remote sensing

Supplementary materials

Table S1. PhenoRice parameters used for analysis.

Parameters	Threshold	Description
meanevi	0.4	Annual average EVI value should be below 0.4 to reduce misclassification with evergreen forests
maxevi	0.5	The maximum EVI value should be above 0.5 as corresponding to rice flowering period
minevi	0. 25	The minimum EVI value should be below 0.25 as corresponding to rice planting period
flowering period	23–32	Potential flowering period should be from July to August
vl	5–14	Possible difference between dates of minimum EVI (planting date) and dates of maximum EVI should be 40–112 days.
winfl	2	Maximum possible difference between planting date and flooding signal should be within 16 days
minndfi	0	Minimum NDFI threshold used to identify flooded conditions should be above 0
windecr	15	Maximum possible difference between date of maximum EVI and harvest date should be less than 120 days
decr	0.7	Percentage decrease threshold (with respect to the min/max EVI range) used for estimation of harvest date
tl	13–23	The total growing length should be around 100–180 days
lst	15	Land surface temperature should be above 15 ℃ when planting rice

Table S2. California state-level satellite estimated rice area and USDA surveyed rice area, and the slope (*p* < 0.001 for all slopes), R², RMSE and rRMSE of the linear regression between California county-level satellite estimated rice area and USDA survey or census reported (in parenthesis) rice area for 2002–2017, and kappa coefficients between satellite detected rice area and CDL identified rice area for 2007–2017.

Year	Predicted Area (10³ ha)	Reported Area (10³ ha)	Slope	R²	RMSE (10³ ha)	rRMSE (%)	Kappa
2002	222	214	1.06**	1.00	1.71	11.23	
			(1.03)	(0.99)	(2.16)	(13.10)	
2003	203	205	0.97**	1.00	1.32	8.34	
2004	236	239	0.99**	1.00	1.38	7.49	
2005	206	213	0.95**	1.00	1.73	10.55	
2006	210	212	0.96**	0.99	1.72	10.58	
2007	210	216	0.96**	0.99	2.19	13.18	0.85
			(0.99)	(1.00)	(1.42)	(8.62)	
2008	214	209	1.00**	1.00	1.30	6.30	0.88
2009	216	225	0.97**	1.00	2.04	7.40	0.89
2010	223	224	1.03**	1.00	1.64	5.99	0.89
2011	245	235	1.03**	1.00	1.19	5.63	0.90
2012	229	225	1.02**	1.00	1.50	5.86	0.90
			(0.99)	(1.00)	(1.41)	(8.08)	
2013	232	227	1.00**	0.99	2.22	8.94	0.91
2014	169	179	0.90**	0.97	3.30	17.28	0.87
2015	160	172	0.82**	0.95	4.55	17.10	0.86
2016	210	217	0.90**	0.98	3.46	11.41	0.89
2017	181	179	0.96**	0.99	2.27	11.88	0.89
			(0.98)	(0.98)	(2.16)	(15.97)	

Table S3. Annual trends of estimated planting, heading and harvest dates, growing periods from planting to heading (vlength), heading to harvest (rlength) and planting to harvest (tlength) for California at county level from 2002 to 2017 ($p < 0.01$ **, $p < 0.05$ *).

Provinces	Planting (days yr^{-1})	Heading (days yr^{-1})	Harvest (days yr^{-1})	Vlength (days yr^{-1})	Rlength (days yr^{-1})	Tlength (days yr^{-1})
Butte	−0.11	0.07	0.02	0.18	−0.04	0.13
Colusa	0.17	0.12	0.54	−0.05	0.42	0.37
Glenn	0.08	−0.15	0.26	−0.23	0.41	0.18
Placer	−0.10	0.18	0.40	0.28	0.22	0.50
Sacramento	0.29	0.45	0.69	0.17	0.24	0.41
Sutter	−0.17	0.02	0.27	0.18	0.26	0.44
Yolo	0.11	0.31	0.75	0.20	0.44**	0.64*
Yuba	−0.22	0.05	0.22	0.27	0.17	0.44

Table S4. Annual trends of total precipitation and average mean temperature for California at county level from 2002 to 2017 ($p < 0.05$ *).

