

# Supplementary Information: Global patterns of forest autotrophic carbon fluxes

Rebecca Banbury Morgan      Valentine Herrmann      Norbert Kunert  
Ben Bond-Lamberty      Helene C. Muller-Landau      Kristina J. Anderson-Teixeira

## List of Tables

1	Table S1. Climate variable definitions, sources, and abbreviations . . . . .	2
2	Table S2. Model form, $\Delta$ AIC and $R^2$ for each climate variable as a single fixed effect in models for each C flux . . . . .	3
3	Table S3. Significance of relationships of forest C fluxes to MAT alone and in combination with MAP. . . . .	4
4	Table S4. Comparison of growing season length and MAT as predictors of forest C fluxes . .	5
5	Table S5. Best models by carbon flux . . . . .	6
6	Table S6. Pairwise comparisons of correlations with climate variables between C fluxes, with all analyses conducted on a set of sites common to each pair. . . . .	7

## List of Figures

1	Figure S1: Maps showing distribution of samples for the nine forest C fluxes analyzed . . . .	8
2	Figure S2: Scatterplots and Pearson's R values for relationships between latitude and climate variables . . . . .	9
3	Figure S3: Ratios among forest C fluxes as a function of latitude and climate variables. . . .	11
4	Figure S4: Individual plots of forest C fluxes in relation to mean annual climate, part 1. . . .	12
5	Figure S5: Individual plots of forest C fluxes in relation to mean annual climate, part 2. . . .	13
6	Figure S6: Individual plots of forest C fluxes in relation to mean climate seasonality, part 1. .	14
7	Figure S7: Individual plots of forest C fluxes in relation to mean climate seasonality, part 2. .	15
8	Figure S8: Growing season length-standardized forest C fluxes in relation to mean growing season climate, part 1. . . . .	16
9	Figure S9: Growing season length-standardized forest C fluxes in relation to mean growing season climate, part 2. . . . .	17

Table S1. Climate variable definitions, sources, and abbreviations

Abbreviation	Climate variable	Units	Definition	Time span	Source
MAT	Mean annual temperature	°C	Annual mean temperature, from primary literature or WorldClim if not reported	1970 - 2000	Primary literature; WorldClim <sup>1</sup>
MAP	Mean annual precipitation	mm yr <sup>-1</sup>	Annual mean precipitation, from primary literature or WorldClim if not reported	1970 - 2000	Primary literature; WorldClim <sup>1</sup>
T Seas	Temperature seasonality	°C	Standard deviation (variation) of monthly temperature averages	1970 - 2000	WorldClim <sup>1</sup>
P Seas	Precipitation seasonality	%	Coefficient of variation of mean monthly precipitation x 100	1970 - 2000	WorldClim <sup>1</sup>
ATR	Annual temperature range	°C	Maximum temperature of warmest month - minimum temperature of coldest month	1970 - 2000	WorldClim <sup>1</sup>
Solar R	Solar radiation	kJ m <sup>-2</sup> yr <sup>-1</sup>	Solar radiation	1970 - 2000	WorldClim2 <sup>2</sup>
Cloud	Cloud cover	%	Cloud percentage cover	1901 - 2014	CRU time-series dataset v 4.03 <sup>3</sup>
AFD	Annual frost days	days yr <sup>-1</sup>	Number of freeze days annually	1901 - 2014	CRU time-series dataset v 4.03 <sup>3</sup>
AWD	Annual wet days	days yr <sup>-1</sup>	Number of days with precipitation >0.1 mm annually	1901 - 2014	CRU time-series dataset v 4.03 <sup>3</sup>
PET	Potential evapotranspiration	mm yr <sup>-1</sup>	Mean annual potential evapotranspiration	1950 - 2000	Global Aridity Index and Potential Evapotranspiration Climate Database <sup>4</sup>
AI	Aridity		MAP/mean annual PET	1950 - 2000	Global Aridity Index and Potential Evapotranspiration Climate Database <sup>4</sup>
VPD	Vapour pressure deficit	kPa	Mean monthly vapour pressure deficit	1958 - 2015	TerraClimate <sup>5</sup>
Max VPD	Maximum vapour pressure deficit	kPa	Maximum monthly vapour pressure deficit	1958 - 2017	Derived from TerraClimate data
WSM	Water stress months	months yr <sup>-1</sup>	Number of months annually with MAP < PET	1970 - 2000	Derived from WorldClim data
LGS	Length of growing season	months yr <sup>-1</sup>	Number of months annually with mean minimum temperature > 0.5°C	1901 - 2014	Derived from CRU data
gsT	Growing season temperature	°C	Mean growing season temperature	1901 - 2014	Derived from CRU data
gsP	Growing season precipitation	mm month <sup>-1</sup>	Mean monthly precipitation during growing season months	1901 - 2014	Derived from CRU data
gsPET	Growing season PET	mm month <sup>-1</sup>	Mean monthly potential evapotranspiration during growing season months	1901 - 2014	Derived from CRU data
gsR	Growing season solar radiation	mm month <sup>-1</sup>	Mean monthly solar radiation during growing season	1901 - 2014	Derived from WorldClim2 data

\* The WorldClim version used was the most recent available at the time of analysis

<sup>1</sup> Hijmans et al. (2005) <sup>2</sup> Fick and Hijmans. (2017) <sup>3</sup> Harris et al. (2017) <sup>4</sup> Trabucco and Zomer (2019) <sup>5</sup> Abatzoglou et al. (2018)

Table S2. Model form,  $\Delta$ AIC, and  $R^2$  for each climate variable as a single fixed effect in models for each C flux.

