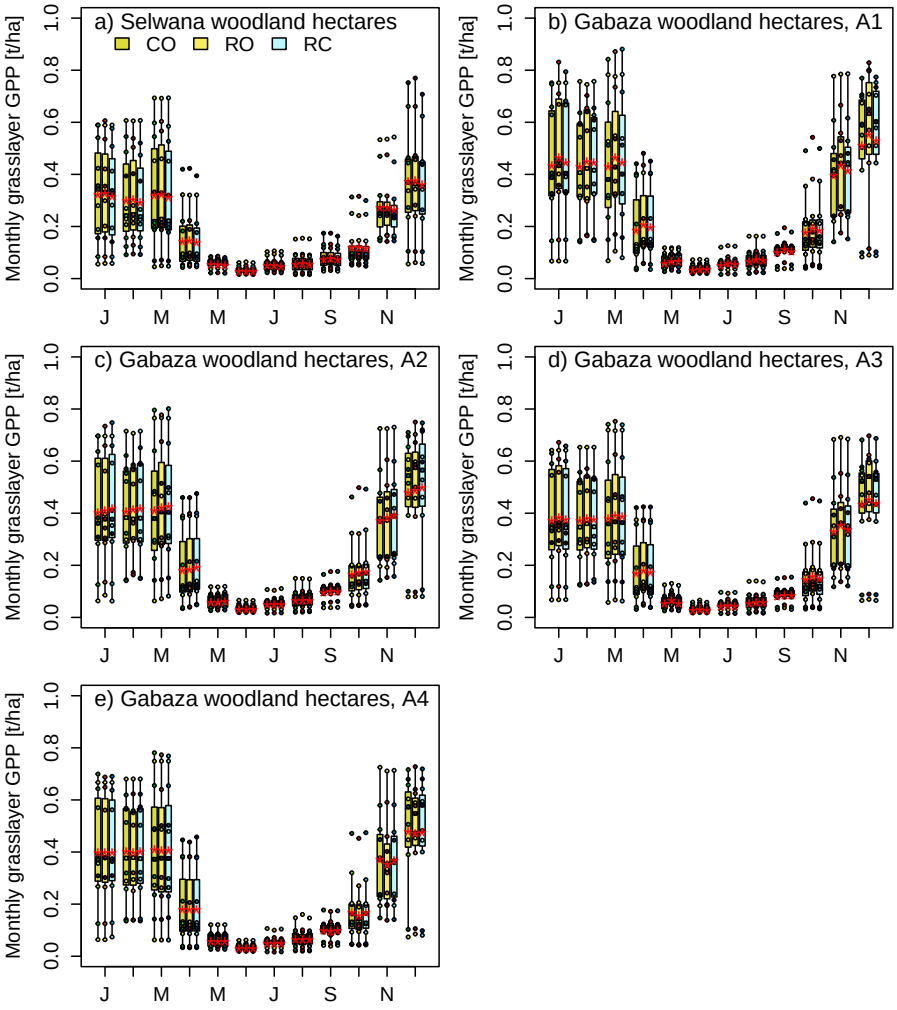

Figure S17. Monthly grass layer GPP per hectare across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years.

