

Theoretical and Applied Climatology

Supporting Information for

An innovative framework for quantifying eco-meteorological droughts in Iran rangeland ecosystems using Copula functions

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Section A.

Figure S1 shows the network of the Thiessen polygons for the studied synoptic stations. The area of each Thiessen polygon is considered as the weight of the monthly precipitation time series of its station to compute the weighted average monthly precipitation for each bio-climatic region.

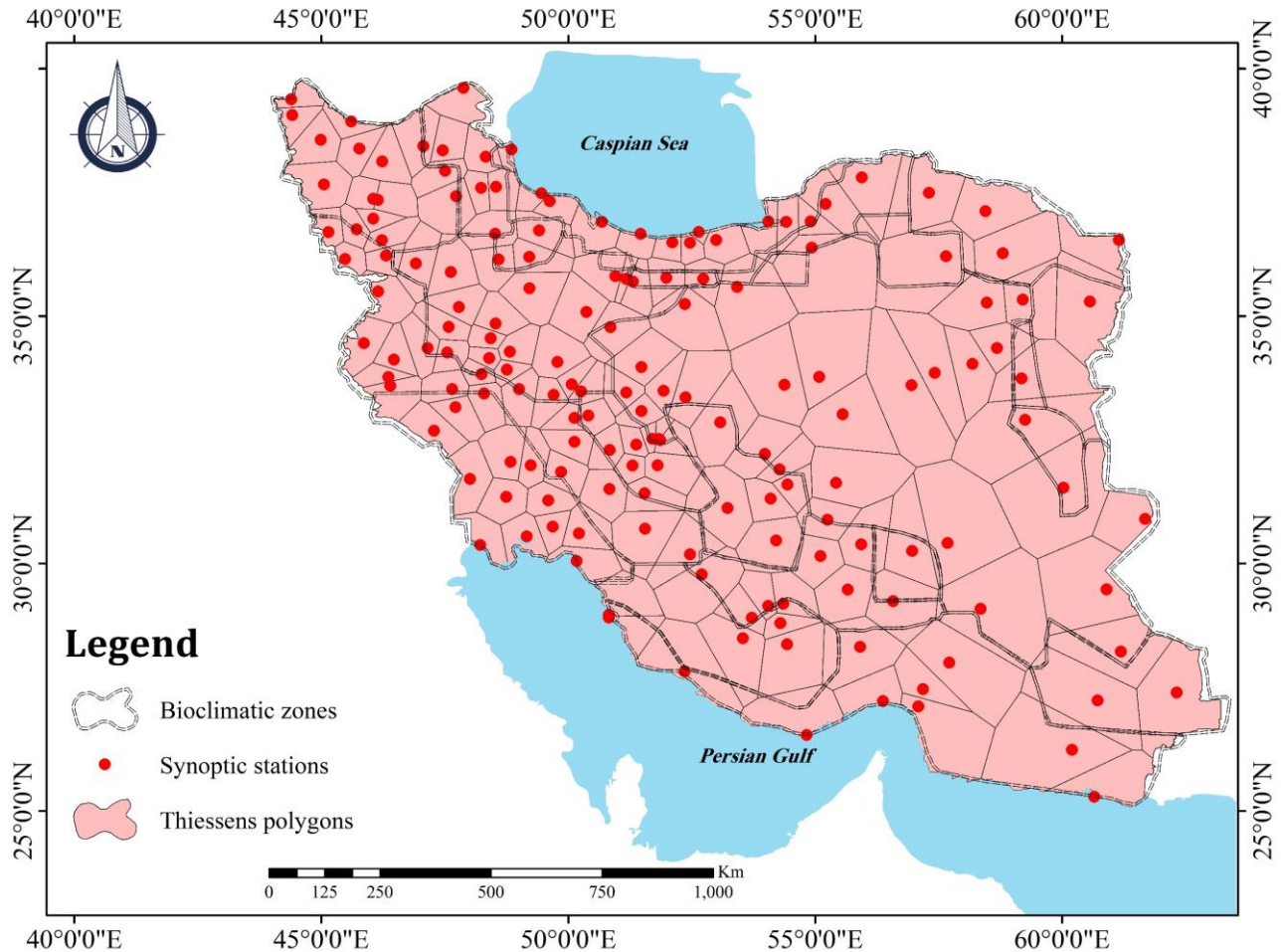


Figure S1. The network of the Thiessen polygons for the studied synoptic stations.

Section B.

In order to determine the most effective component of the SPI index for VHI changes for each month of the year within the studied bioclimatic sub-regions, the cross-correlation analysis between VHI and different SPI components was done separately in each sub-region. The results are shown in Figures S2_S25.

Region:Region_01_Eastern

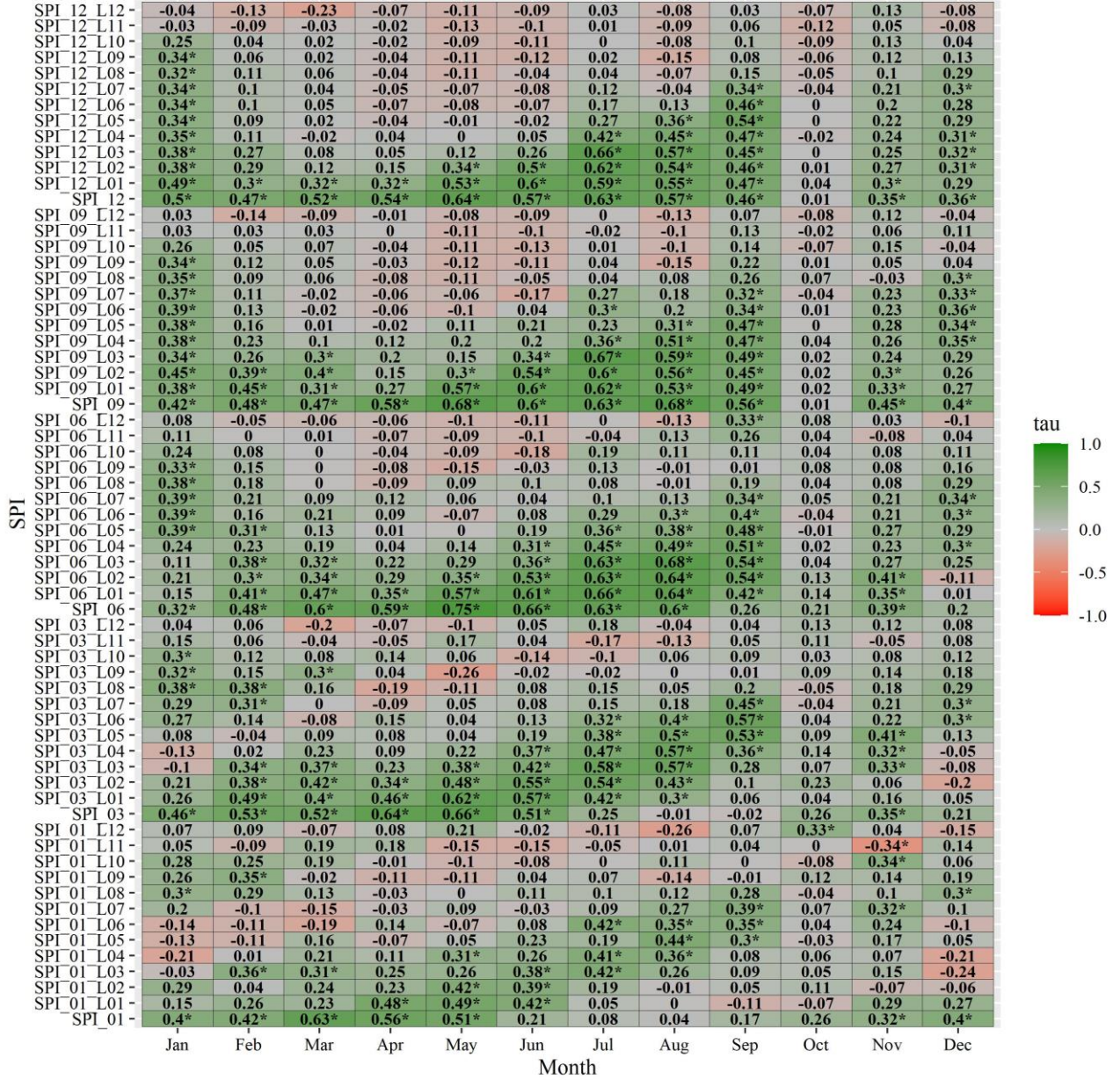


Figure S2. Kendall's correlation coefficients between VHI variation of each month and different SPI components in sub-region_01_Eastern. For the vertical axis labels, the middle and right numbers represent the time-scale and lag-time of the SPI component, respectively.

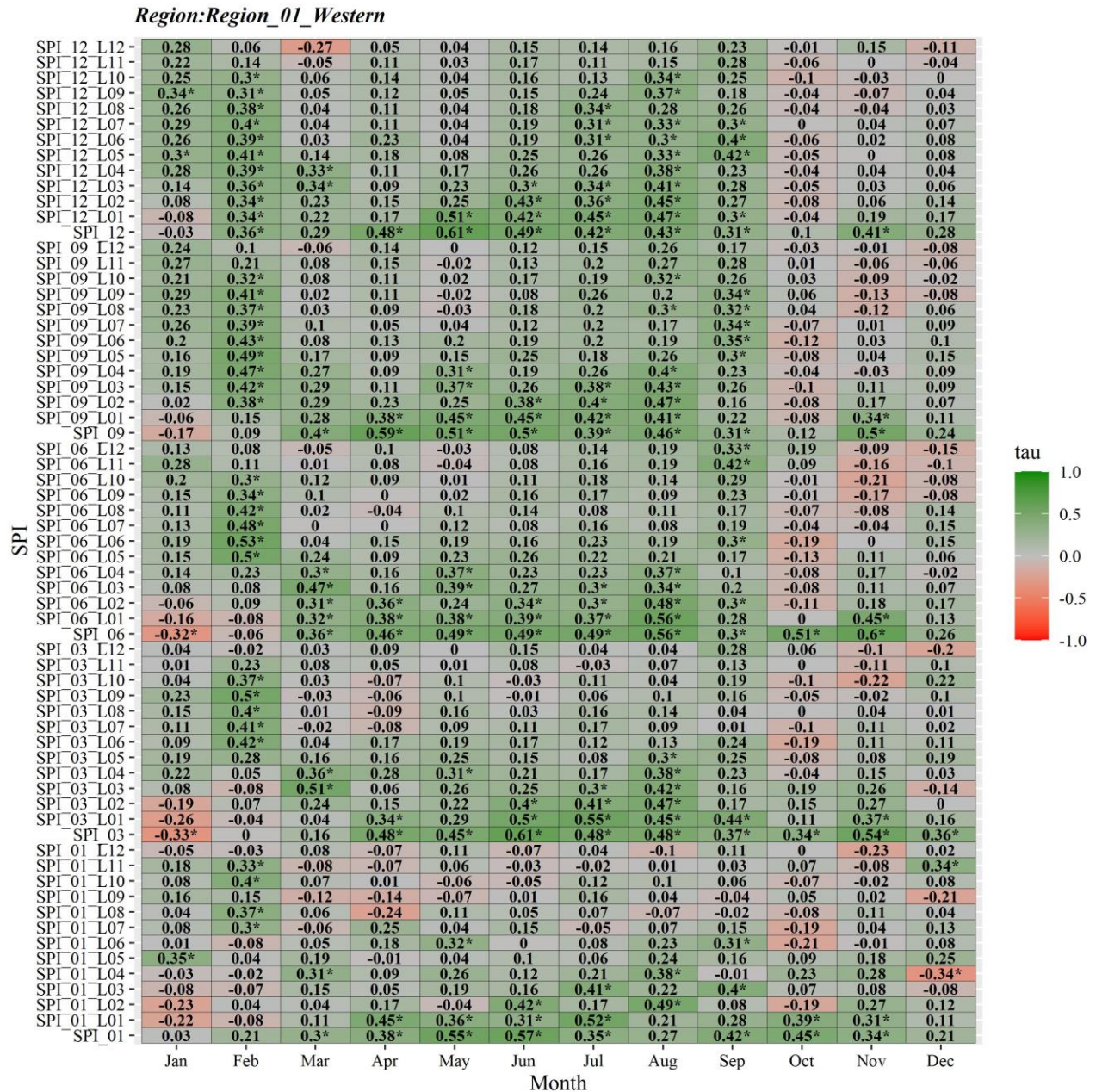


Figure S3. Same as Fig. S2 but for sub-region_01_western.