| Provinces	Precipitation (mm decade^{-1})	p-value	Mean temperature (°C decade^{-1})	p-value
Butte	−70.50	0.56	0.45	0.11
Colusa	−32.74	0.68	0.49	0.07
Glenn	−84.67	0.39	0.55	0.05*
Placer	39.15	0.67	0.09	0.75
Sacramento	12.24	0.87	0.35	0.19
Sutter	16.80	0.84	0.33	0.22
Yolo	0.58	0.99	0.31	0.26
Yuba	8.74	0.93	0.38	0.17
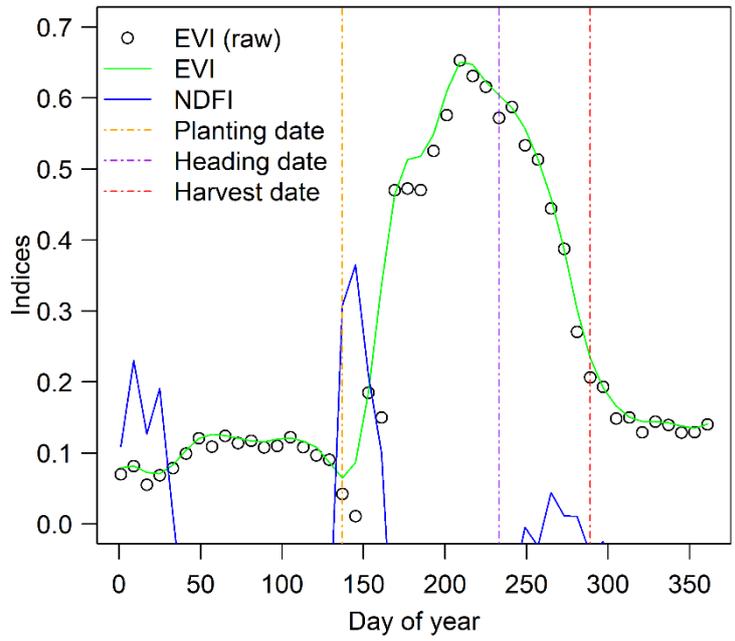
**Figure S1.** Example of PhenoRice results for a rice pixel in California.
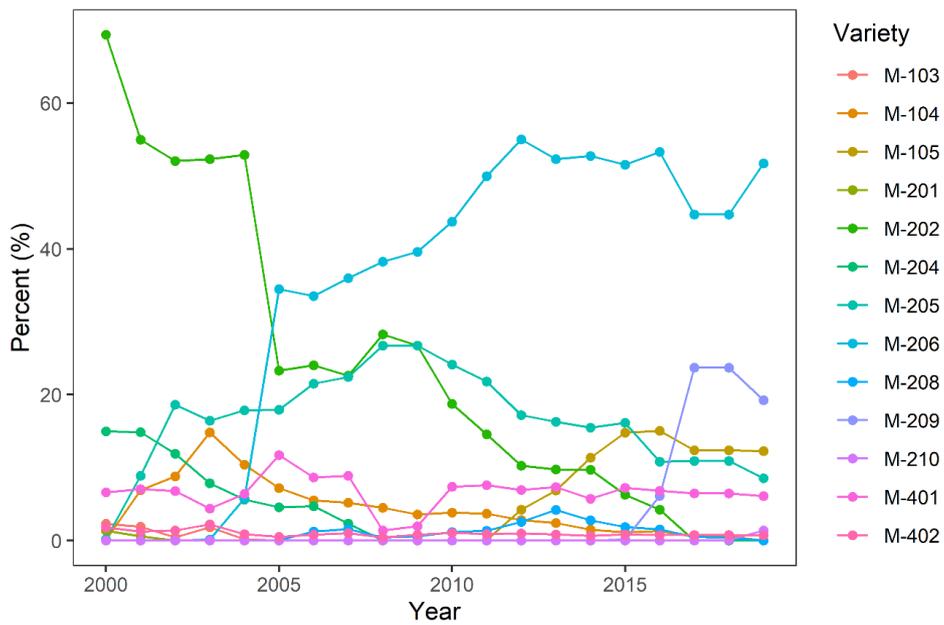
Figure S2. Medium grain variety acreage as a percent of total medium grain acreage from 2000 to 2019. (During this period medium grains averaged 90% (range 86%–94%) of total acreage in CA based on the Quick Stats Database published by USDA NASS).