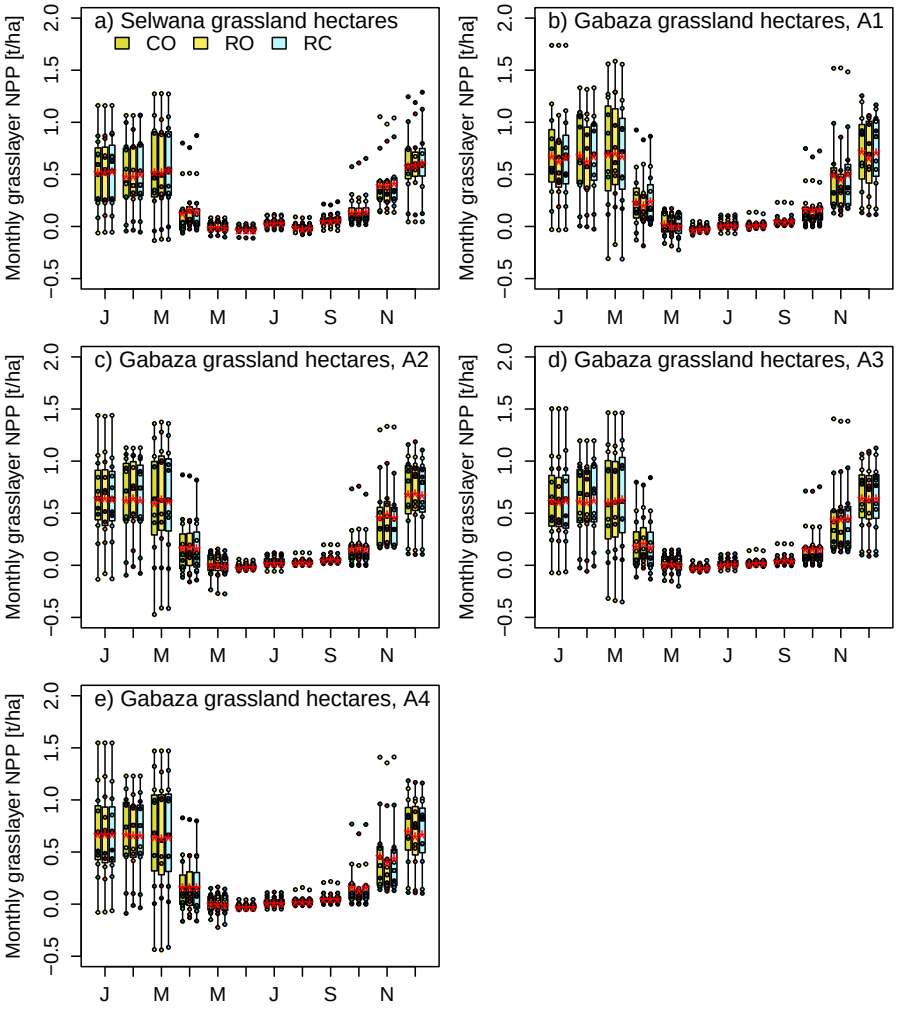

Figure S18. Monthly grass layer NPP per hectare across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years.

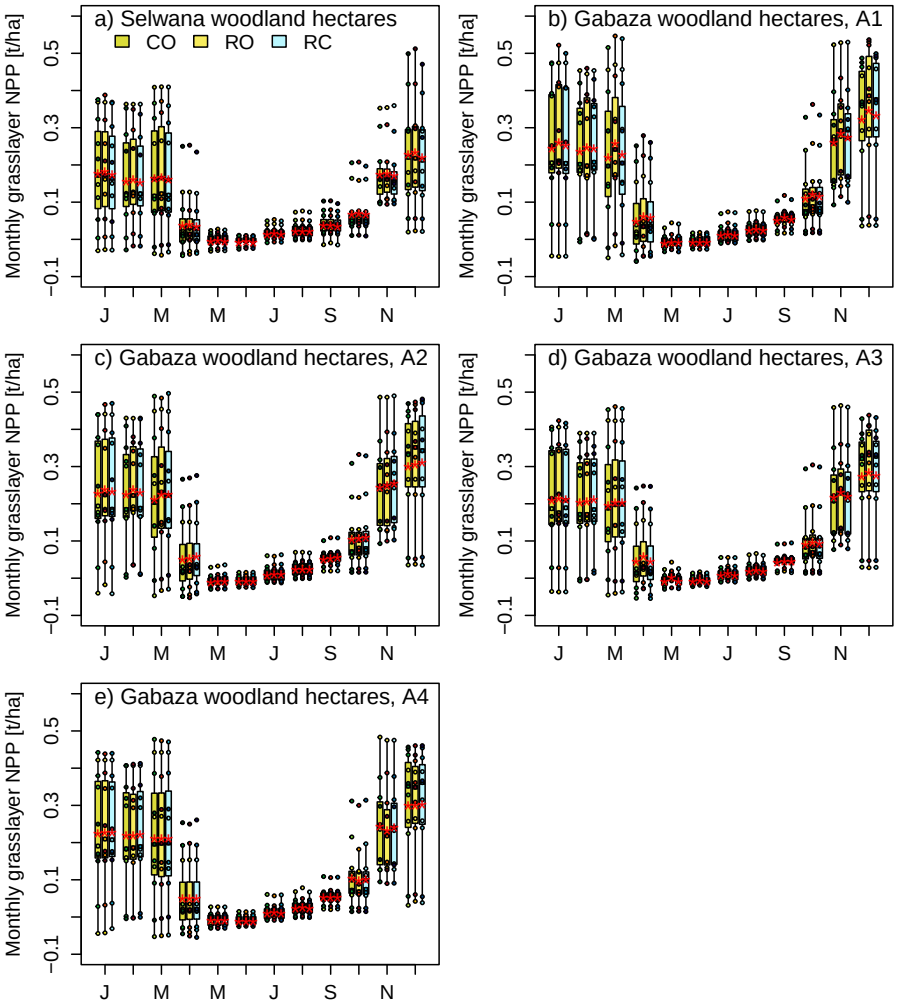

Figure S19. Monthly grass layer NPP per hectare across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years.