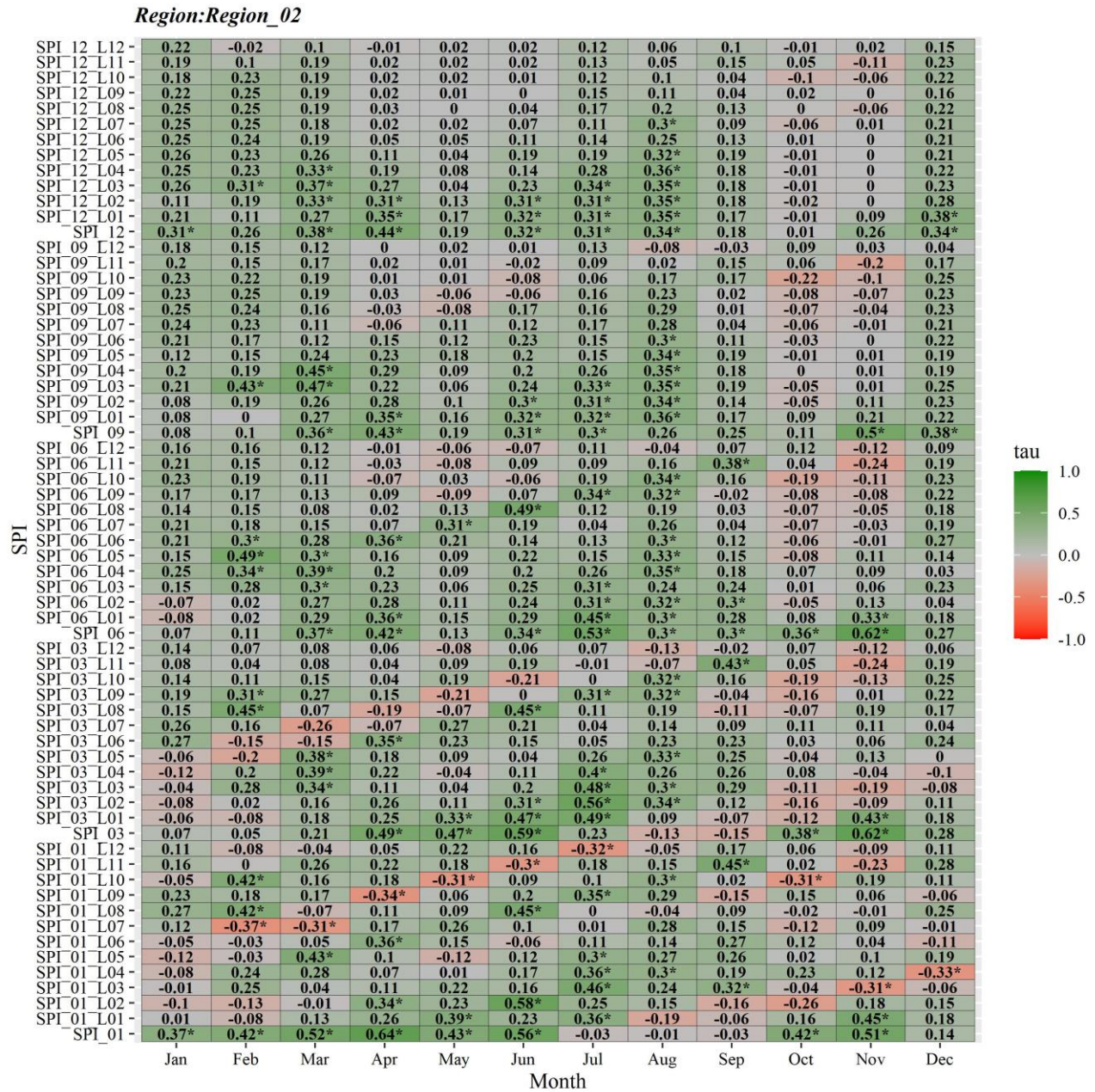


Figure S4. Same as Fig. S2 but for sub-region_02.

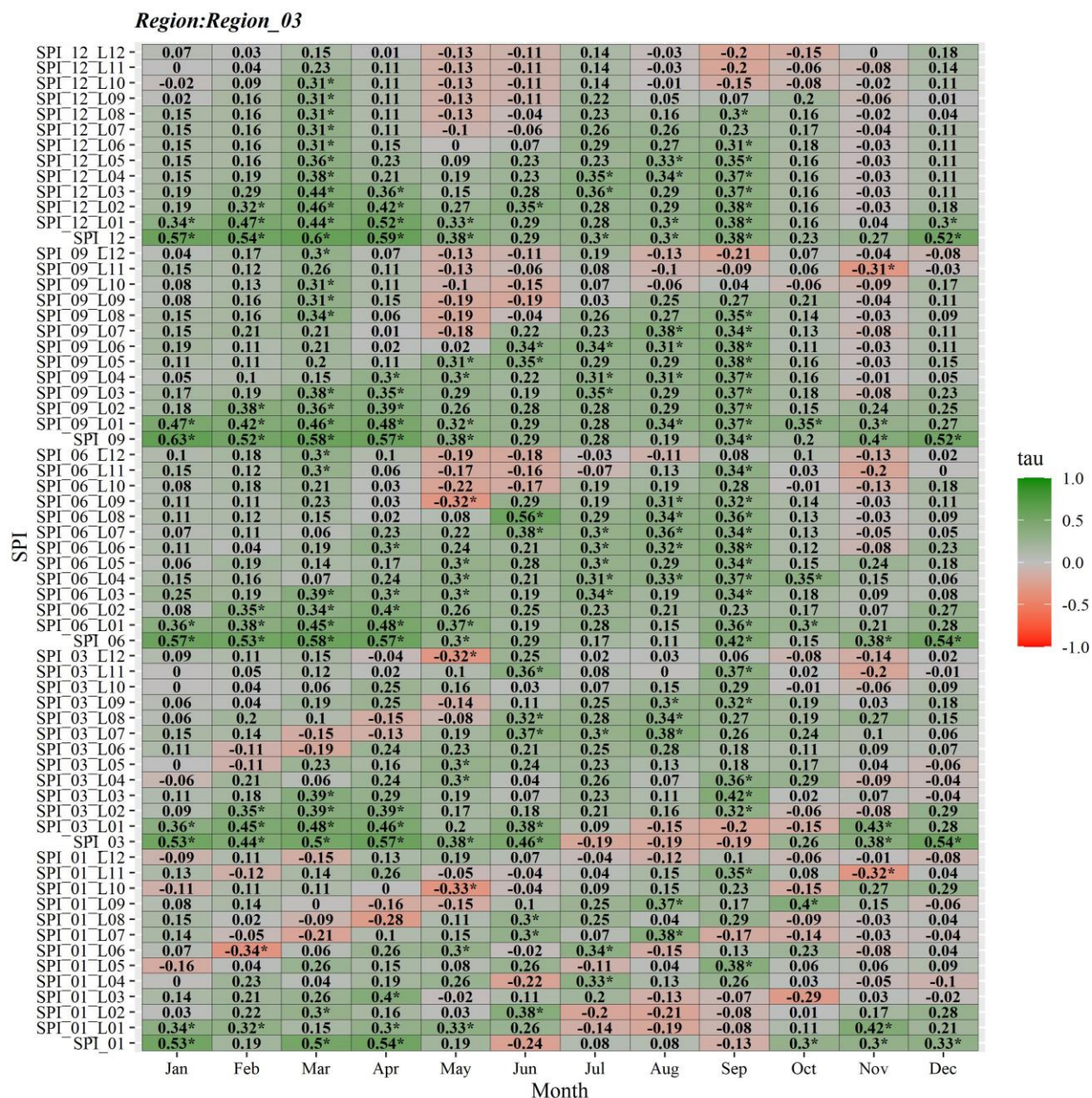


Figure S5. Same as Fig. S2 but for sub-region_03.

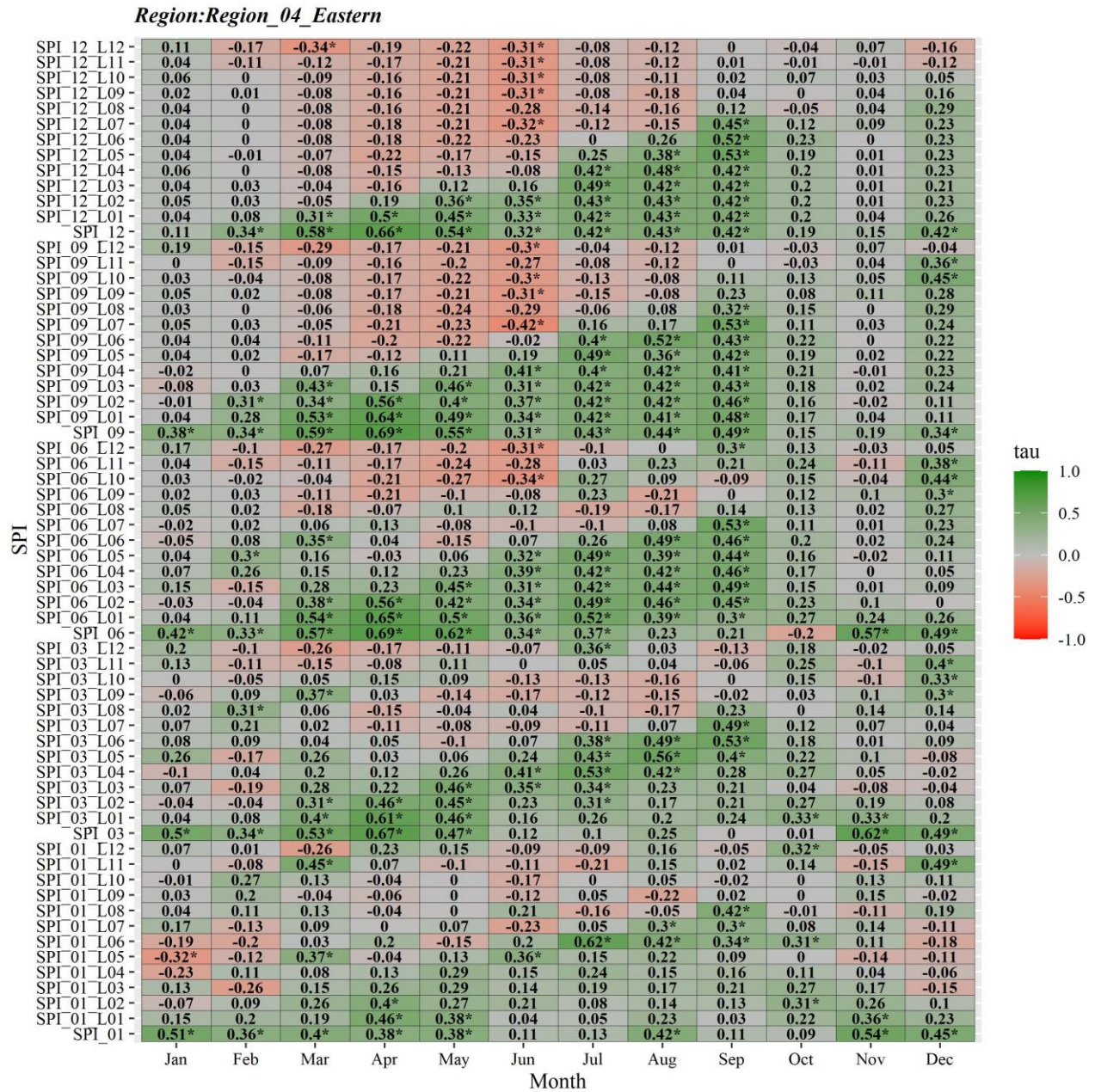


Figure S6. Same as Fig. S2 but for sub-region_04_Eastern.

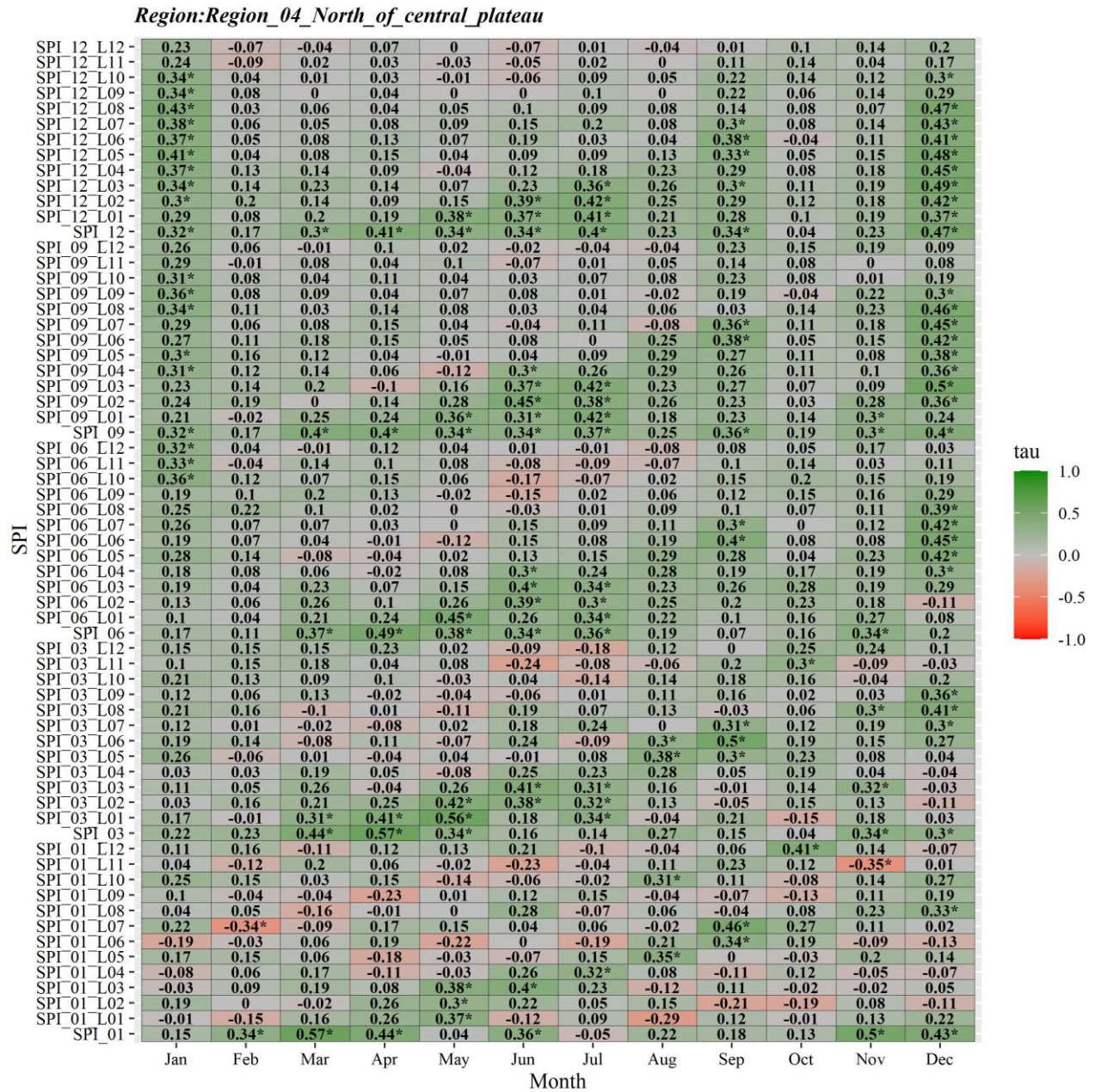


Figure S7. Same as Fig. S2 but for sub-region_04_North of the central plateau.