Carbon Flux	Latitude			MAT			MAP			T Seas			P Seas			ATR			Solar R			AI		
	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R-sq	$\Delta$ AIC
GPP	Lin	0.64	54.9	Lin	0.61	52.5	Lin	0.18	33.3	Poly	0.71	69.5	-	-	-	Poly	0.69	63.0	Log	0.16	8.9	-	-	-
NPP	Log	0.50	44.3	Lin	0.42	41.5	Poly	0.21	16.7	Log	0.52	44.3	-	-	-	Log	0.49	42.3	Poly	0.16	12.5	Lin	0.04	2.8
ANPP	Lin	0.44	63.4	Lin	0.44	80.5	Poly	0.16	19.7	Log	0.41	58.7	-	-	-	Log	0.37	51.9	Lin	0.11	12.3	Lin	0.05	2.1
ANPP stem	Lin	0.18	22.2	Lin	0.24	38.5	Log	0.05	7.3	Lin	0.14	17.6	Poly	0.05	5	Lin	0.12	13.6	Log	0.06	6.8	Lin	0.07	4
ANPP foliage	Lin	0.50	37.7	Lin	0.58	52.9	Poly	0.25	13.3	Lin	0.48	34.1	-	-	-	Lin	0.50	36.1	Log	0.17	10.1	Lin	0.11	6.8
BNPP root	Lin	0.34	22.9	Log	0.31	21.0	Poly	0.15	6.2	Log	0.36	26.6	-	-	-	Log	0.33	23.6	Poly	0.29	18.8	-	-	-
BNPP fine root	Lin	0.17	8.0	Lin	0.15	7.2	Log	0.11	5.4	Lin	0.17	8.4	-	-	-	Log	0.19	10.9	Log	0.14	7.2	Log	0.06	2.4
R auto	Lin	0.65	13.1	Lin	0.59	10.9	Poly	0.60	8.6	Log	0.65	13.1	-	-	-	Log	0.60	11.5	Log	0.27	2.4	Poly	0.48	3.7
R root	Log	0.22	8.8	Lin	0.24	8.3	Lin	0.15	6.8	Log	0.24	9.5	-	-	-	Log	0.22	8.8	-	-	-	Lin	0.16	7.3

Carbon Flux	Cloud			AFD			AWD			PET			VPD			Max VPD			WSM			LGS		
	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC	Model	R <sup>2</sup>	$\Delta$ AIC
GPP	-	-	-	Log	0.54	50.0	Lin	0.11	5.7	Poly	0.36	19.7	Poly	0.31	15.9	-	-	-	-	-	-	Lin	0.53	38.2
NPP	Lin	0.06	3.6	Lin	0.40	38.5	Lin	0.11	7.3	Poly	0.32	24.3	Poly	0.18	15.3	-	-	-	Lin	0.04	4	Lin	0.38	28.4
ANPP	Poly	0.09	7.1	Log	0.41	61.6	Lin	0.17	18.7	Poly	0.27	24.5	Poly	0.23	21.4	Poly	0.06	2.2	Poly	0.06	3	Lin	0.34	44.0
ANPP stem	Poly	0.09	5.4	Log	0.17	22.3	-	-	-	Poly	0.20	14.0	Poly	0.21	17.7	Log	0.14	7.5	-	-	-	Log	0.11	12.6
ANPP foliage	-	-	-	Lin	0.53	43.4	Lin	0.15	7	Log	0.32	24.2	Log	0.35	30.0	Poly	0.07	4.9	Poly	0.17	7.8	Log	0.46	32.9
BNPP root	-	-	-	Lin	0.28	19.1	Poly	0.11	3.4	Poly	0.36	23.2	Poly	0.26	13.9	-	-	-	-	-	-	Lin	0.26	14.7
BNPP fine root	-	-	-	Lin	0.16	9.2	Lin	0.08	2.7	Log	0.14	7.1	Log	0.06	1.9	-	-	-	-	-	-	Lin	0.13	5.8
R auto	-	-	-	Log	0.57	9.4	Null	0.26	0.6	Log	0.36	4.8	Log	0.35	4.3	-	-	-	Null	0.3	1.5	Lin	0.47	5.8
R root	Log	0.16	1.9	Log	0.19	7.3	Lin	0.17	3.5	Poly	0.19	1.7	Poly	0.27	6.7	-	-	-	Lin	0.14	6.1	Lin	0.19	5.9

Model forms tested include first-order linear (Lin), second-order polynomial (Poly), and logarithmic (Log). Shown are models with lowest AIC value.  $\Delta$ AIC value is calculated with respect to the null.

Table S3. Significance of relationships of forest C fluxes to MAT alone and in combination with MAP.  $R^2$  values refer to the best model.

Carbon flux	MAT	MAT + MAP	MAT x MAP	Best model	$R^2$
GPP	<0.0001	<0.0001	NS	MAT + MAP	0.66
NPP	<0.0001	NS	0.018	MAT x MAP	0.48
ANPP	<0.0001	0.035	NS	MAT + MAP	0.45
ANPP stem	<0.0001	NS	0.021	MAT x MAP	0.26
ANPP foliage	<0.0001	NS	NS	MAT	0.59
BNPP root	<0.0001	NS	NS	MAT	0.29
BNPP fine root	0.0021	NS	NS	MAT	0.15
R auto	0.00016	0.041	NS	MAT + MAP	0.71
R root	0.0011	NS	NS	MAT	0.25

Table S4. Comparison of growing season length and MAT as predictors of forest C fluxes

Fixed effect	AIC value	$\Delta$ AIC relative to best model	Marginal R <sup>2</sup>
<b>GPP</b>			
MAT	126.43	0.00	0.62
Growing season length	140.81	14.38	0.54
None	178.96	52.54	0.00
<b>NPP</b>			
MAT	174.88	0.00	0.52
Growing season length	191.54	16.65	0.40
None	216.17	41.29	0.00
<b>ANPP</b>			
MAT	249.51	0.00	0.29
Growing season length	254.21	4.70	0.26
None	268.94	19.43	0.00
<b>ANPP stem</b>			
MAT	235.96	0.00	0.15
Growing season length	237.29	1.33	0.14
None	243.14	7.18	0.00
<b>ANPP foliage</b>			
MAT	484.88	0.00	0.45
Growing season length	520.96	36.09	0.35
None	560.35	75.47	0.00
<b>BNPP root</b>			
MAT	184.54	0.00	0.59
Growing season length	204.93	20.38	0.46
None	237.47	52.92	0.00
<b>BNPP fine root</b>			
MAT	540.19	0.00	0.24
Growing season length	566.37	26.18	0.11
None	578.66	38.46	0.00
<b>R auto</b>			
MAT	45.26	0.00	0.63
Growing season length	50.36	5.10	0.50
None	56.17	10.91	0.00
<b>R root</b>			
MAT	133.54	0.00	0.25
Growing season length	135.93	2.39	0.20
None	141.79	8.25	0.00

Table S5. Best (lowest  $\Delta\text{AIC}$ ) single-climate variable models by C flux.