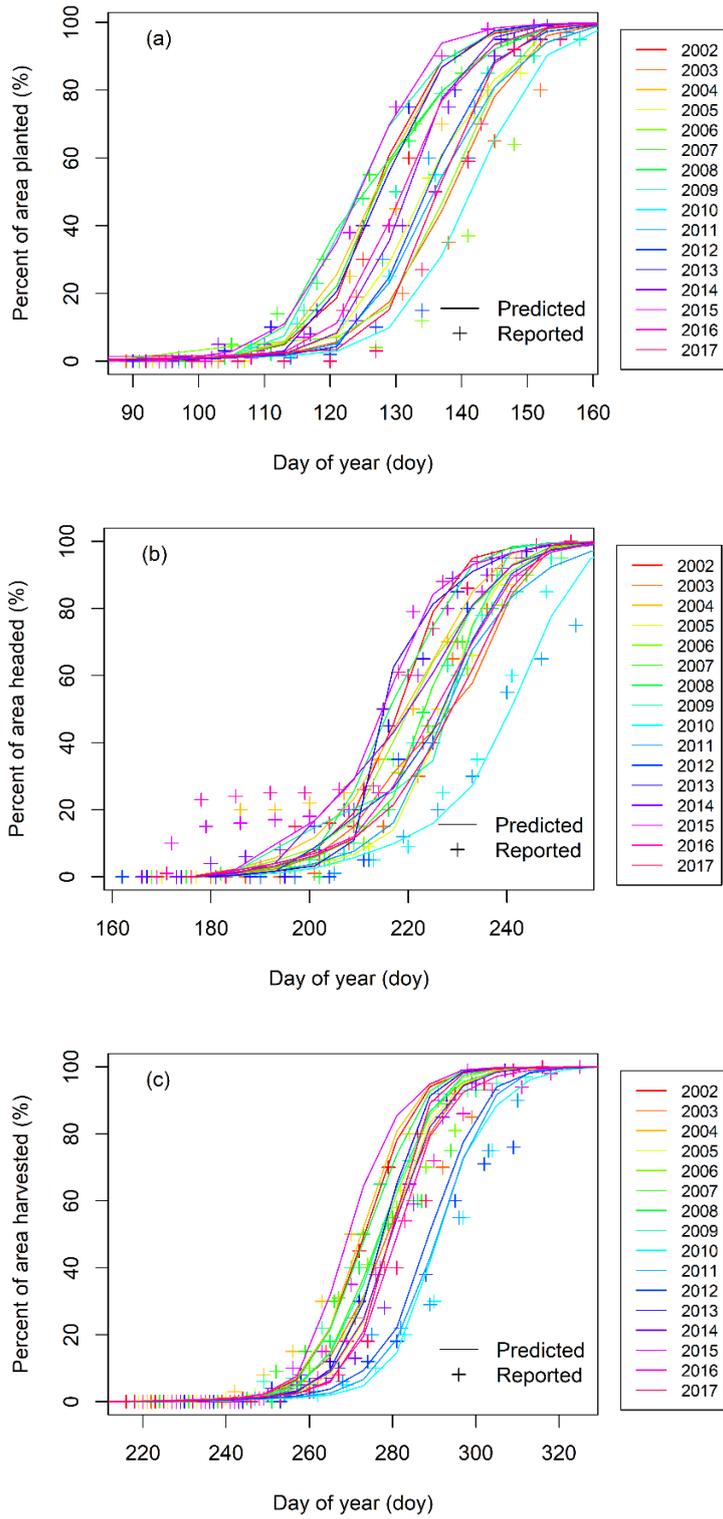
**Figure S3.** Estimated and reported (**a**) planting, (**b**) heading and (**c**) harvest dates occurred at California State by percent area.