Region:Region_04_Northeastern_of_central_plateau

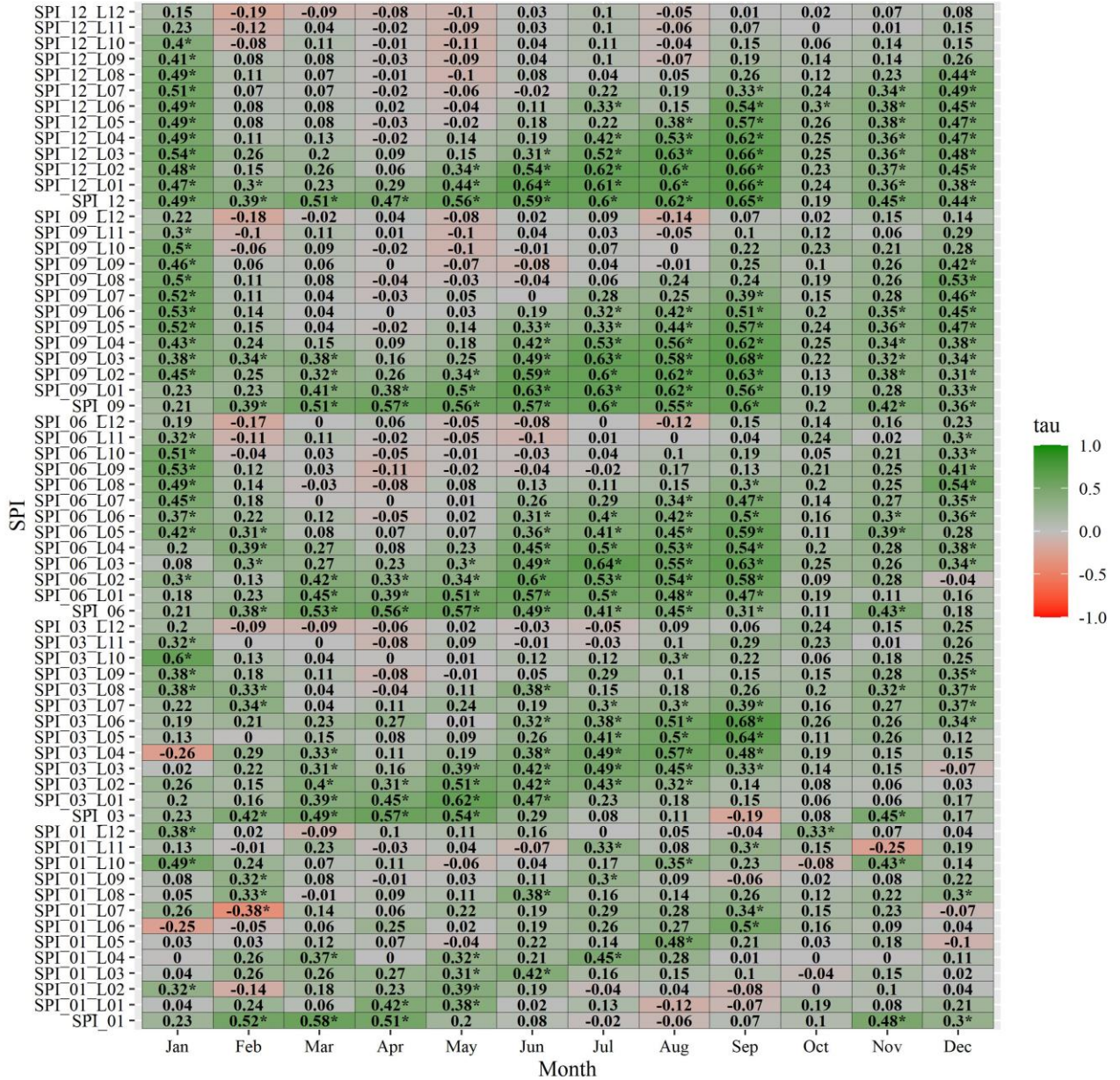


Figure S8. Same as Fig. S2 but for sub-region_04_Northeastern of the central plateau.

Region:Region_04_Northwestern_of_central_plateau

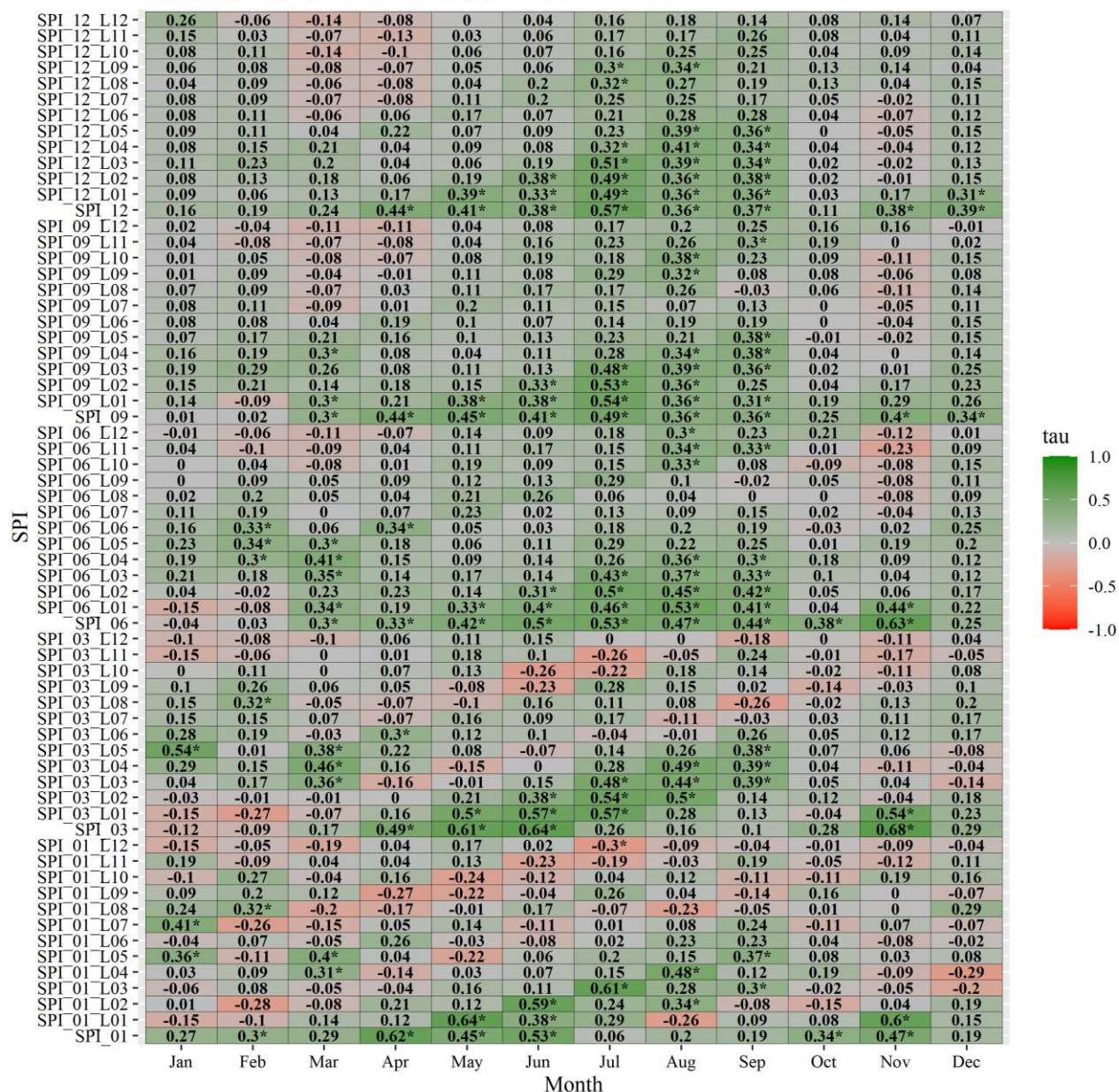


Figure S9. Same as Fig. S2 but for sub-region_04_Northwestern of the central plateau.

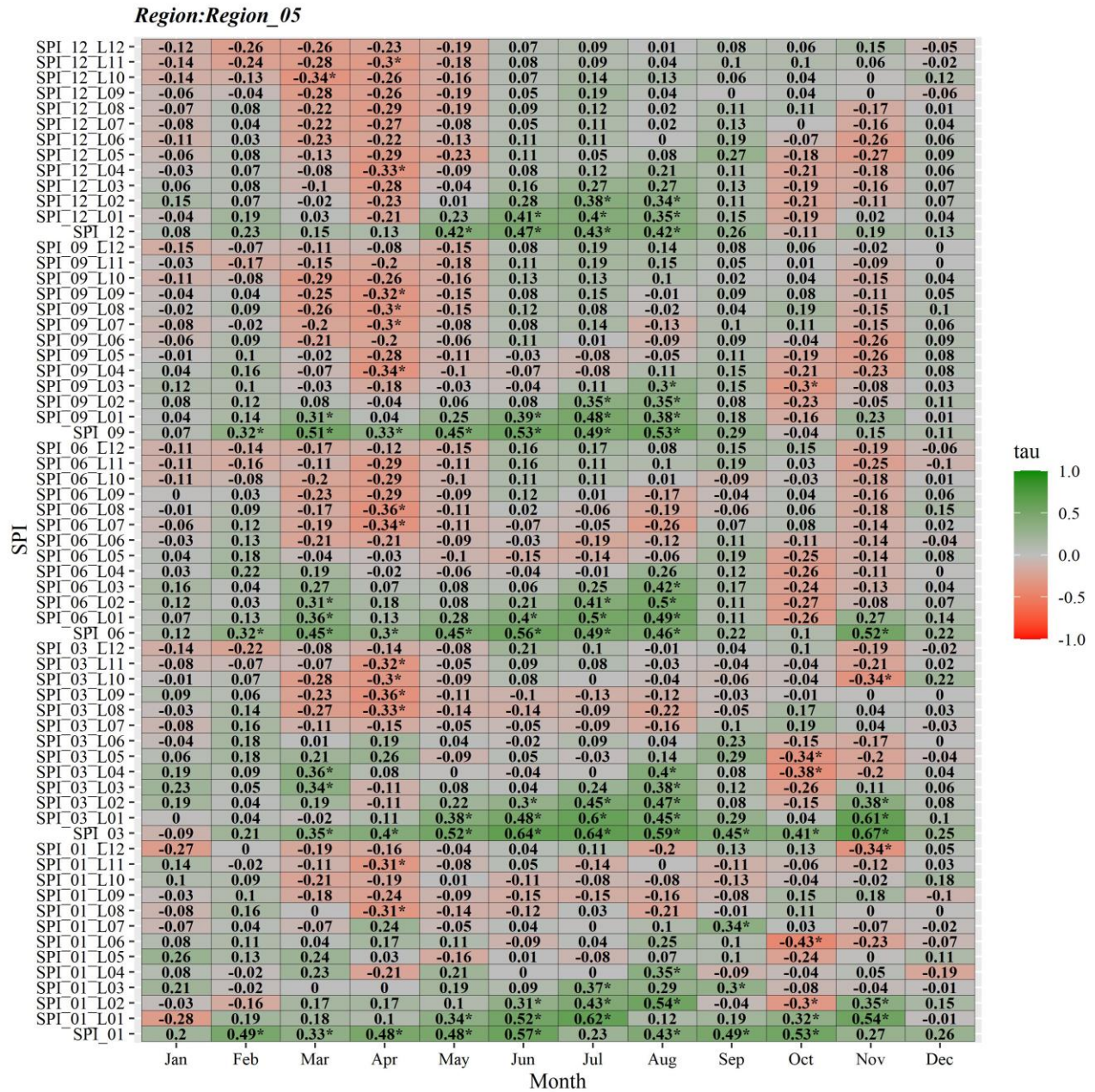


Figure S10. Same as Fig. S2 but for sub-region_05.

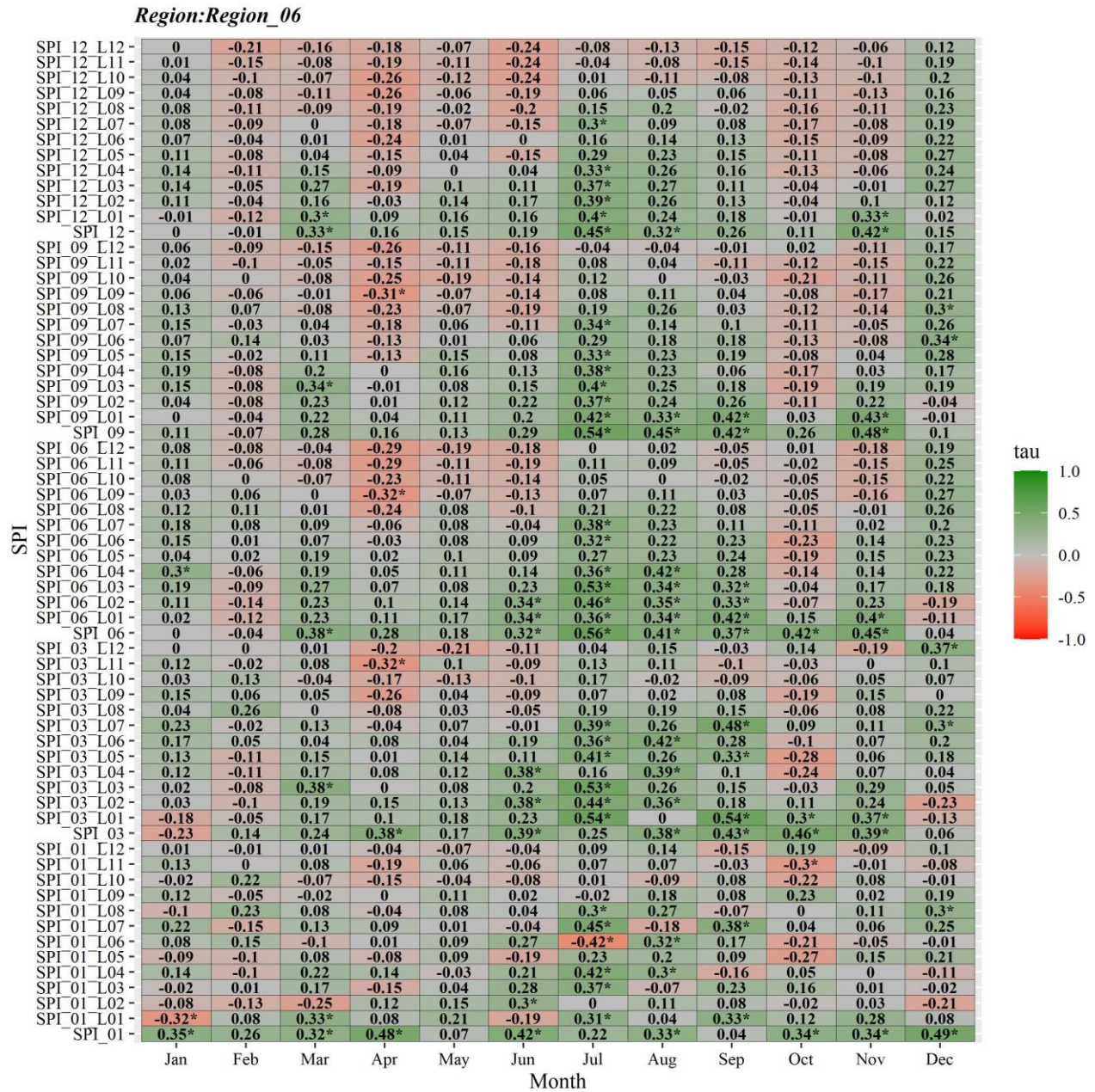


Figure S11. Same as Fig. S2 but for sub-region_06.