Carbon flux	Climate variable	Model type	$\Delta\text{AIC}$ relative to null model	$\Delta\text{AIC}$ relative to next best model	$R^2$
GPP	T Seas	Poly	69.5	6.55	0.71
NPP	MAT	Lin	41.5	0.21	0.42
	T Seas	Log	44.3	-	0.52
ANPP	MAT	Lin	80.5	21.4	0.44
ANPP stem	MAT	Lin	38.5	15.87	0.24
ANPP foliage	MAT	Lin	52.9	11.05	0.58
BNPP root	T Seas	Log	26.6	3.01	0.36
BNPP fine root	ATR	Log	10.9	2.11	0.19
R auto	T Seas	Log	13.1	1.62	0.65
	ATR	Log	11.5	-	0.60
R root	T Seas	Log	9.5	0.76	0.24
	ATR	Log	8.8	-	0.22
	MAT	Lin	8.3	-	0.24

Table includes all models within  $\Delta\text{AIC} \leq 2.0$  of the best model

Table S6. Pairwise comparisons of correlations with climate variables between C fluxes, with all analyses conducted on a set of sites common to each pair.

C flux variable 1	C flux variable 2	Climate variable	R <sup>2</sup> variable 1	R <sup>2</sup> variable 2	Model type variable 1	Model type variable 2	Number of plots	Variable with higher R <sup>2</sup>
GPP	NPP	Latitude	0.62	0.66	Lin	Lin	37	NPP
		MAT	0.62	0.70	Log	Lin	37	NPP
		T Seas	0.65	0.70	Log	Log	37	NPP
NPP	ANPP	Latitude	0.52	0.48	Log	Log	158	NPP
		MAT	0.30	0.44	Log	Lin	158	ANPP
		T Seas	0.47	0.43	Lin	Lin	158	NPP
	BNPP	Latitude	0.49	0.34	Log	Lin	116	NPP
		MAT	0.41	0.22	Log	Log	116	NPP
		T Seas	0.49	0.41	Log	Log	116	NPP
ANPP	ANPP stem	Latitude	0.35	0.13	Lin	Lin	176	ANPP
		MAT	0.42	0.17	Lin	Lin	176	ANPP
		T Seas	0.29	0.09	Lin	Lin	176	ANPP
	ANPP foliage	Latitude	0.32	0.45	Log	Log	96	ANPP foliage
		MAT	0.36	0.50	Lin	Lin	96	ANPP foliage
		T Seas	0.27	0.42	Lin	Lin	96	ANPP foliage
GPP	R auto	Latitude	0.64	0.34	Null	Null	11	GPP
		MAT	0.69	0.34	Null	Null	11	GPP
		T Seas	0.64	0.32	Null	Null	11	GPP
BNPP	R root	Latitude	0.01	0.39	Null	Null	9	R root
		MAT	0.08	0.35	Null	Null	9	R root
		T Seas	0.01	0.63	Null	Null	9	R root

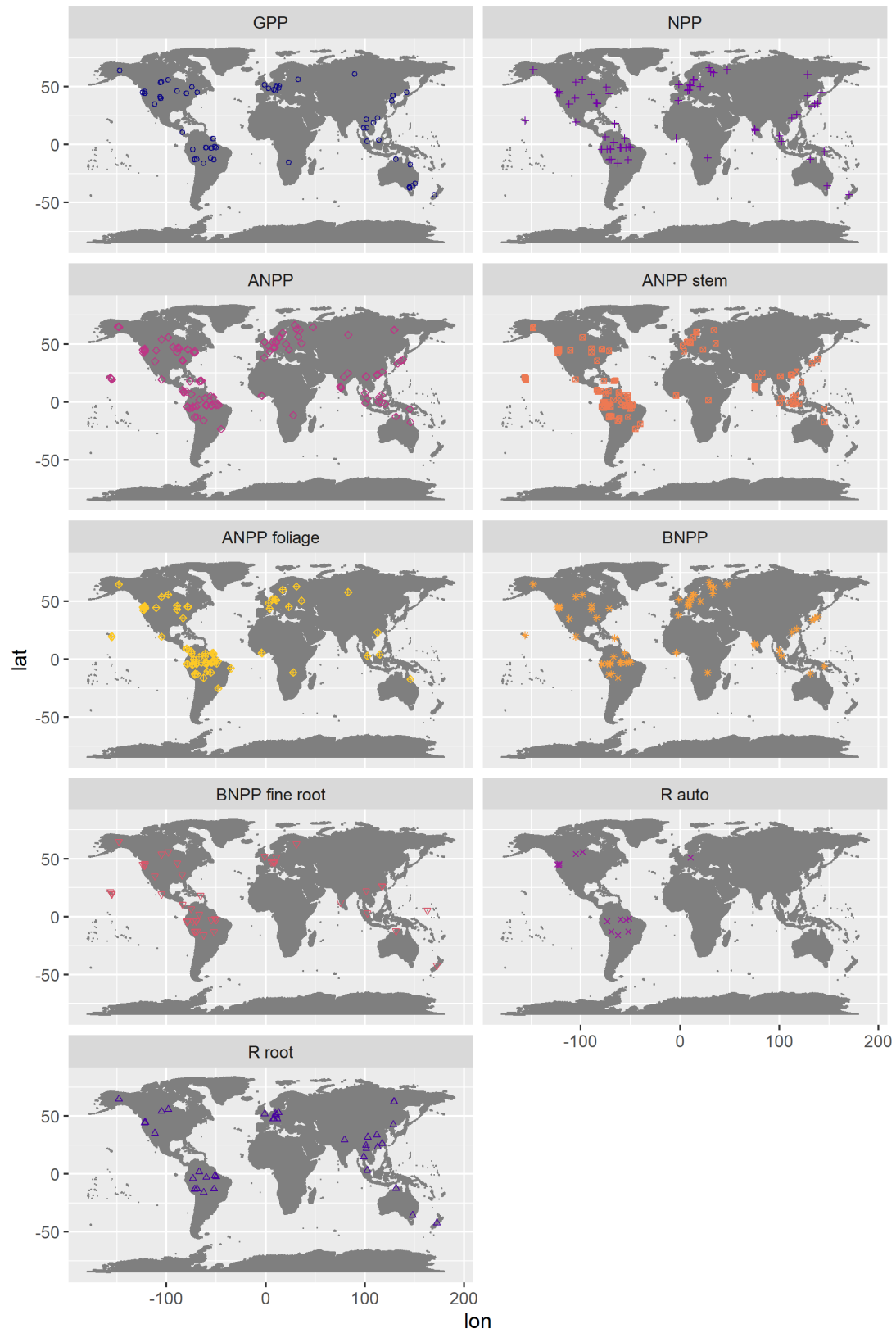


Figure S1: Maps showing distribution of samples for the nine forest C fluxes analyzed