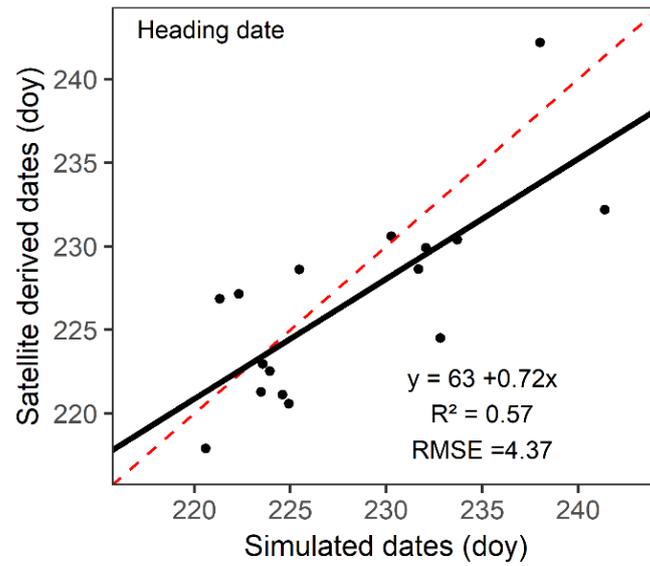
Figure S4. Comparison between satellite derived and DD10 simulated heading dates in California from 2002 to 2017. Each dot represents a year. Black line is regression line and red dashed line is $y = x$.
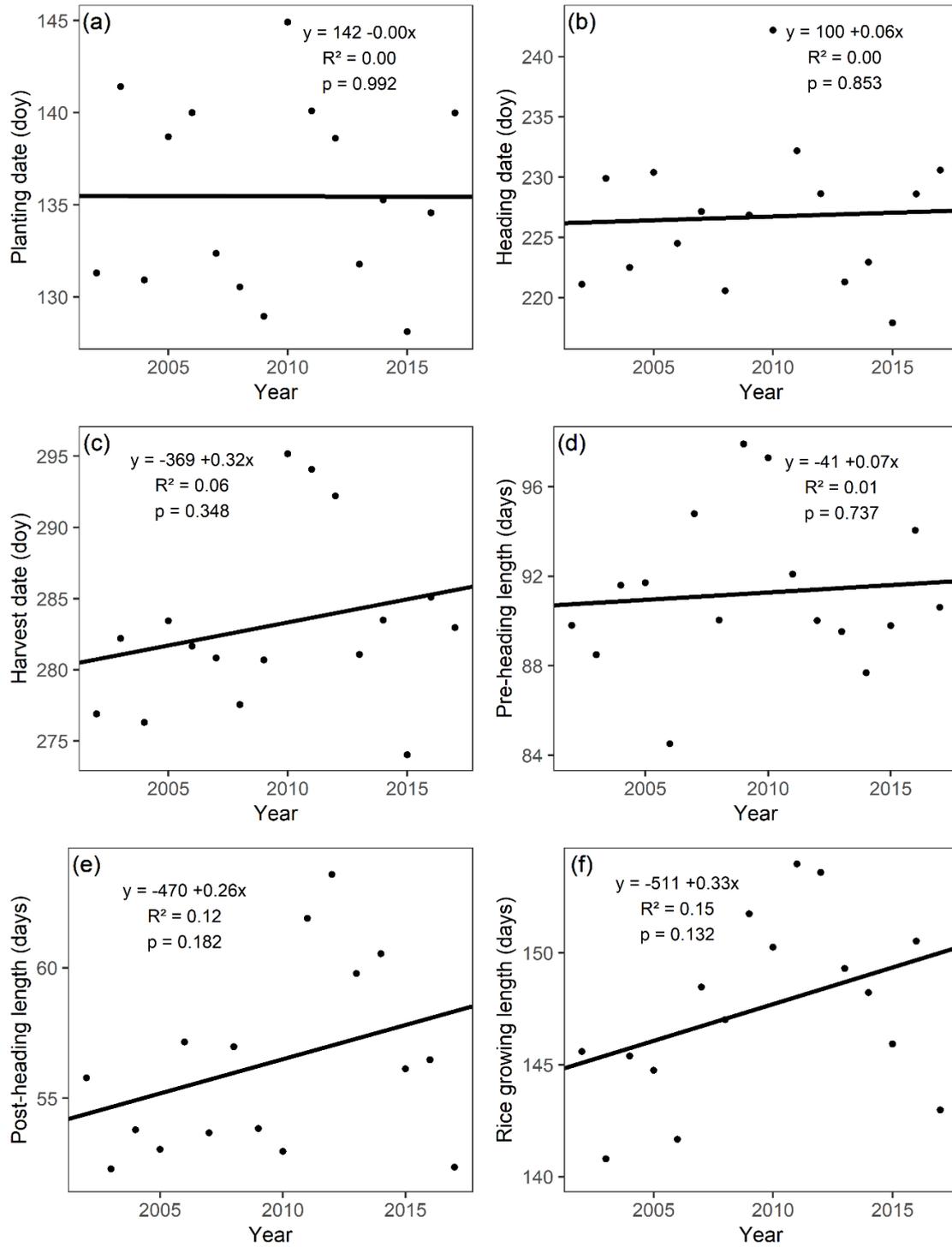
Figure S5. Estimated (**a**) planting, (**b**) heading and (**c**) harvest dates, (**d**) growing period from planting to heading, (**e**) heading to harvest and (**f**) planting to harvest for California at state level from 2002 to 2017.