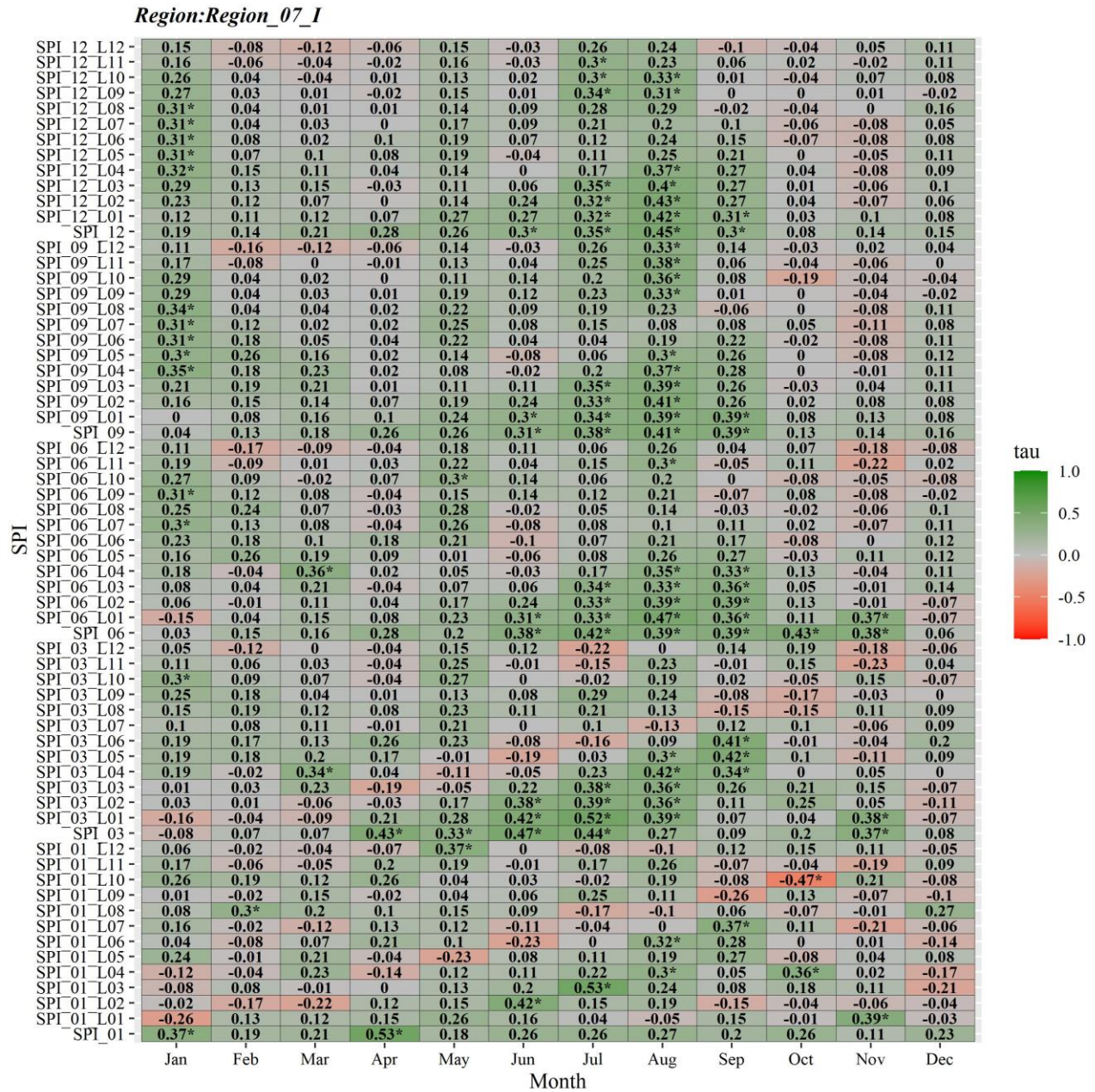


Figure S12. Same as Fig. S2 but for sub-region_07_I.

Region:Region_07_II

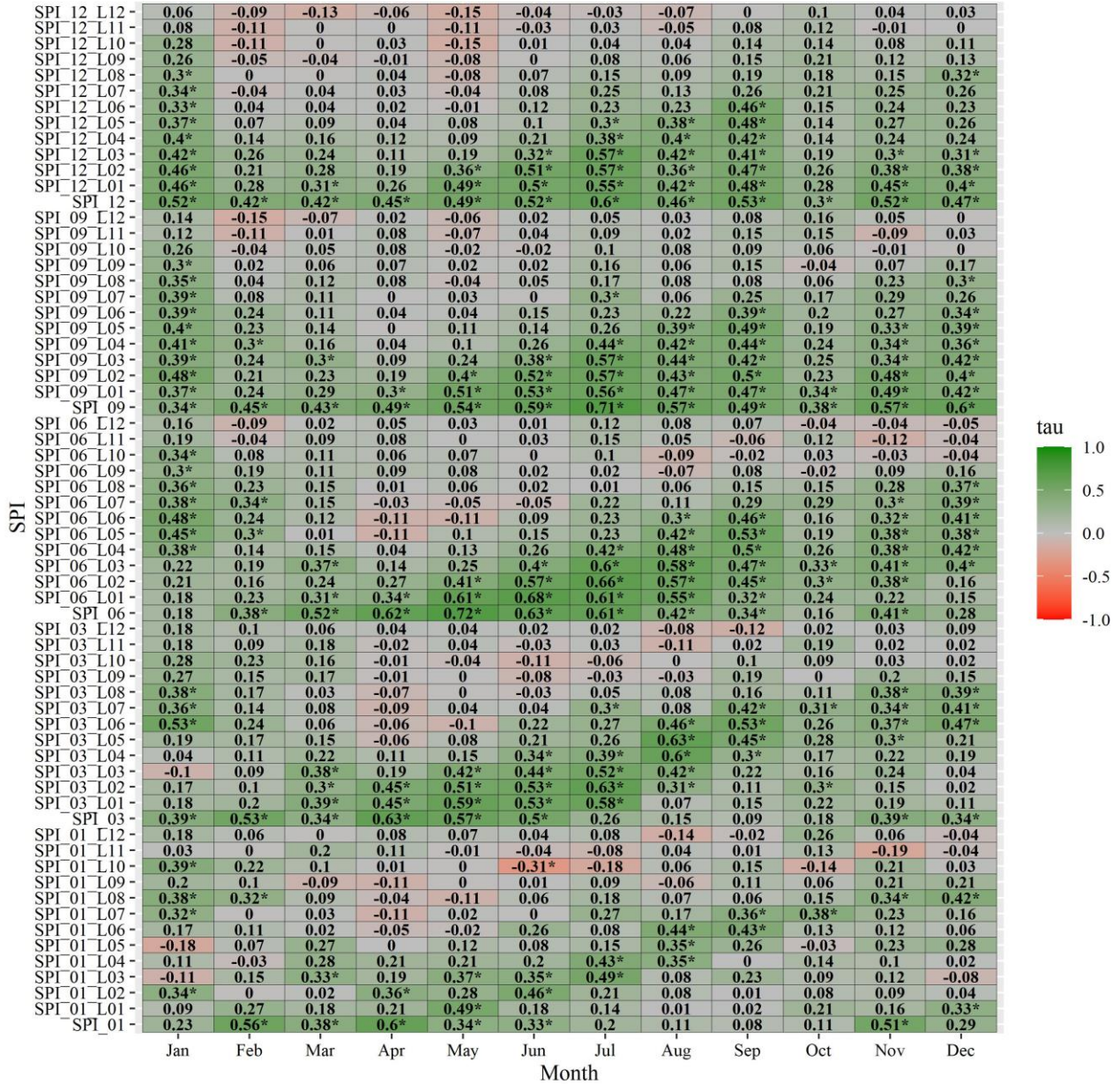


Figure S13. Same as Fig. S2 but for sub-region_07_II.

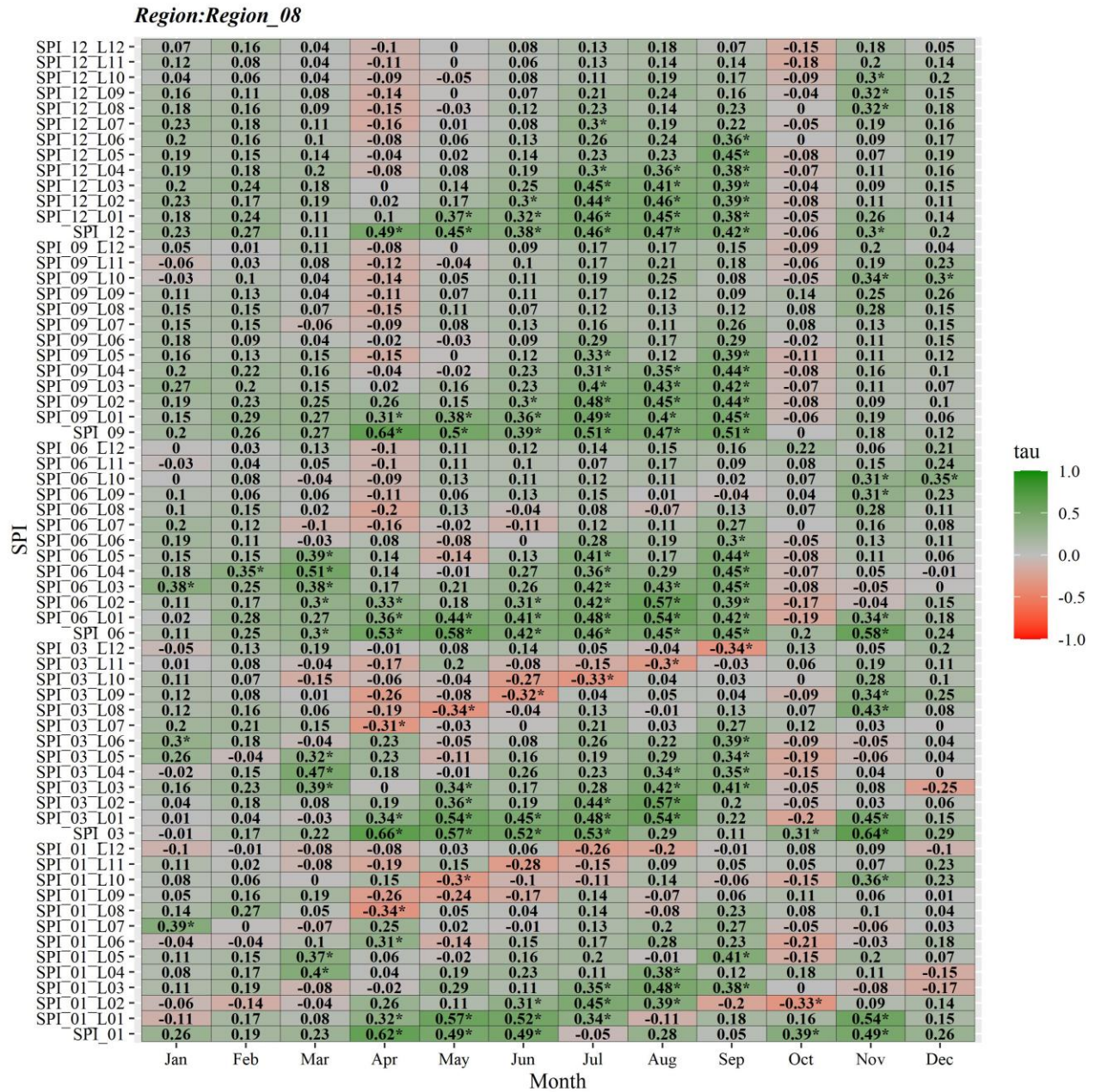


Figure S14. Same as Fig. S2 but for sub-region_08.