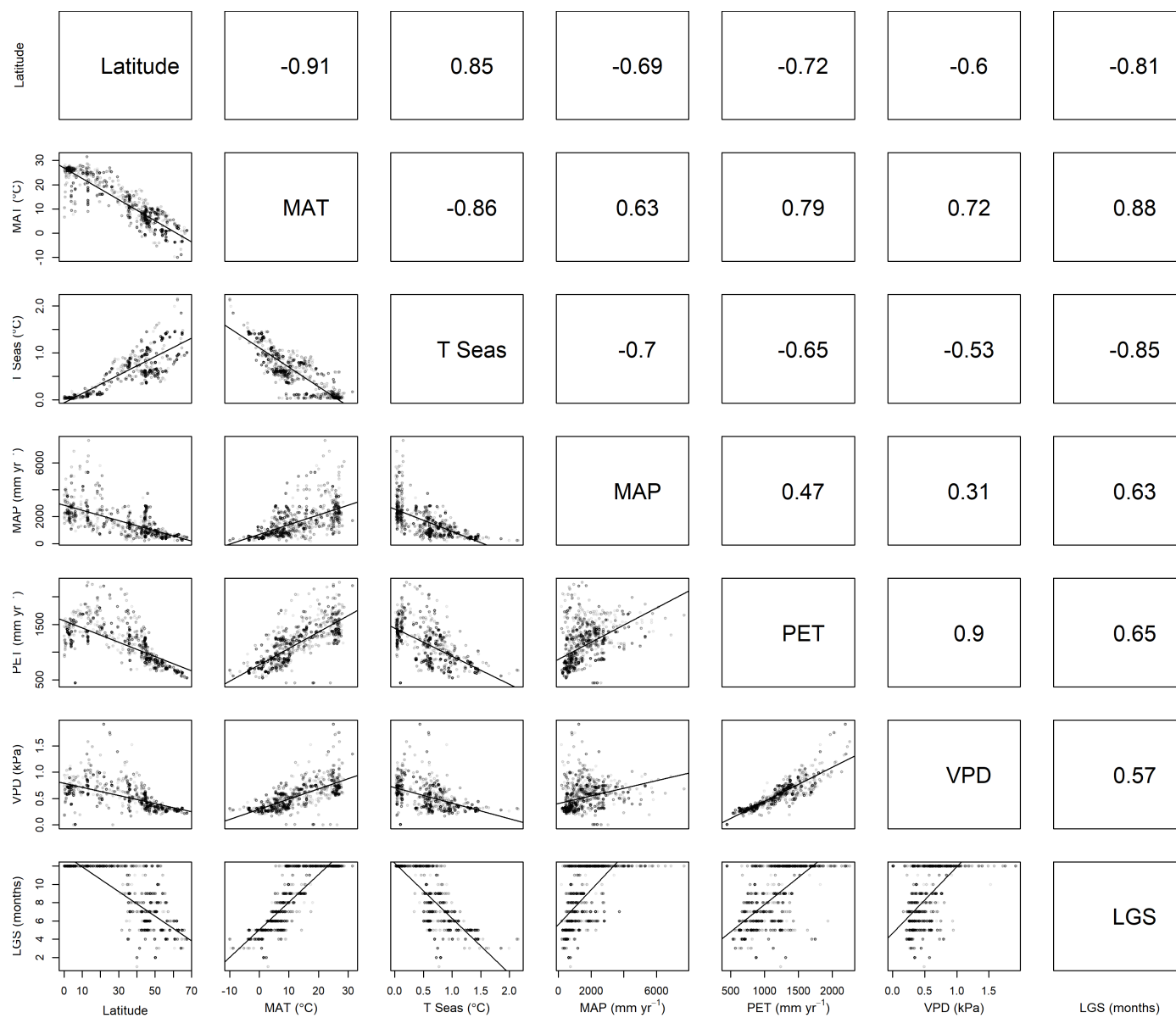


Figure S2: Scatterplots and Pearson's R values for relationships between latitude and climate variables