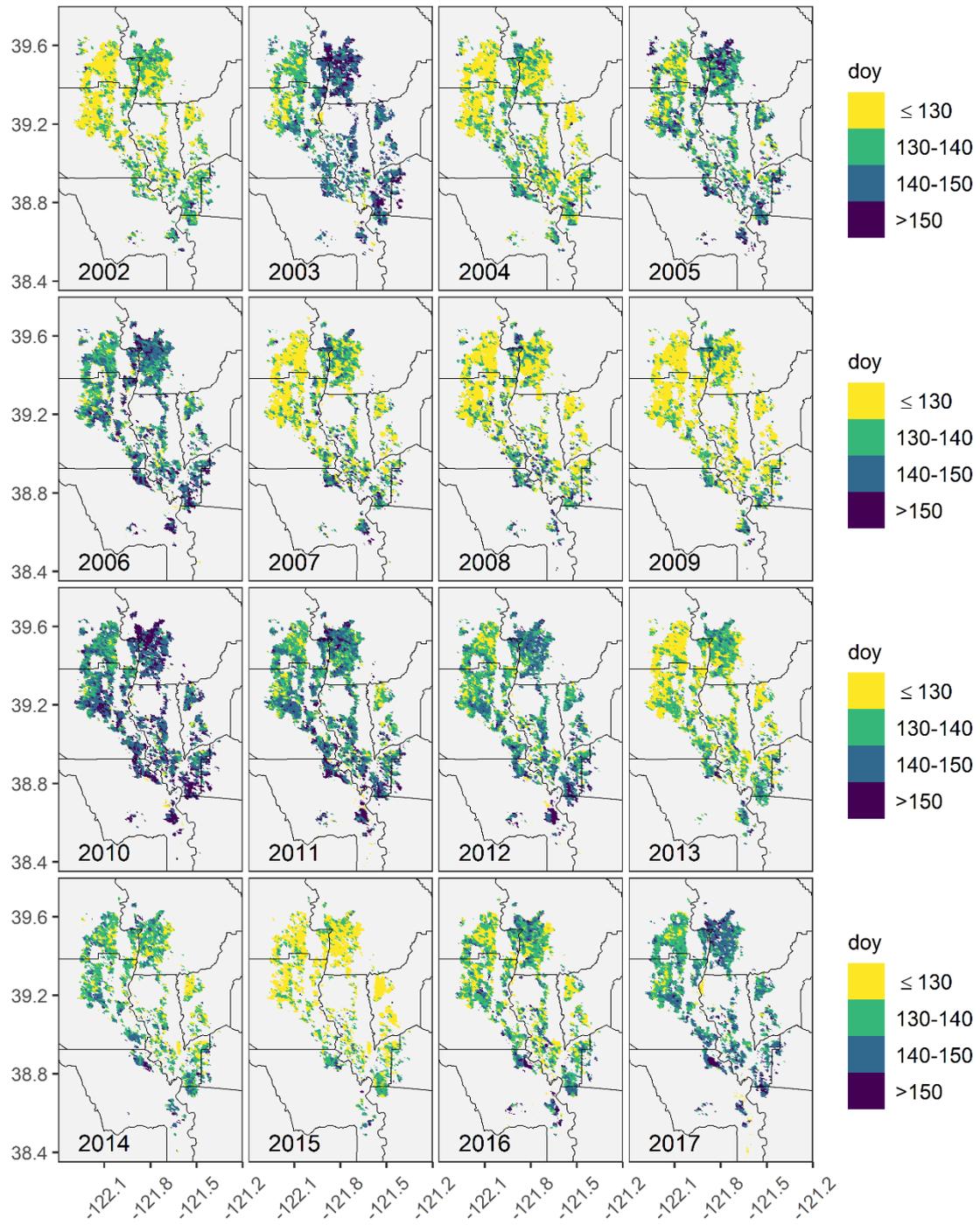
Figure S6a. Spatial maps of planting dates during 2002–2017 in Sacramento Valley.