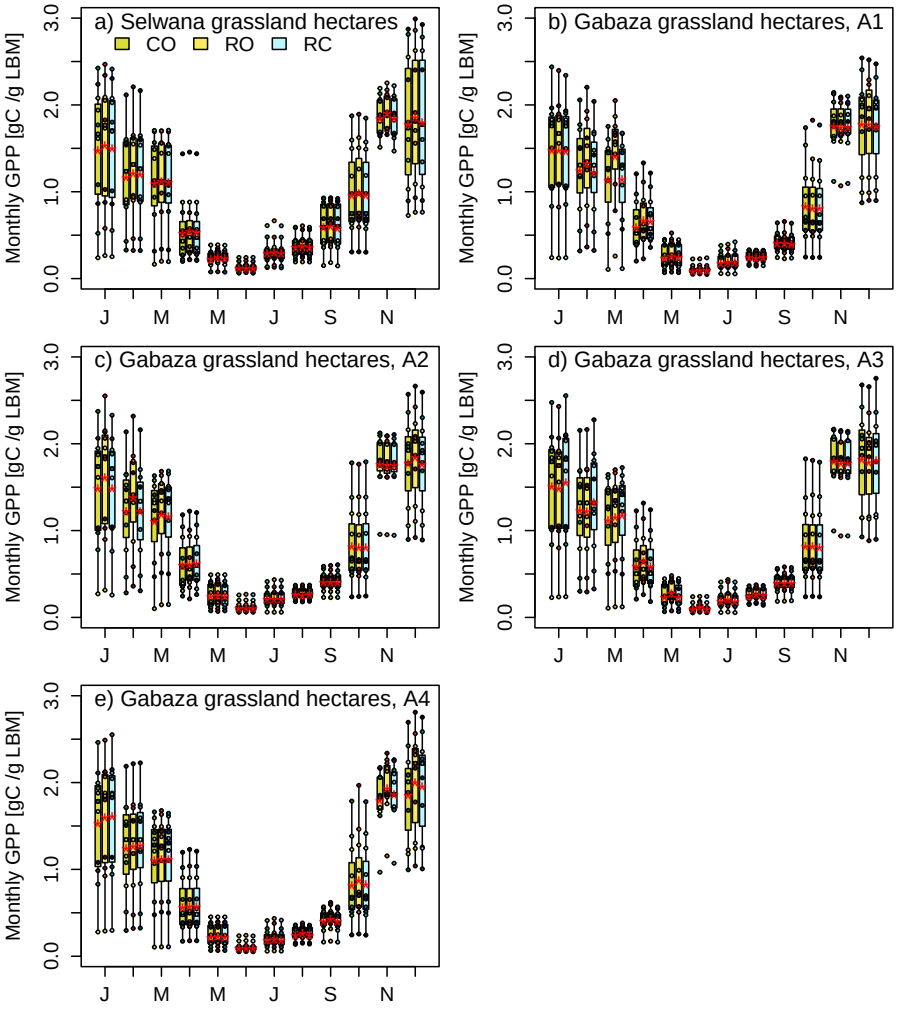

Figure S20. Monthly grass layer GPP per unit of living grass leaf biomass across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years.