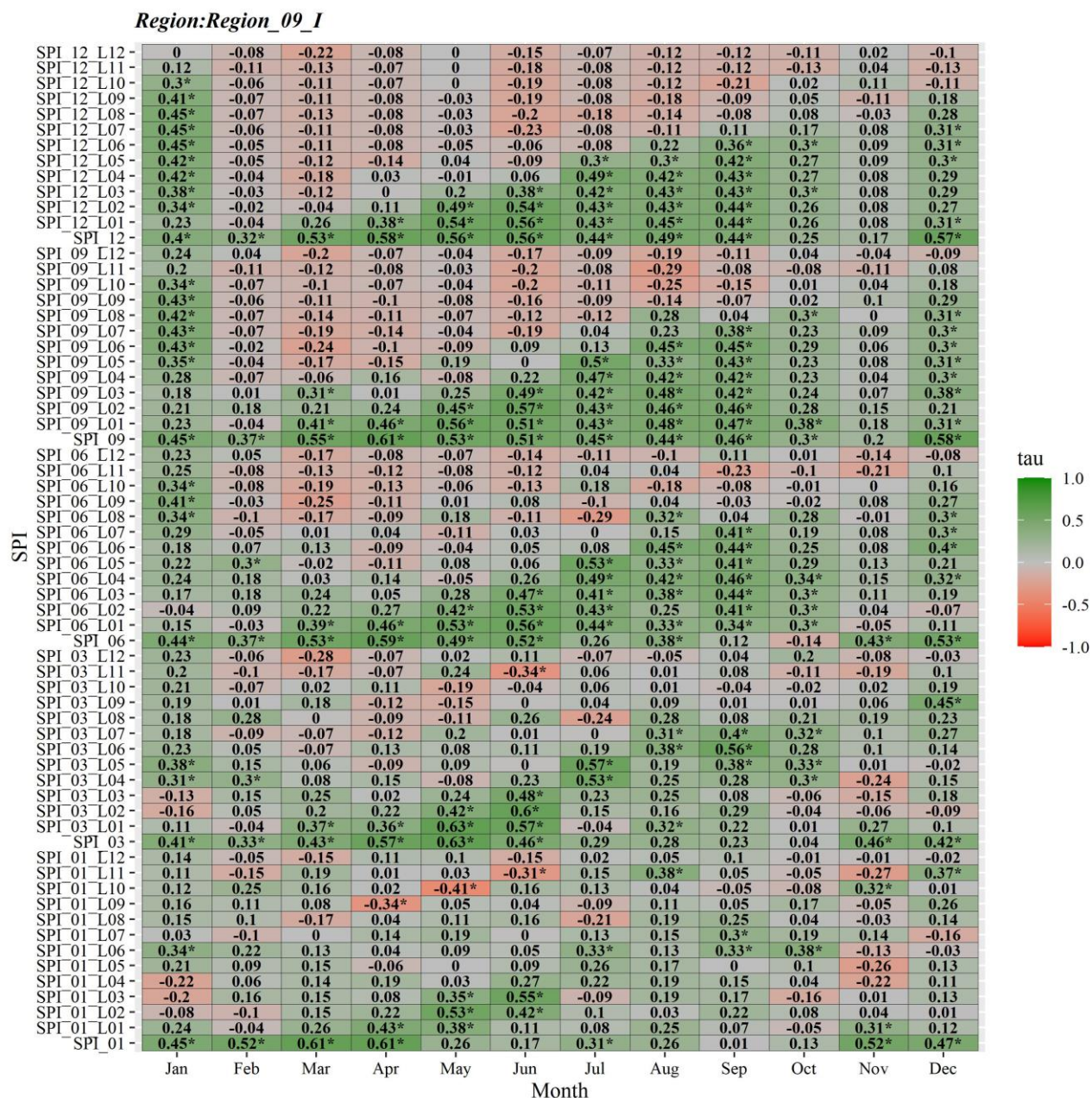


Figure S15. Same as Fig. S2 but for sub-region_09_I.

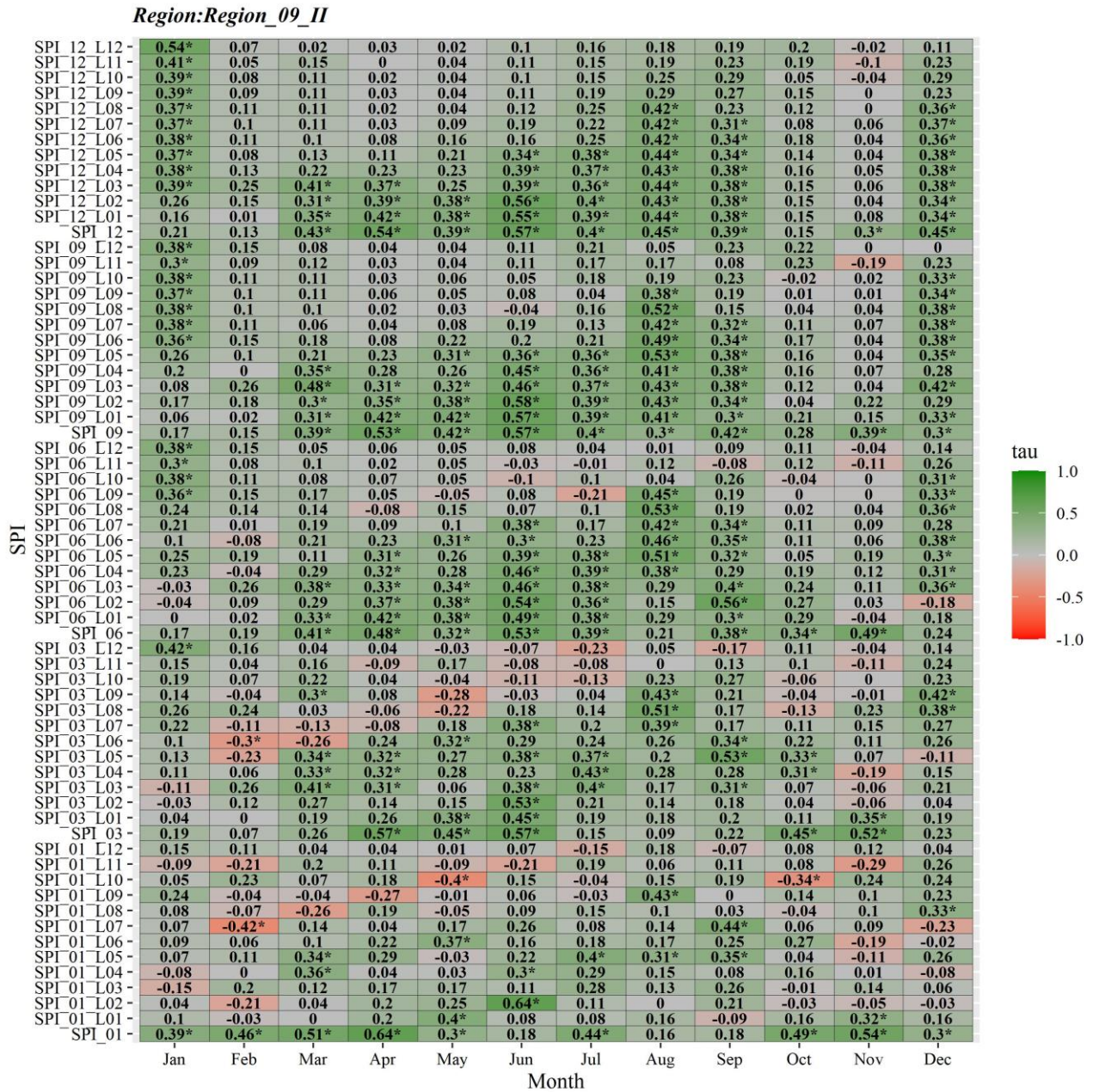


Figure S16. Same as Fig. S2 but for sub-region_09_II.

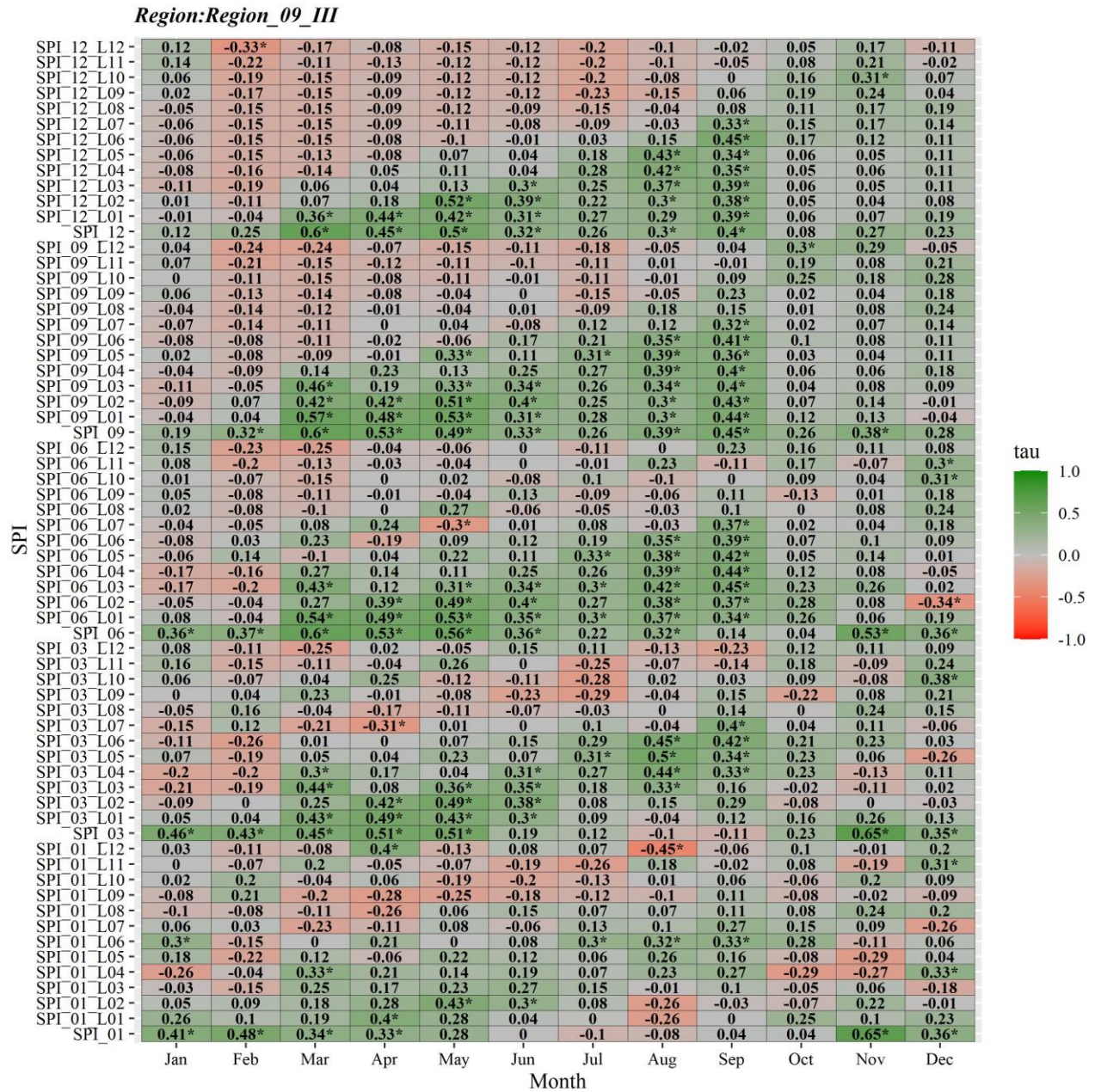


Figure S17. Same as Fig. S2 but for sub-region_09_III.

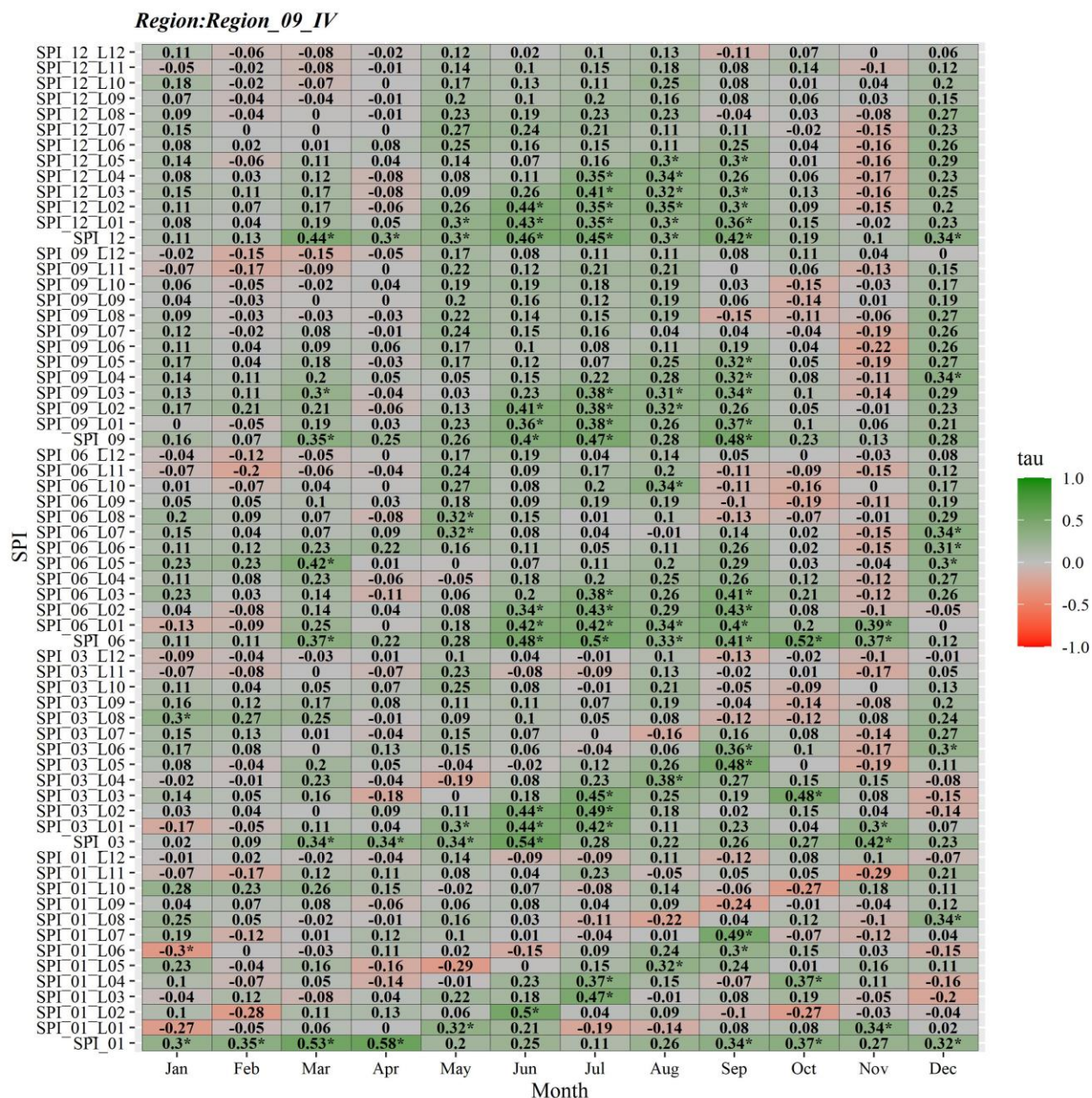


Figure S18. Same as Fig. S2 but for sub-region_09_IV.