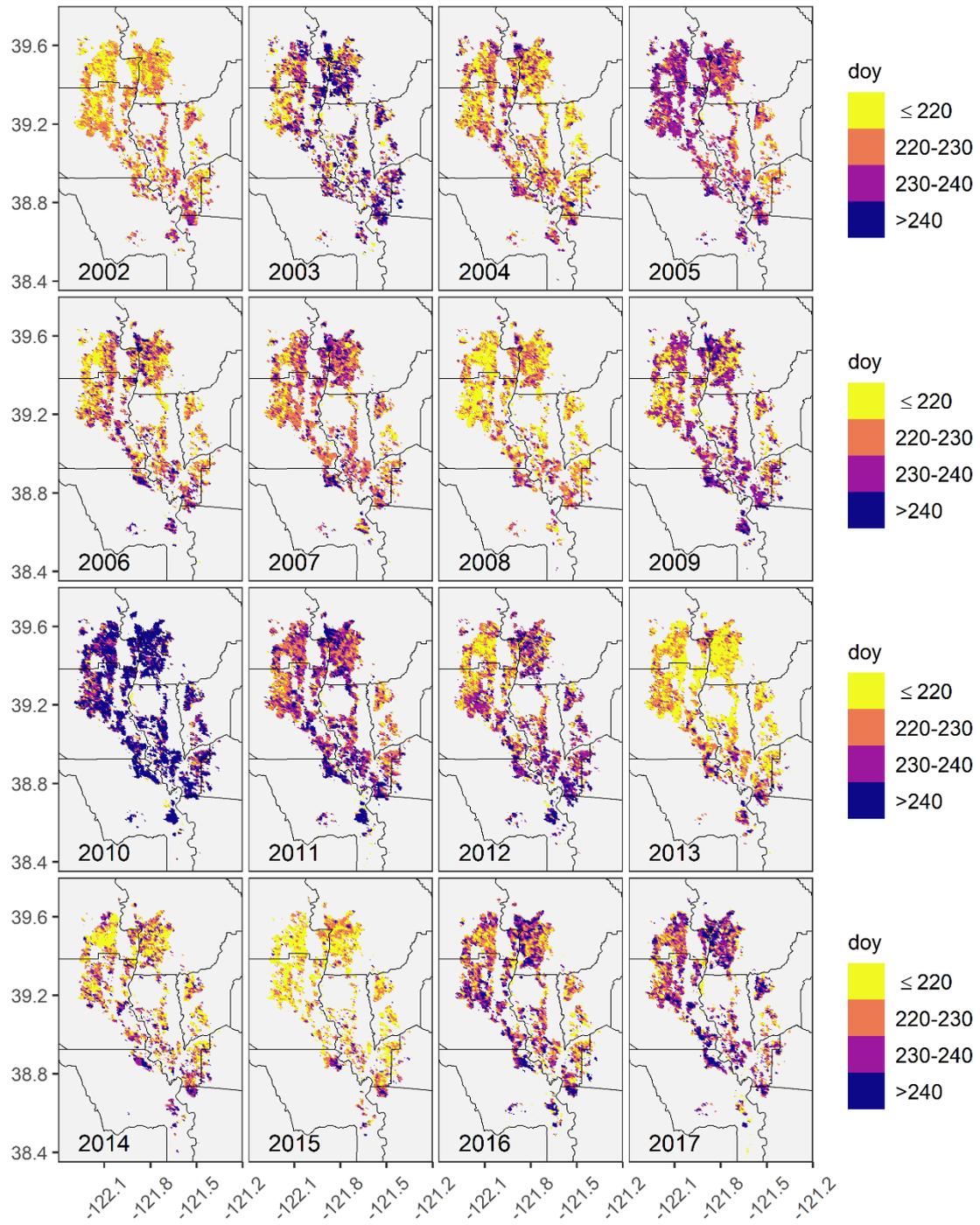
**Figure S6b.** Spatial maps of heading dates during 2002–2017 in Sacramento Valley.