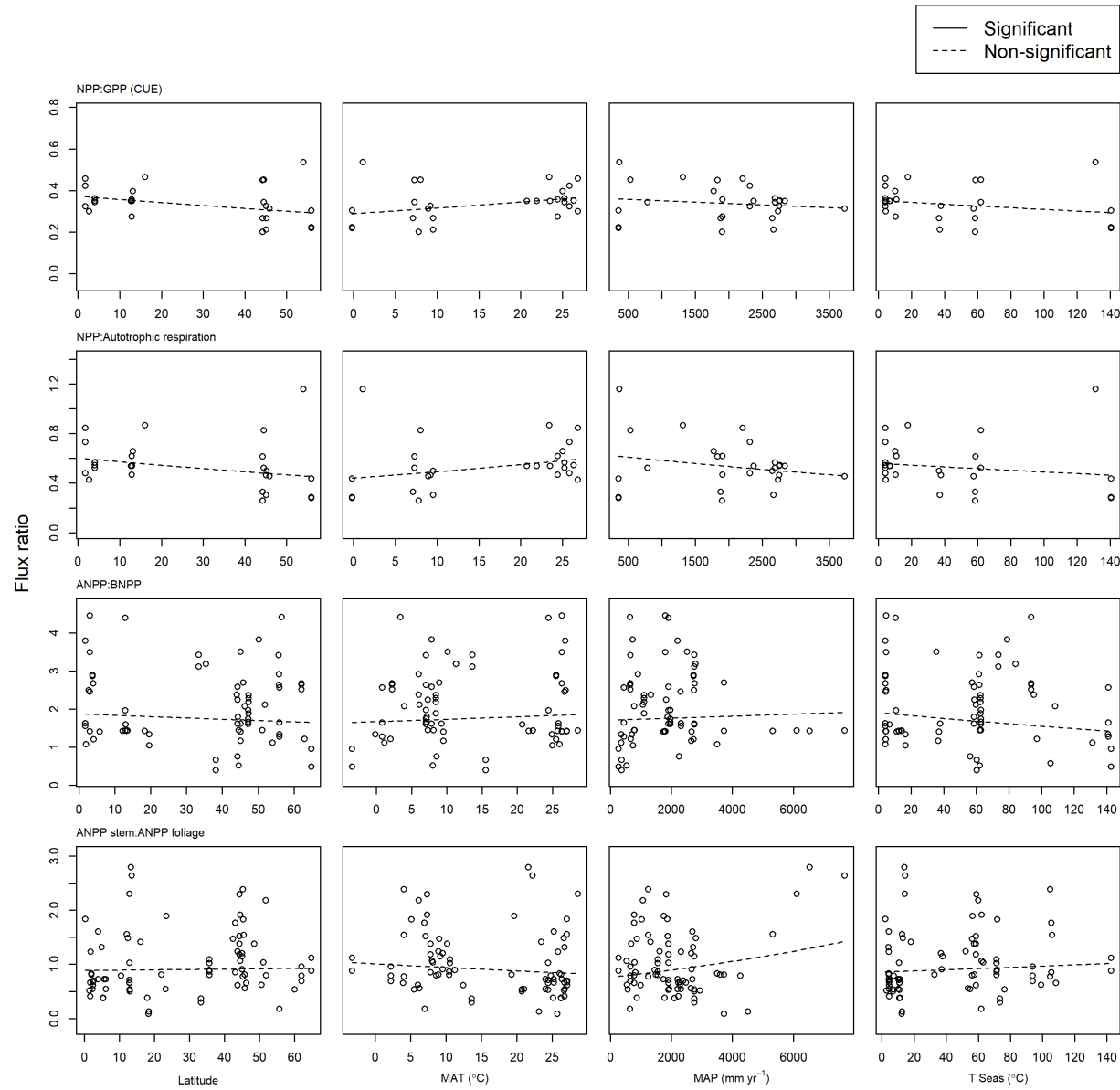


Figure S3: Ratios among forest C fluxes as a function of latitude and climate variables.

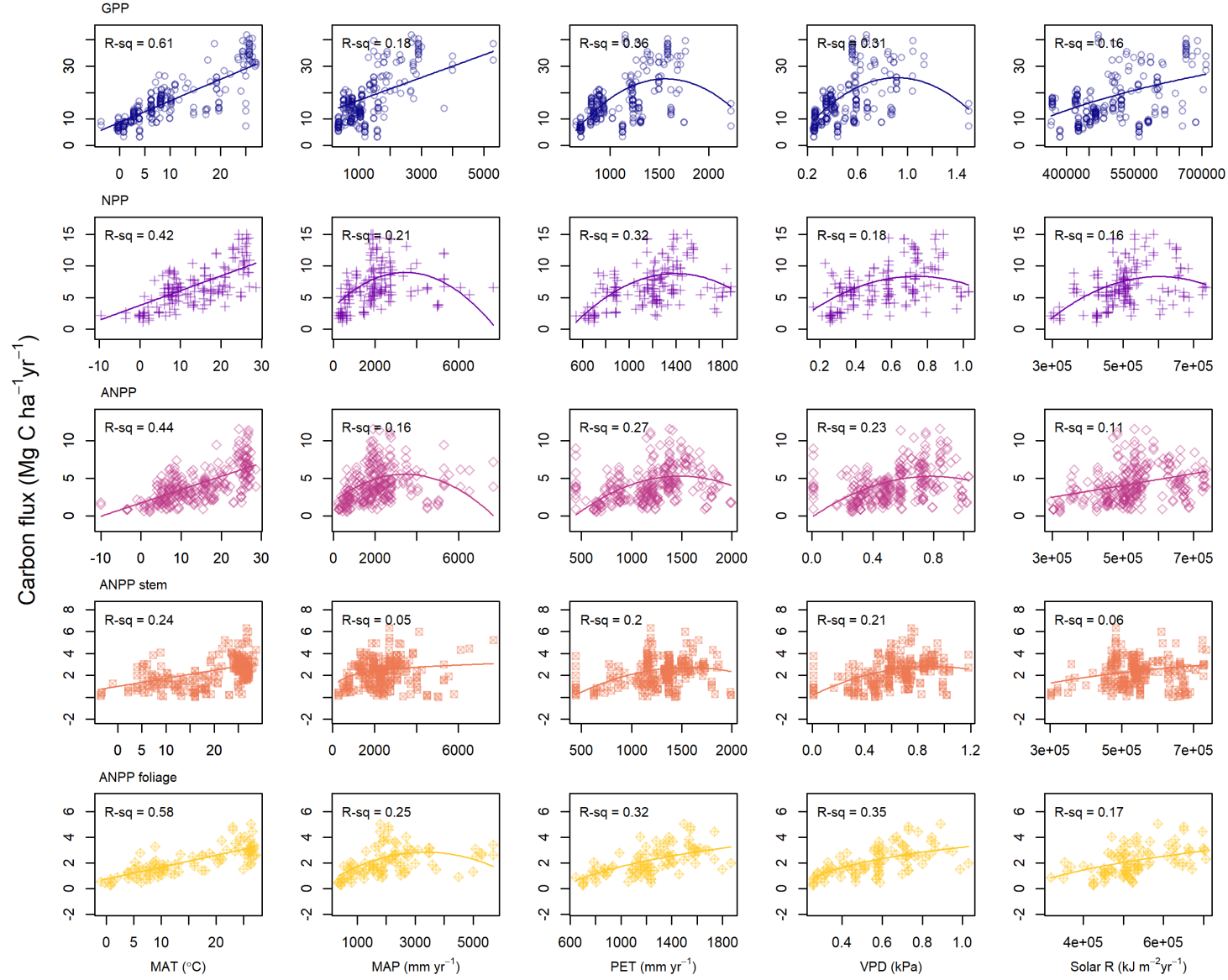


Figure S4: Individual plots of forest C fluxes in relation to mean annual climate, part 1.