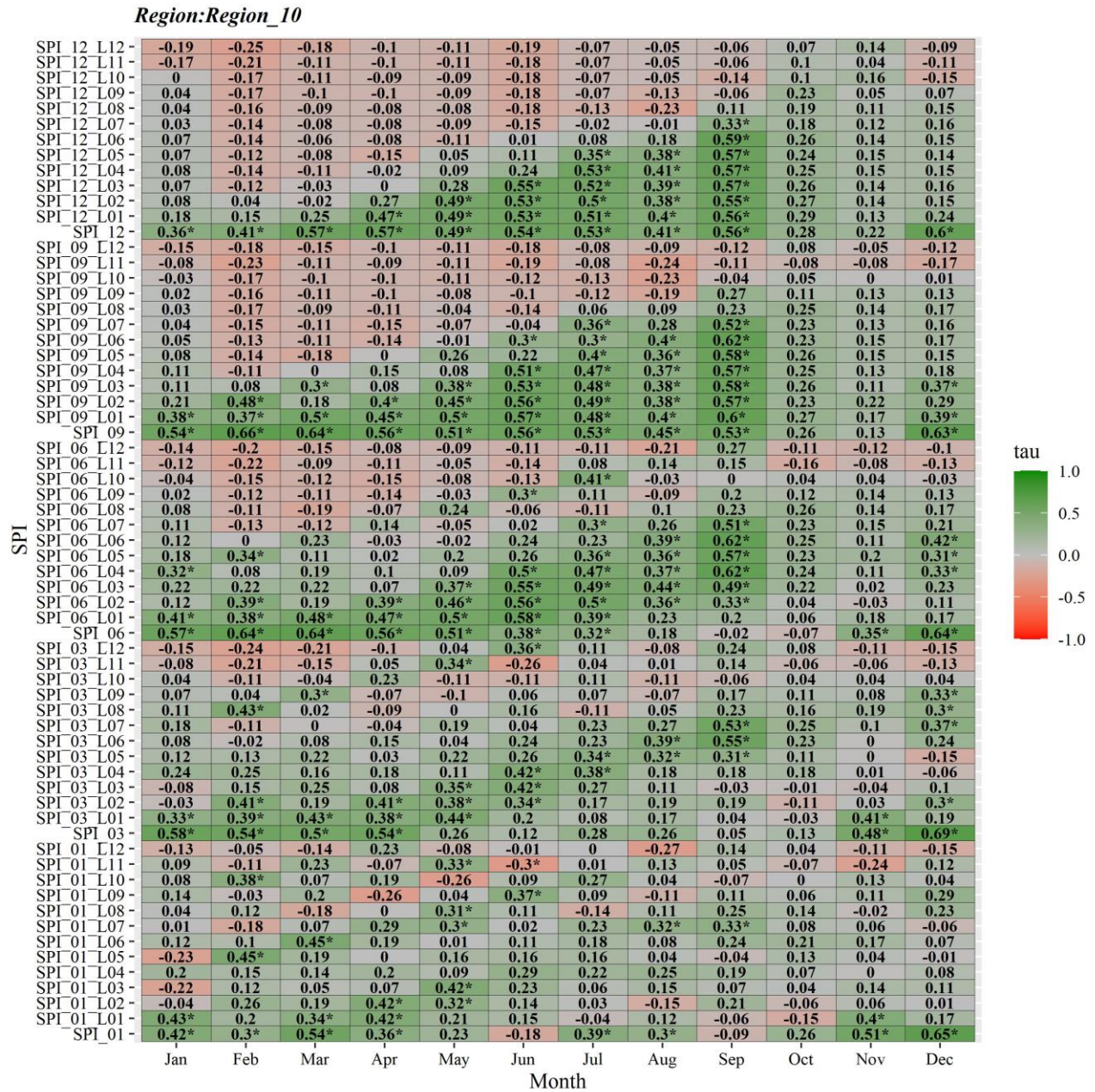


Figure S19. Same as Fig. S2 but for sub-region_10.

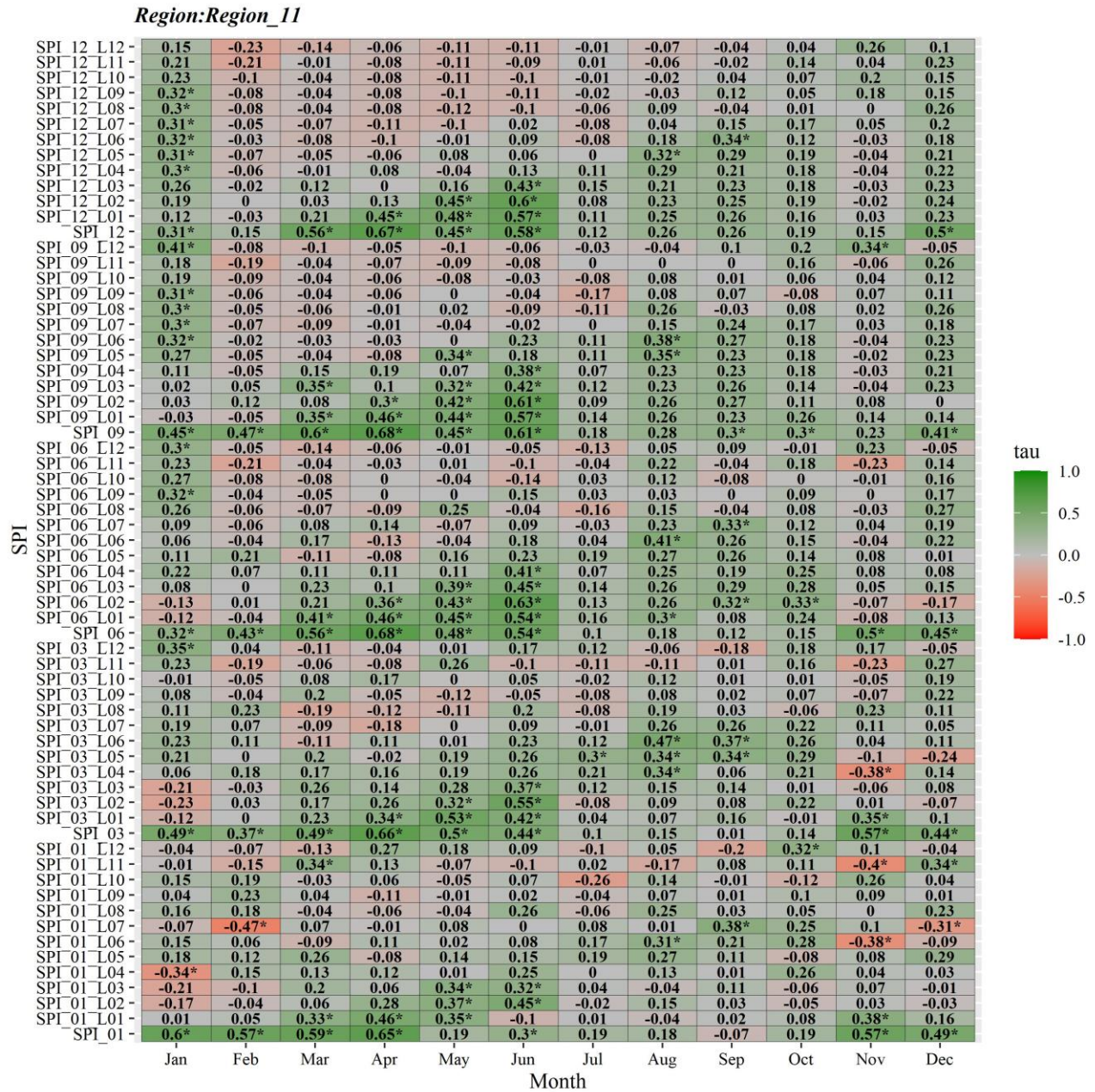


Figure S20. Same as Fig. S2 but for sub-region_11.

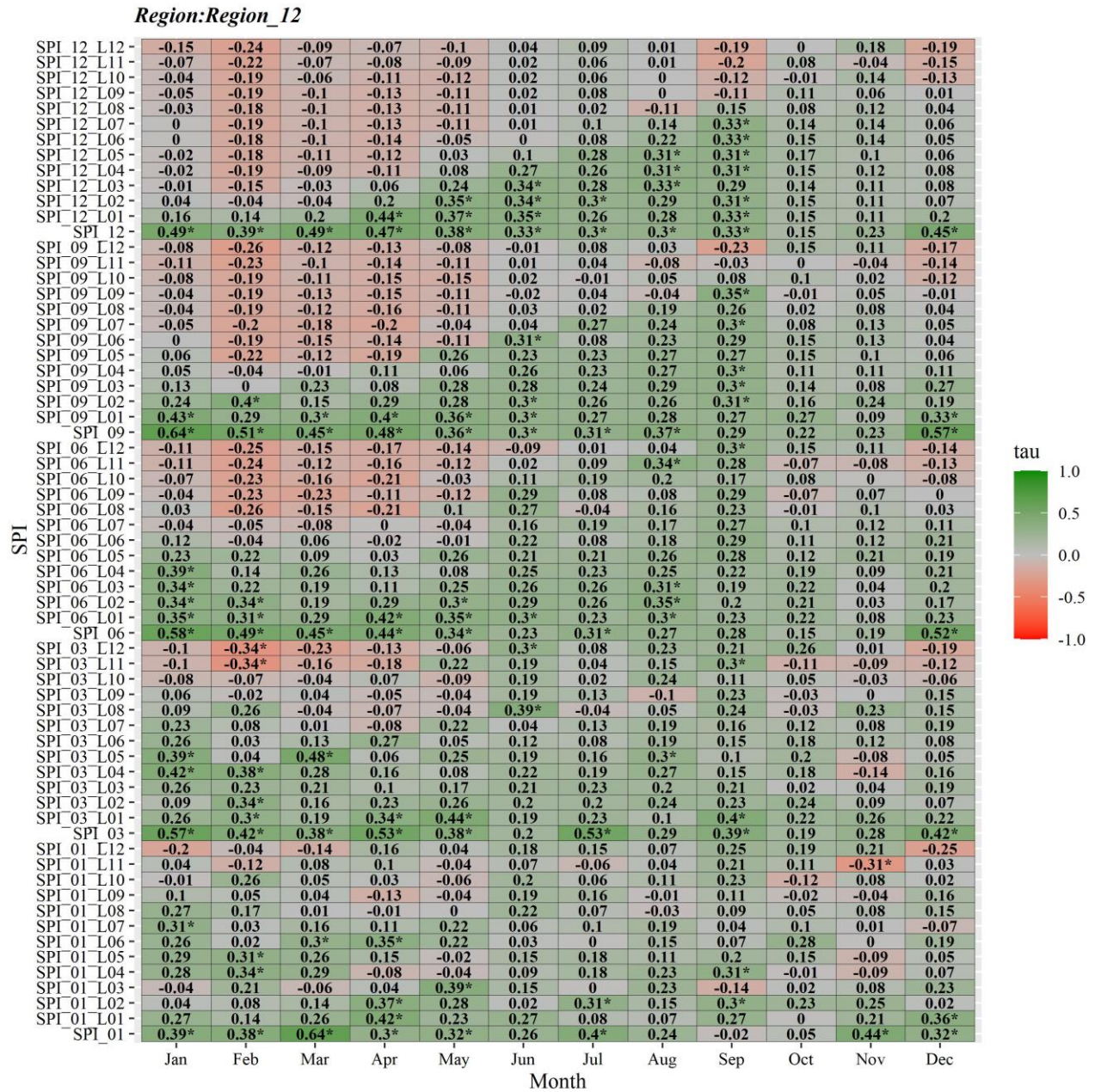


Figure S21. Same as Fig. S2 but for sub-region_12.