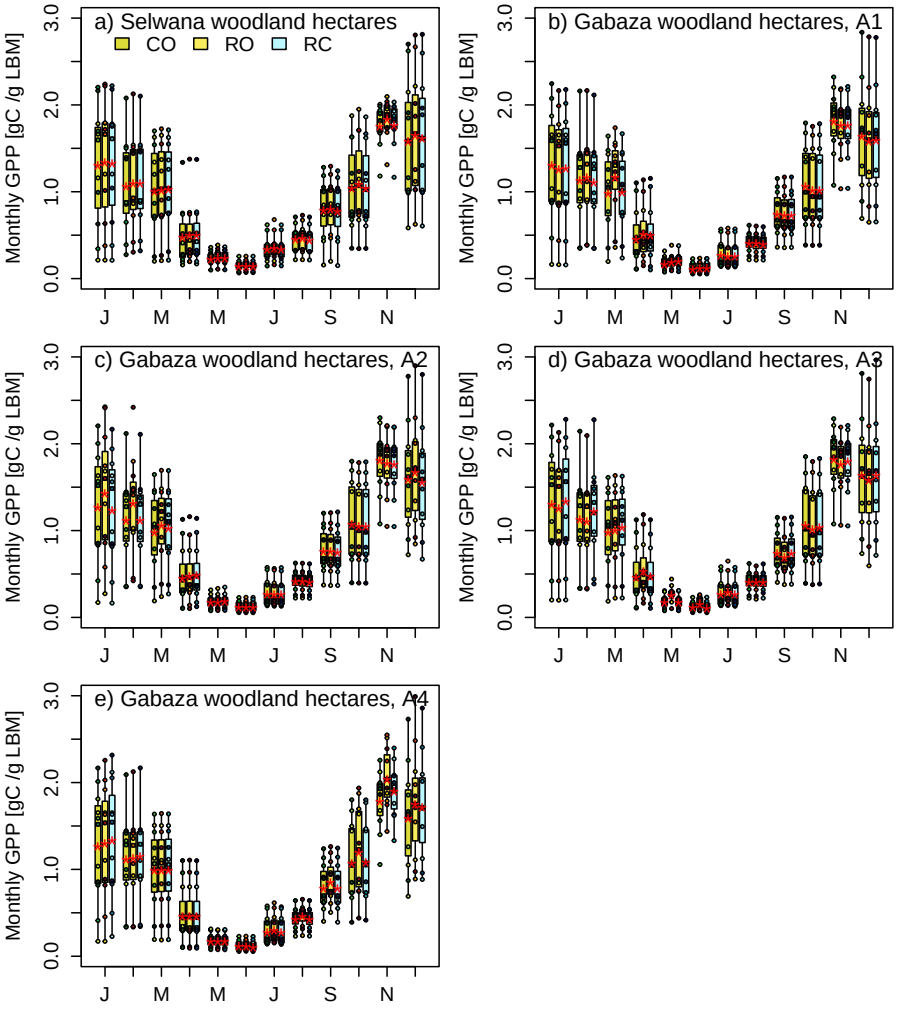

Figure S21. Monthly grass layer GPP per unit of living grass leaf biomass across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years.