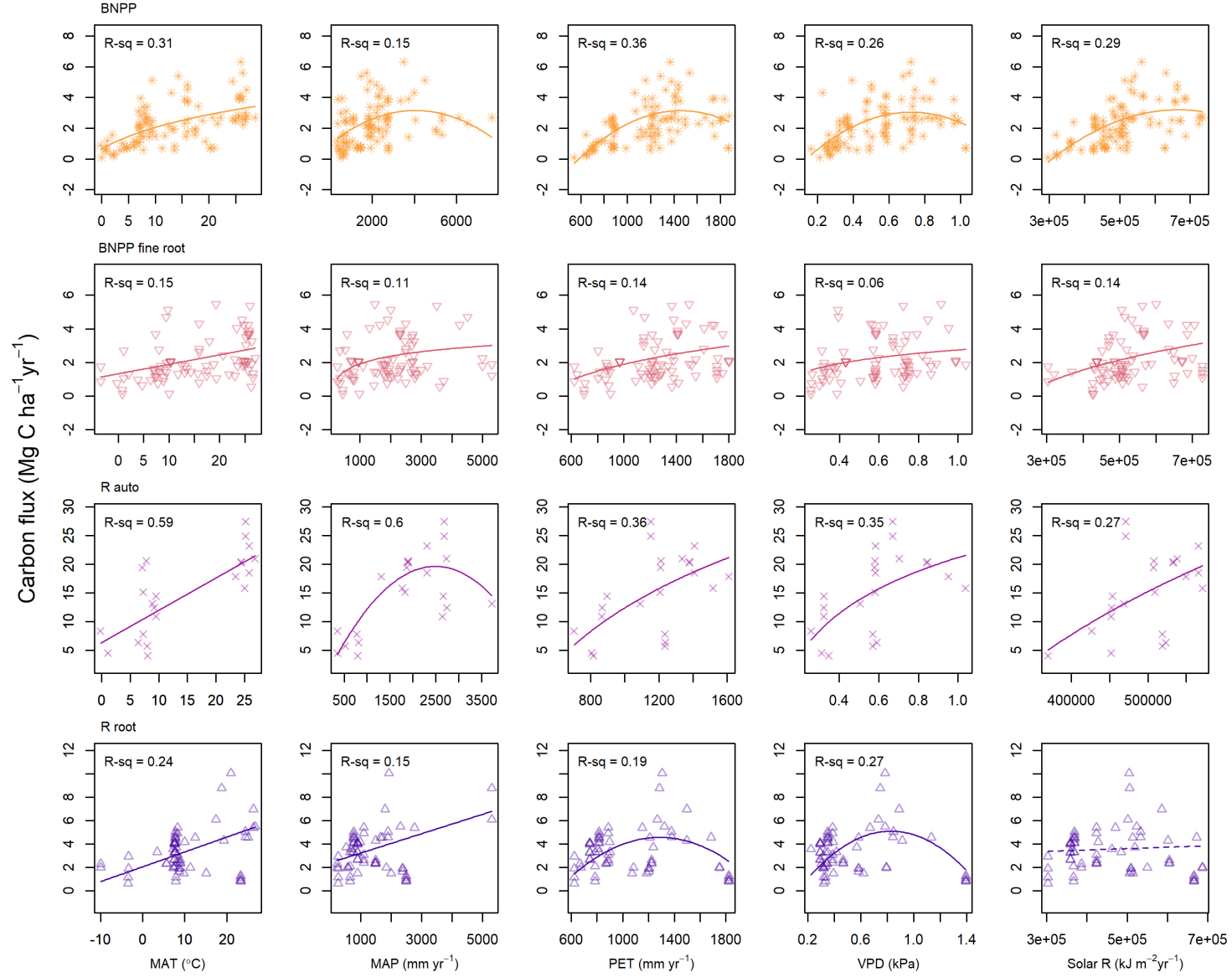


Figure S5: Individual plots of forest C fluxes in relation to mean annual climate, part 2.

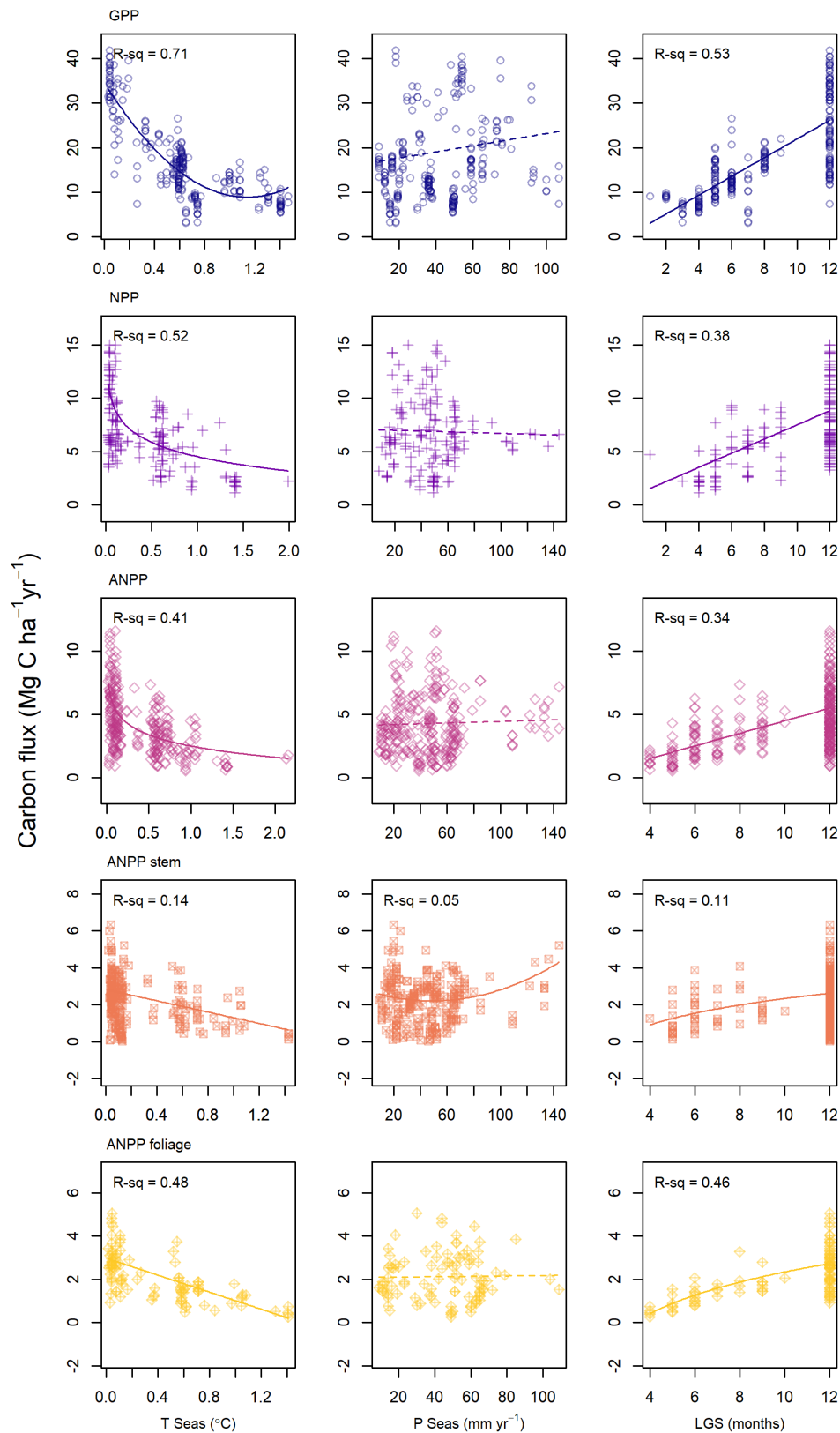


Figure S6: Individual plots of forest C fluxes in relation to mean climate seasonality, part 1.