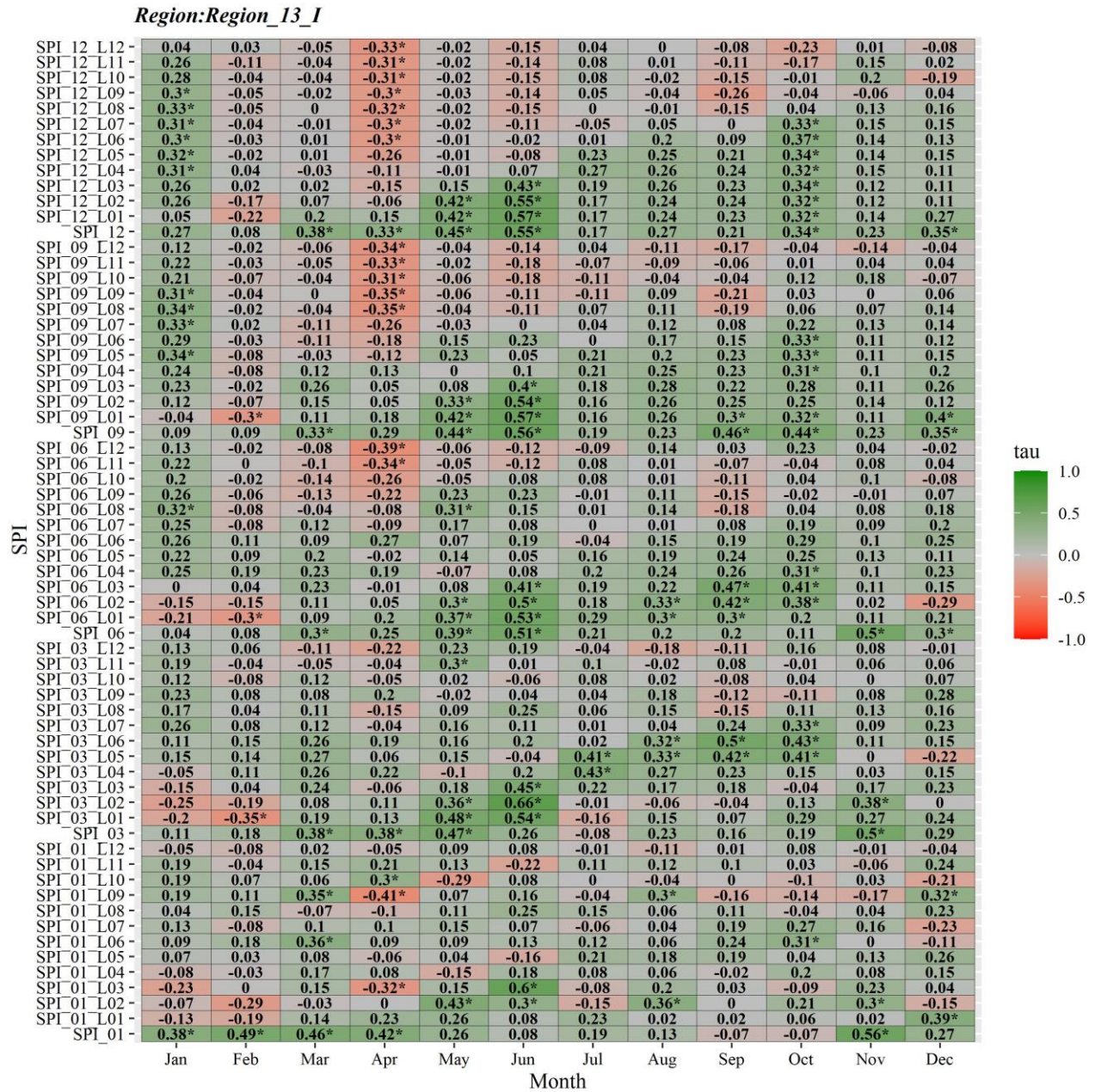


Figure S22. Same as Fig. S2 but for sub-region_13_I.

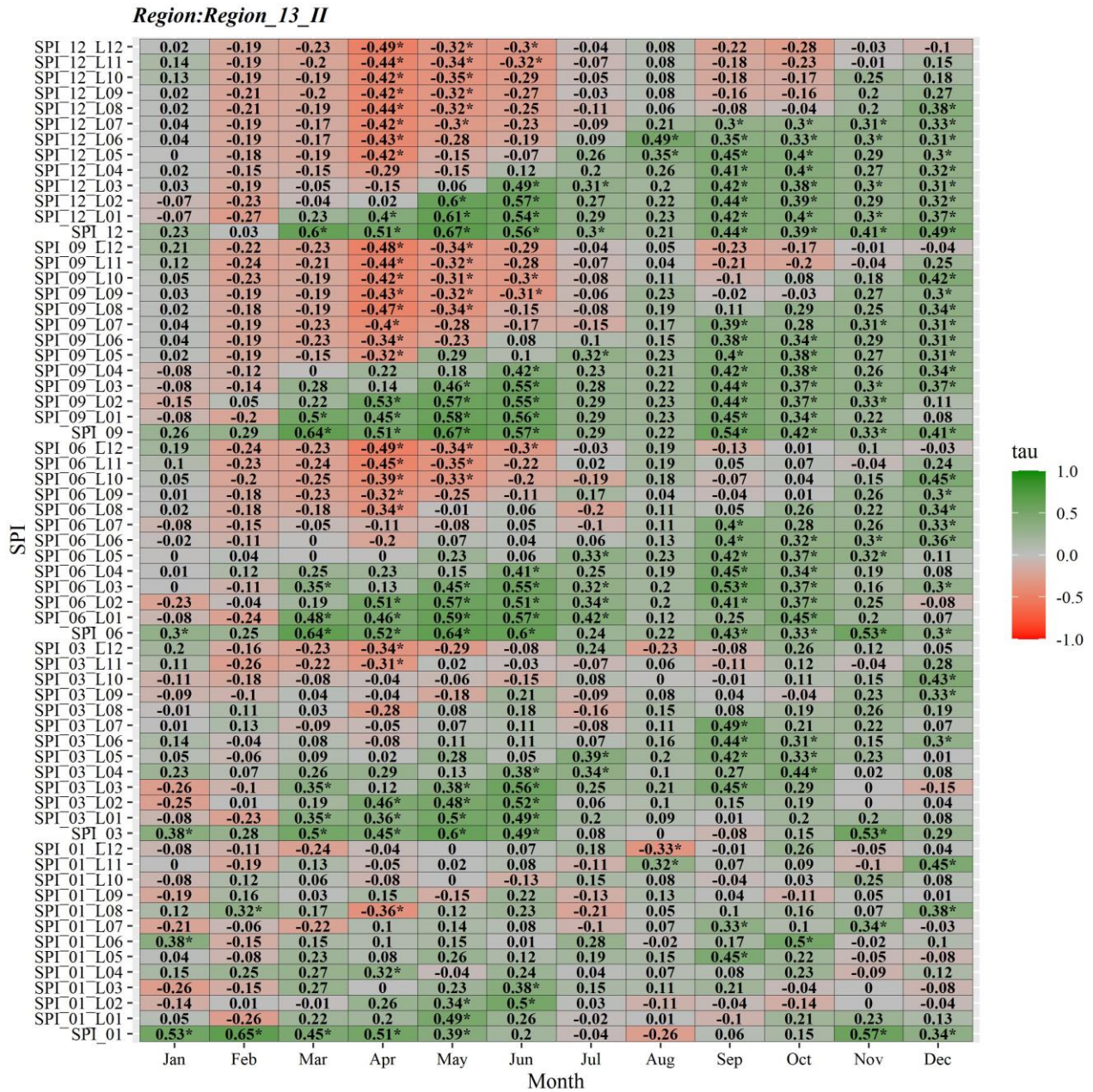


Figure S23. Same as Fig. S2 but for sub-region_13_II.

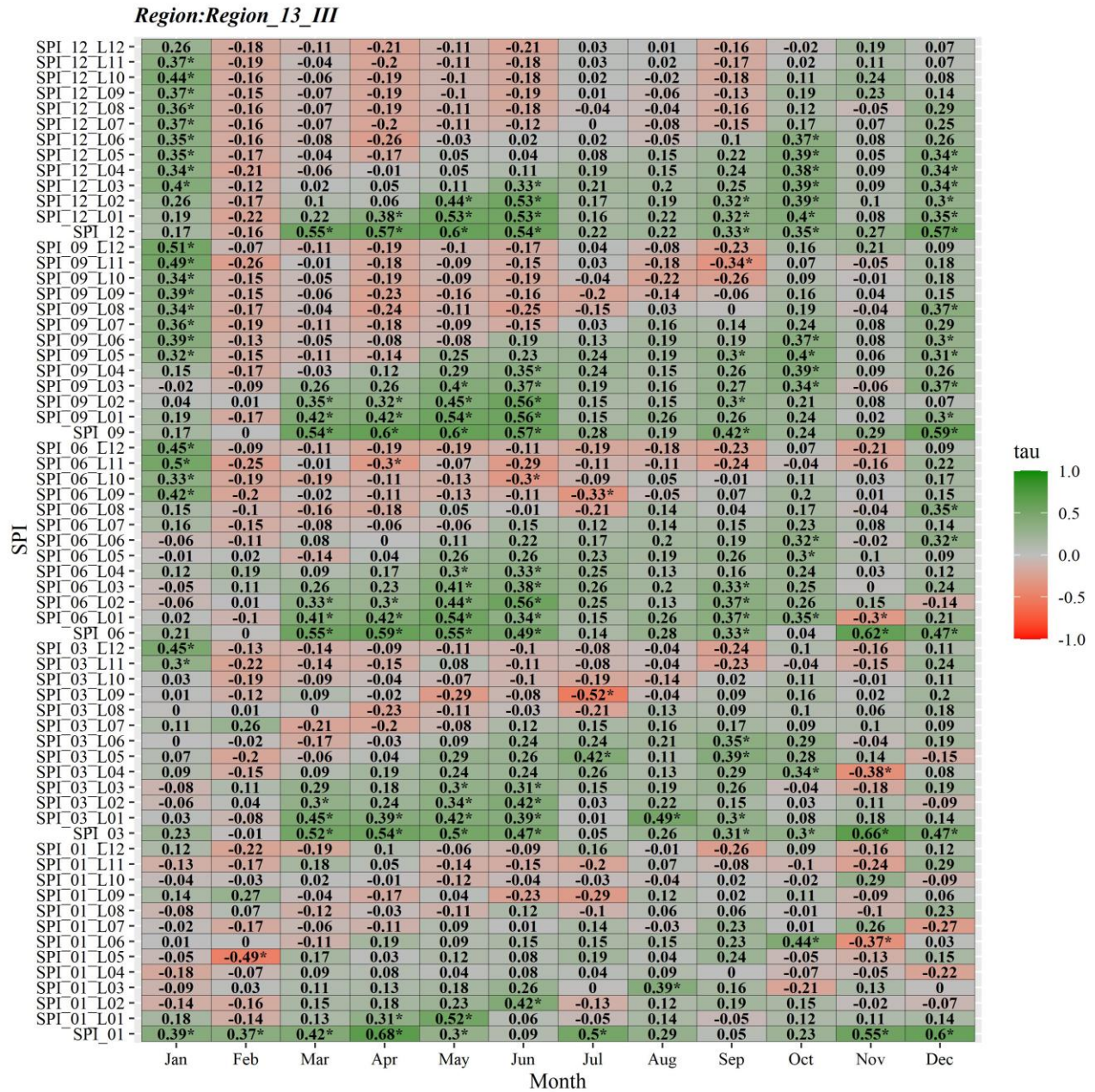


Figure S24. Same as Fig. S2 but for sub-region_13_III.

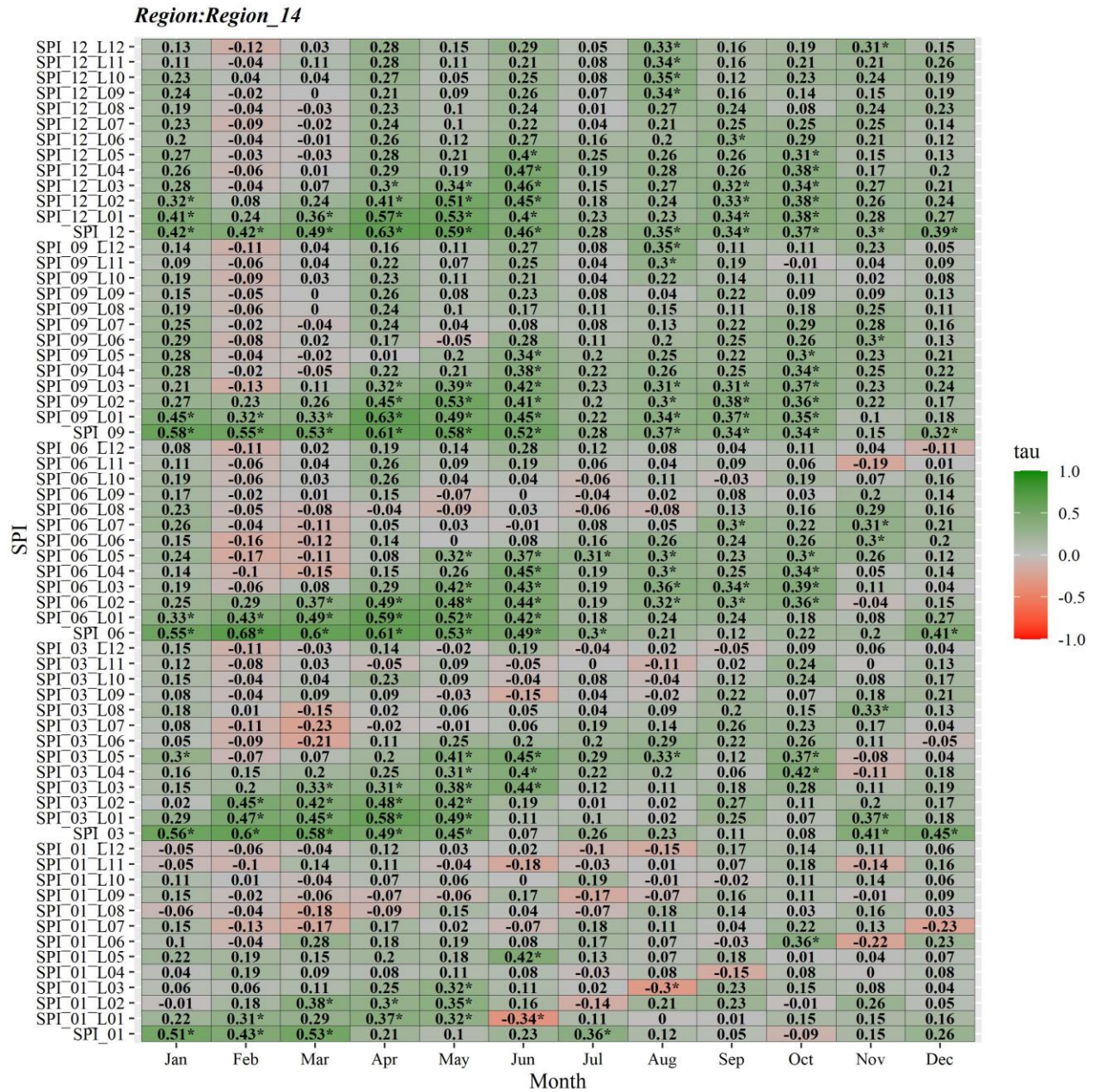


Figure S25. Same as Fig. S2 but for sub-region_14.