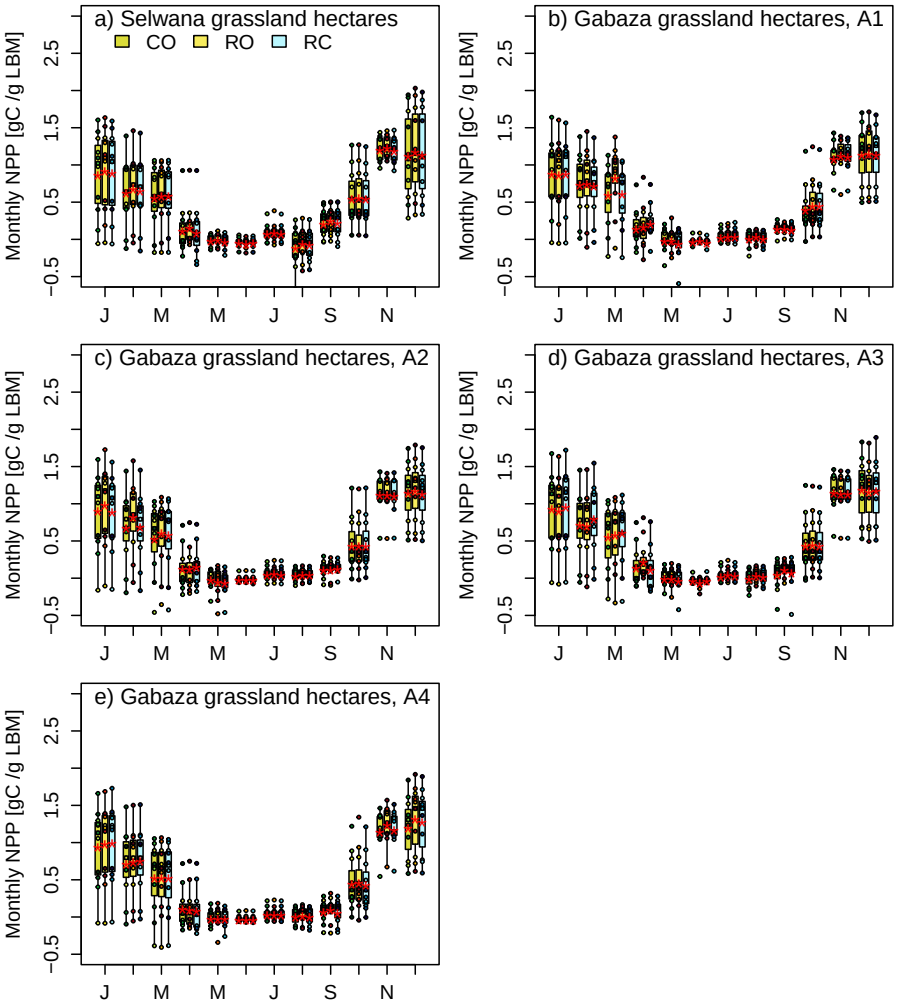

Figure S22. Monthly grass layer NPP per unit of living grass leaf biomass across simulated grassland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years.

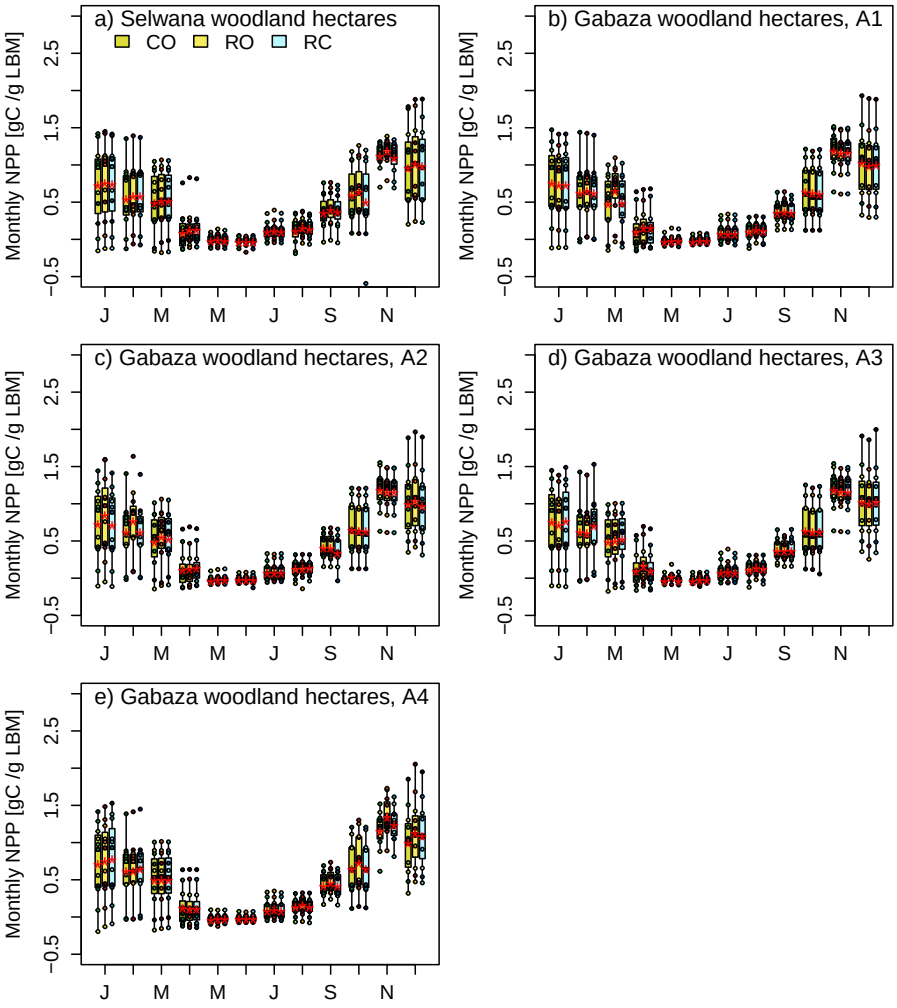

Figure S23. Monthly grass layer NPP per unit of living grass leaf biomass across simulated woodland hectares at Selwana (panel a) and the four sub-areas at Gabaza (panel b-e). Different colored boxes mark the three different scenarios (control, rangeland-only, rangeland+cropland grazing), single dots mark the average-across-hectare values of individual years, and red stars mark the average value across all years. .