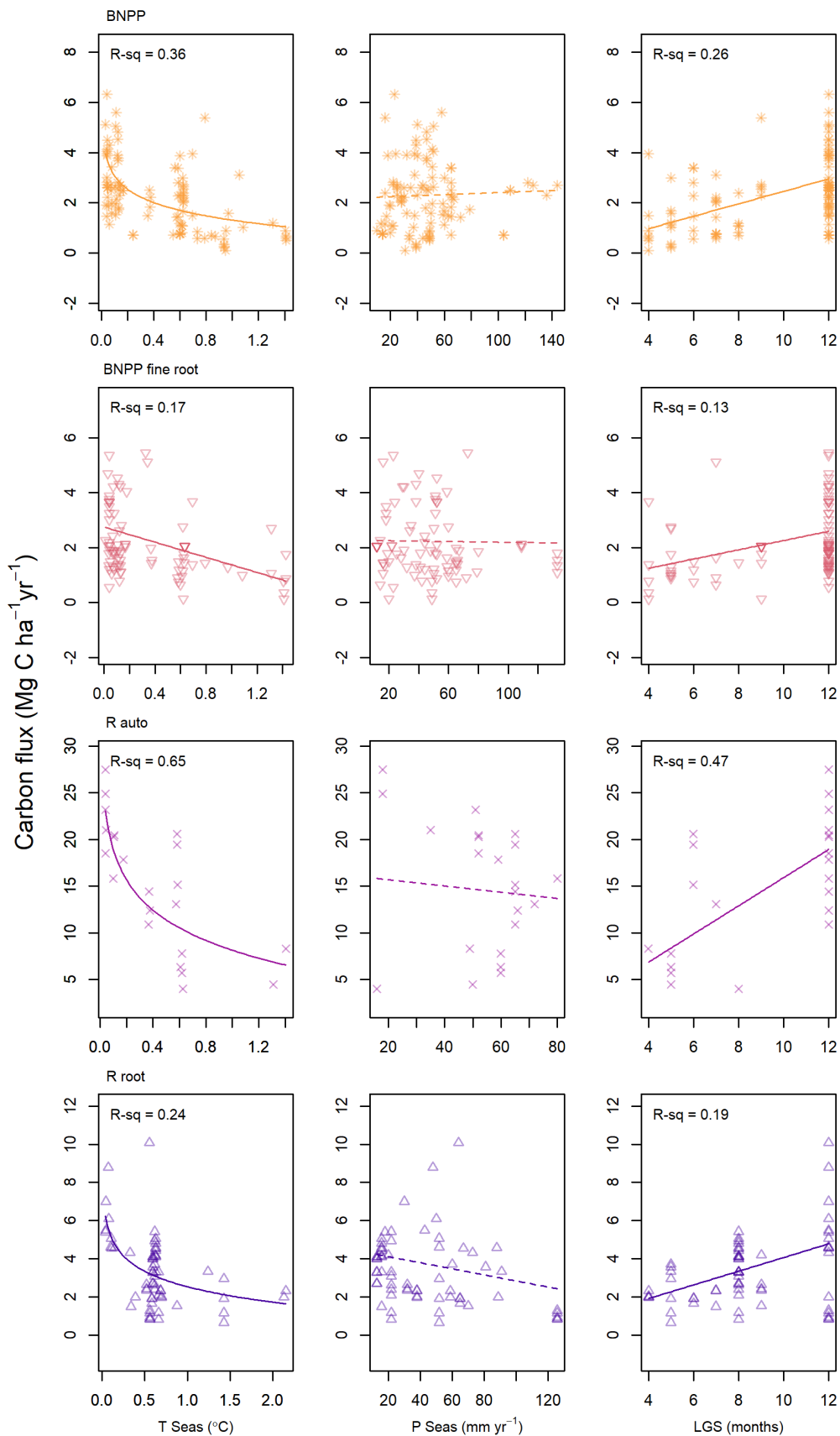


Figure S7: Individual plots of forest C fluxes in relation to mean climate seasonality, part 2.