Section C.

After determining the effective SPIs for the VHI changes in the bioclimatic sub-regions, based on the Cramér-Von Mises goodness-of-fit test and the Akaike information criterion (AIC), for the VHI and SPI pair observations of each month of the year the most suitable univariate and bivariate distributions were determined. The results are reported in Table S1. All reported probability distributions in Table S1, had an acceptable p-value for the Cramér-Von Mises goodness-of-fit test at 95% confidence level (p-value > 0.05). Moreover, these distributions had the lowest AIC value among all tested distributions.

Table S1. The most appropriate univariate and bivariate probability distribution for the VHI, SPI, and their pairs (VHI, SPI).

Region	Month	VHI	SPI	Copula
Iran	Jan	GUM	SNO	Frank
	Feb	GEV	SNO	Frank
	Mar	NOR	SNO	Gumbel
	Apr	NOR	SNO	Frank
	May	GEV	SNO	Gumbel
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Frank
	Aug	NOR	SNO	Frank
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Gumbel
	Nov	NOR	SNO	Frank
	Dec	NOR	SNO	Frank
Region_01_Eastern	Jan	NOR	SNO	Gumbel
	Feb	NOR	SNO	Frank
	Mar	GEV	SNO	Gumbel
	Apr	NOR	SNO	Clayton
	May	NOR	SNO	Gumbel
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Frank
	Aug	NOR	SNO	Clayton
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Gumbel
	Nov	NOR	SNO	Gumbel
	Dec	NOR	SNO	Clayton
Region_01_Western	Jan	GLO	SNO	Frank
	Feb	NOR	SNO	Gumbel
	Mar	NOR	SNO	Frank
	Apr	NOR	SNO	Clayton
	May	NOR	SNO	Clayton
	Jun	GEV	SNO	Frank
	Jul	GEV	SNO	Frank
	Aug	NOR	SNO	Gumbel
	Sep	NOR	SNO	Clayton

Table S1. The most appropriate univariate and bivariate probability distribution for the VHI, SPI, and their pairs (VHI, SPI).

Region	Month	VHI	SPI	Copula
Region_02	Oct	GUM	SNO	Gumbel
	Nov	NOR	SNO	Frank
	Dec	NOR	SNO	Clayton
	Jan	GUM	SNO	Clayton
	Feb	NOR	SNO	Frank
	Mar	NOR	SNO	Gumbel
	Apr	NOR	SNO	Frank
	May	GLO	SNO	Clayton
	Jun	GEV	SNO	Clayton
	Jul	NOR	SNO	Frank
	Aug	GEV	SNO	Frank
	Sep	NOR	SNO	Frank
Region_03	Oct	GUM	SNO	Frank
	Nov	GEV	SNO	Frank
	Dec	GEV	SNO	Clayton
	Jan	NOR	SNO	Gumbel
	Feb	NOR	SNO	Gumbel
	Mar	NOR	SNO	Gumbel
	Apr	GUM	SNO	Gumbel
	May	NOR	SNO	Gumbel
	Jun	NOR	SNO	Gumbel
	Jul	NOR	SNO	Gumbel
	Aug	NOR	SNO	Frank
	Sep	NOR	SNO	Frank
Region_04_Eastern	Oct	NOR	SNO	Gumbel
	Nov	NOR	SNO	Gumbel
	Dec	GEV	SNO	Clayton
	Jan	NOR	SNO	Frank
	Feb	NOR	SNO	Frank
	Mar	NOR	SNO	Gumbel
	Apr	NOR	SNO	Frank
	May	NOR	SNO	Gumbel
	Jun	NOR	SNO	Frank
	Jul	GEV	SNO	Frank
	Aug	GUM	SNO	Gumbel
	Sep	GUM	SNO	Gumbel
Region_04_North_of_central_plateau	Oct	NOR	SNO	Clayton
	Nov	GUM	SNO	Gumbel
	Dec	NOR	SNO	Gumbel
	Jan	NOR	SNO	Gumbel
	Feb	GUM	SNO	Gumbel
	Mar	NOR	SNO	Frank
	Apr	GUM	SNO	Frank
	May	GEV	SNO	Gumbel
	Jun	NOR	SNO	Gumbel

Table S1. The most appropriate univariate and bivariate probability distribution for the VHI, SPI, and their pairs (VHI, SPI).

Region	Month	VHI	SPI	Copula
	Jul	NOR	SNO	Gumbel
	Aug	GUM	SNO	Frank
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Gumbel
	Nov	GUM	SNO	Gumbel
	Dec	NOR	SNO	Frank
Region_04_Northeastern_of_central_plateau	Jan	NOR	SNO	Gumbel
	Feb	NOR	SNO	Gumbel
	Mar	NOR	SNO	Gumbel
	Apr	NOR	SNO	Clayton
	May	NOR	SNO	Clayton
	Jun	NOR	SNO	Frank
	Jul	GEV	SNO	Gumbel
	Aug	GUM	SNO	Gumbel
	Sep	NOR	SNO	Frank
	Oct	NOR	SNO	Gumbel
	Nov	NOR	SNO	Clayton
	Dec	NOR	SNO	Gumbel
Region_04_Northwestern_of_central_plateau	Jan	NOR	SNO	Gumbel
	Feb	NOR	SNO	Frank
	Mar	NOR	SNO	Frank
	Apr	GUM	SNO	Frank
	May	NOR	SNO	Frank
	Jun	GEV	SNO	Clayton
	Jul	NOR	SNO	Frank
	Aug	NOR	SNO	Gumbel
	Sep	GUM	SNO	Frank
	Oct	GUM	SNO	Frank
	Nov	GEV	SNO	Clayton
	Dec	GEV	SNO	Frank
Region_05	Jan	NOR	SNO	Frank
	Feb	NOR	SNO	Frank
	Mar	NOR	SNO	Gumbel
	Apr	NOR	SNO	Clayton
	May	NOR	SNO	Frank
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Frank
	Aug	GEV	SNO	Frank
	Sep	NOR	SNO	Gumbel
	Oct	NOR	SNO	Gumbel
	Nov	GEV	SNO	Frank
	Dec	GEV	SNO	Clayton
Region_06	Jan	GUM	SNO	Clayton
	Feb	GUM	SNO	Gumbel
	Mar	NOR	SNO	Frank

Table S1. The most appropriate univariate and bivariate probability distribution for the VHI, SPI, and their pairs (VHI, SPI).

Region	Month	VHI	SPI	Copula
	Apr	GUM	SNO	Gumbel
	May	GLO	SNO	Clayton
	Jun	GEV	SNO	Frank
	Jul	NOR	SNO	Frank
	Aug	NOR	SNO	Clayton
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Frank
	Nov	NOR	SNO	Frank
	Dec	NOR	SNO	Gumbel
Region_07_I	Jan	NOR	SNO	Gumbel
	Feb	GUM	SNO	Frank
	Mar	NOR	SNO	Frank
	Apr	GUM	SNO	Gumbel
	May	GLO	SNO	Frank
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Gumbel
	Aug	NOR	SNO	Clayton
	Sep	GLO	SNO	Frank
	Oct	NOR	SNO	Frank
	Nov	NOR	SNO	Gumbel
	Dec	GUM	SNO	Clayton
Region_07_II	Jan	GUM	SNO	Frank
	Feb	NOR	SNO	Frank
	Mar	GEV	SNO	Frank
	Apr	NOR	SNO	Frank
	May	GEV	SNO	Frank
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Frank
	Aug	GUM	SNO	Frank
	Sep	NOR	SNO	Frank
	Oct	NOR	SNO	Frank
	Nov	NOR	SNO	Frank
	Dec	GEV	SNO	Frank
Region_08	Jan	NOR	SNO	Frank
	Feb	NOR	SNO	Gumbel
	Mar	NOR	SNO	Frank
	Apr	NOR	SNO	Gumbel
	May	GEV	SNO	Frank
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Clayton
	Aug	NOR	SNO	Clayton
	Sep	NOR	SNO	Frank
	Oct	NOR	SNO	Frank
	Nov	GEV	SNO	Clayton
	Dec	NOR	SNO	Frank

Table S1. The most appropriate univariate and bivariate probability distribution for the VHI, SPI, and their pairs (VHI, SPI).

Region	Month	VHI	SPI	Copula
Region_09_I	Jan	GUM	SNO	Frank
	Feb	GEV	SNO	Frank
	Mar	NOR	SNO	Frank
	Apr	NOR	SNO	Frank
	May	NOR	SNO	Gumbel
	Jun	NOR	SNO	Frank
	Jul	GUM	SNO	Clayton
	Aug	NOR	SNO	Frank
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Frank
	Nov	NOR	SNO	Frank
	Dec	NOR	SNO	Clayton
Region_09_II	Jan	NOR	SNO	Gumbel
	Feb	NOR	SNO	Frank
	Mar	GEV	SNO	Frank
	Apr	NOR	SNO	Frank
	May	GLO	SNO	Clayton
	Jun	NOR	SNO	Frank
	Jul	GUM	SNO	Clayton
	Aug	NOR	SNO	Frank
	Sep	GUM	SNO	Gumbel
	Oct	NOR	SNO	Clayton
	Nov	GEV	SNO	Frank
	Dec	NOR	SNO	Gumbel
Region_09_III	Jan	GUM	SNO	Gumbel
	Feb	GUM	SNO	Frank
	Mar	NOR	SNO	Gumbel
	Apr	NOR	SNO	Frank
	May	NOR	SNO	Gumbel
	Jun	GUM	SNO	Clayton
	Jul	NOR	SNO	Gumbel
	Aug	GUM	SNO	Gumbel
	Sep	GUM	SNO	Gumbel
	Oct	GUM	SNO	Gumbel
	Nov	GUM	SNO	Frank
	Dec	NOR	SNO	Clayton
Region_09_IV	Jan	GUM	SNO	Frank
	Feb	NOR	SNO	Clayton
	Mar	NOR	SNO	Frank
	Apr	NOR	SNO	Clayton
	May	GLO	SNO	Clayton
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Clayton
	Aug	GEV	SNO	Gumbel
	Sep	GUM	SNO	Frank

Table S1. The most appropriate univariate and bivariate probability distribution for the VHI, SPI, and their pairs (VHI, SPI).

Region	Month	VHI	SPI	Copula
Region_10	Oct	GUM	SNO	Frank
	Nov	NOR	SNO	Gumbel
	Dec	GEV	SNO	Clayton
	Jan	GUM	SNO	Gumbel
	Feb	GEV	SNO	Frank
	Mar	GUM	SNO	Clayton
	Apr	GLO	SNO	Frank
	May	NOR	SNO	Frank
	Jun	NOR	SNO	Clayton
	Jul	GUM	SNO	Frank
	Aug	NOR	SNO	Clayton
	Sep	NOR	SNO	Frank
	Oct	NOR	SNO	Gumbel
Region_11	Nov	GUM	SNO	Clayton
	Dec	NOR	SNO	Frank
	Jan	NOR	SNO	Frank
	Feb	NOR	SNO	Gumbel
	Mar	NOR	SNO	Frank
	Apr	NOR	SNO	Frank
	May	GEV	SNO	Frank
	Jun	NOR	SNO	Frank
	Jul	GEV	SNO	Clayton
	Aug	NOR	SNO	Frank
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Gumbel
	Nov	NOR	SNO	Clayton
Region_12	Dec	NOR	SNO	Frank
	Jan	GUM	SNO	Frank
	Feb	NOR	SNO	Frank
	Mar	GUM	SNO	Frank
	Apr	GUM	SNO	Gumbel
	May	NOR	SNO	Gumbel
	Jun	GUM	SNO	Clayton
	Jul	GUM	SNO	Frank
	Aug	NOR	SNO	Gumbel
	Sep	GUM	SNO	Clayton
	Oct	NOR	SNO	Clayton
	Nov	GUM	SNO	Frank
	Dec	NOR	SNO	Frank
Region_13_I	Jan	NOR	SNO	Frank
	Feb	NOR	SNO	Frank
	Mar	NOR	SNO	Clayton
	Apr	NOR	SNO	Gumbel
	May	NOR	SNO	Gumbel
	Jun	NOR	SNO	Frank

Table S1. The most appropriate univariate and bivariate probability distribution for the VHI, SPI, and their pairs (VHI, SPI).

Region	Month	VHI	SPI	Copula
	Jul	GUM	SNO	Frank
	Aug	NOR	SNO	Frank
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Gumbel
	Nov	NOR	SNO	Clayton
	Dec	GUM	SNO	Gumbel
Region_13_II	Jan	GUM	SNO	Frank
	Feb	NOR	SNO	Frank
	Mar	NOR	SNO	Clayton
	Apr	NOR	SNO	Frank
	May	GEV	SNO	Gumbel
	Jun	GUM	SNO	Frank
	Jul	NOR	SNO	Gumbel
	Aug	GLO	SNO	Frank
	Sep	GUM	SNO	Frank
	Oct	NOR	SNO	Gumbel
	Nov	NOR	SNO	Frank
	Dec	NOR	SNO	Clayton
Region_13_III	Jan	GUM	SNO	Clayton
	Feb	NOR	SNO	Gumbel
	Mar	gno	SNO	Frank
	Apr	NOR	SNO	Frank
	May	GLO	SNO	Frank
	Jun	GUM	SNO	Frank
	Jul	GUM	SNO	Frank
	Aug	NOR	SNO	Frank
	Sep	GUM	SNO	Gumbel
	Oct	NOR	SNO	Frank
	Nov	GEV	SNO	Frank
	Dec	NOR	SNO	Gumbel
Region_14	Jan	GUM	SNO	Gumbel
	Feb	GEV	SNO	Clayton
	Mar	GUM	SNO	Clayton
	Apr	NOR	SNO	Frank
	May	GEV	SNO	Clayton
	Jun	NOR	SNO	Frank
	Jul	NOR	SNO	Frank
	Aug	GUM	SNO	Clayton
	Sep	GUM	SNO	Gumbel
	Oct	NOR	SNO	Frank
	Nov	NOR	SNO	Frank
	Dec	NOR	SNO	Gumbel