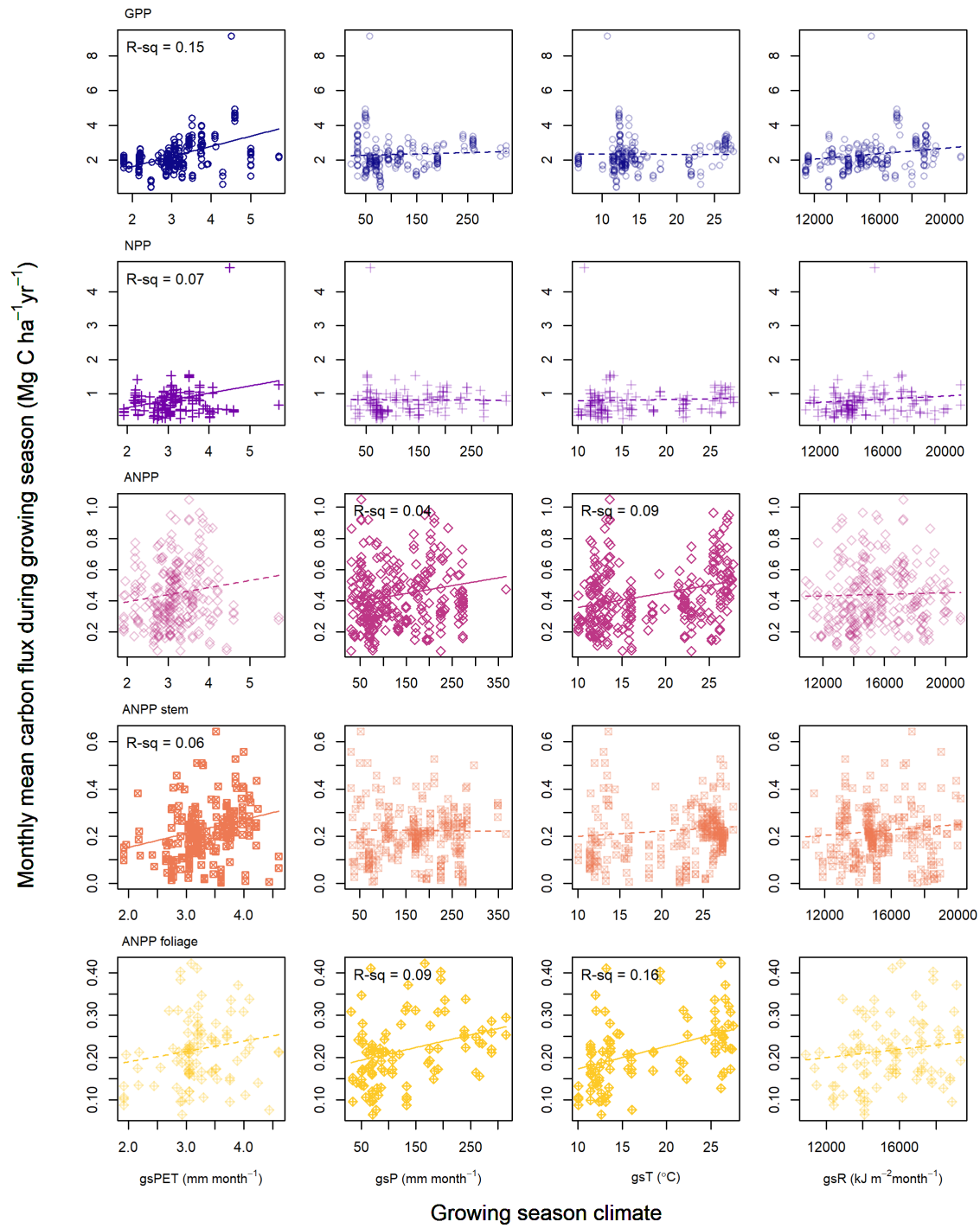


Figure S8: Growing season length-standardized forest C fluxes in relation to mean growing season climate, part 1.



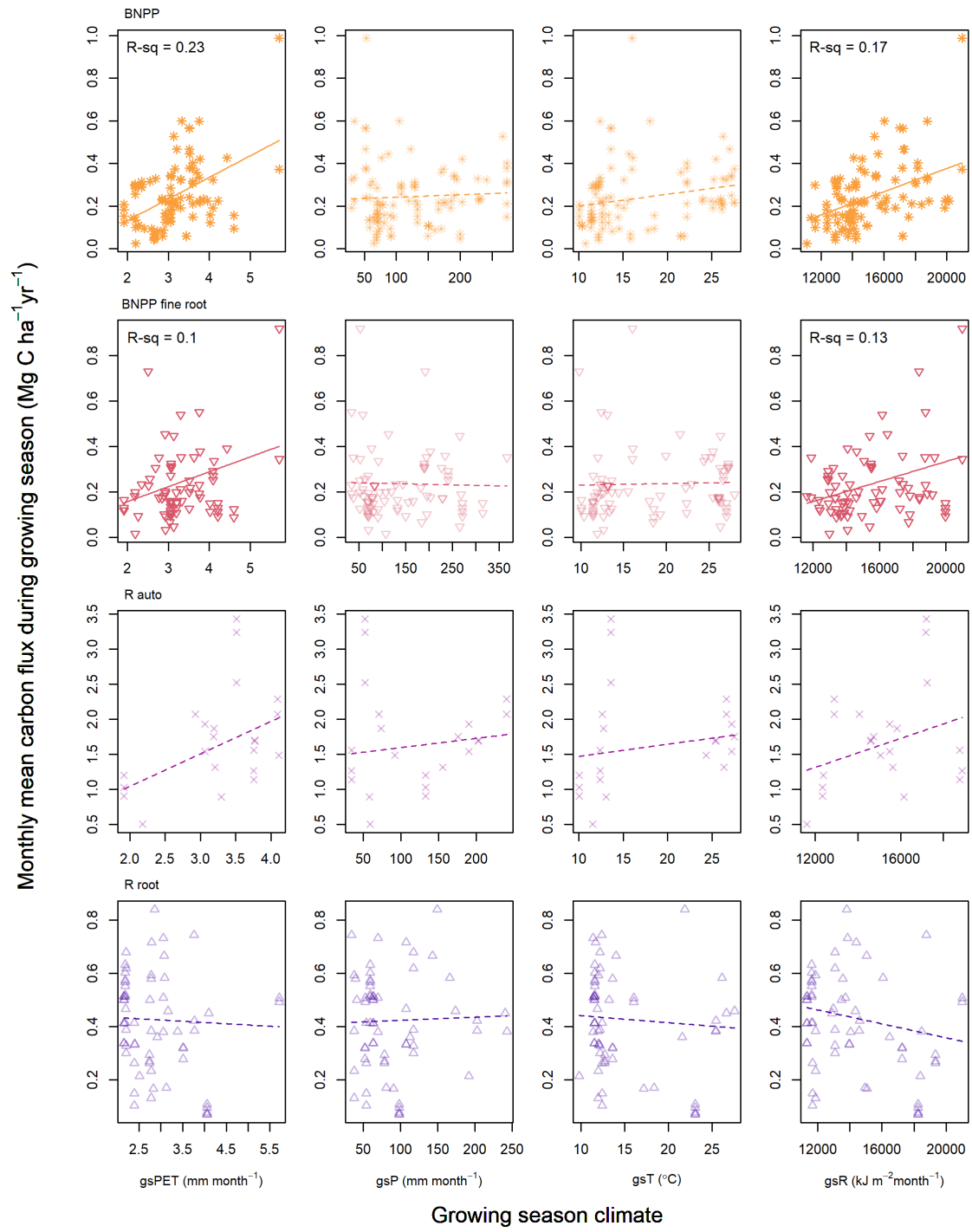


Figure S9: Growing season length-standardized forest C fluxes in relation to mean growing season climate, part 2.

## References