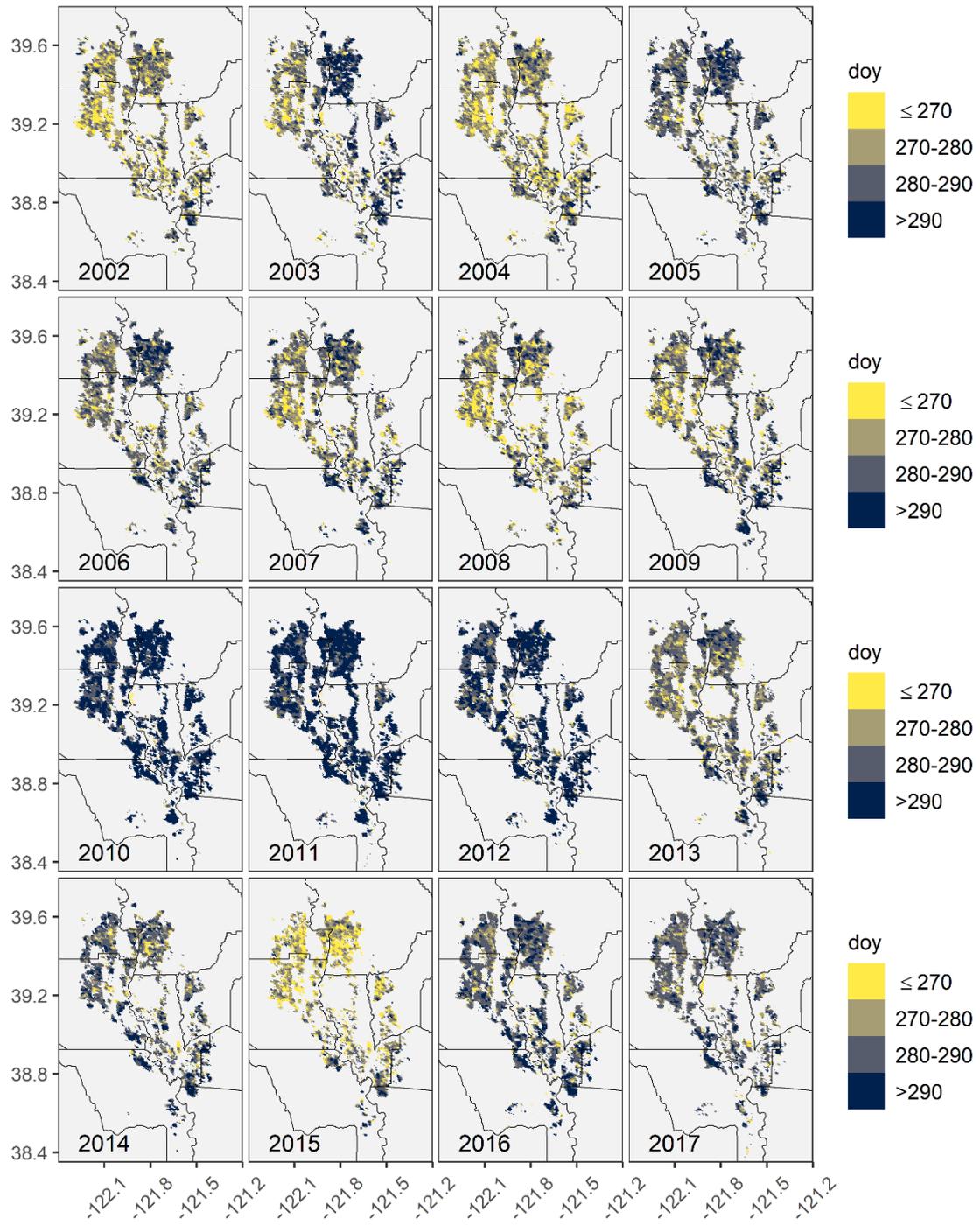
Figure S6c. Spatial maps of harvest dates during 2002–2017 in Sacramento Valley.
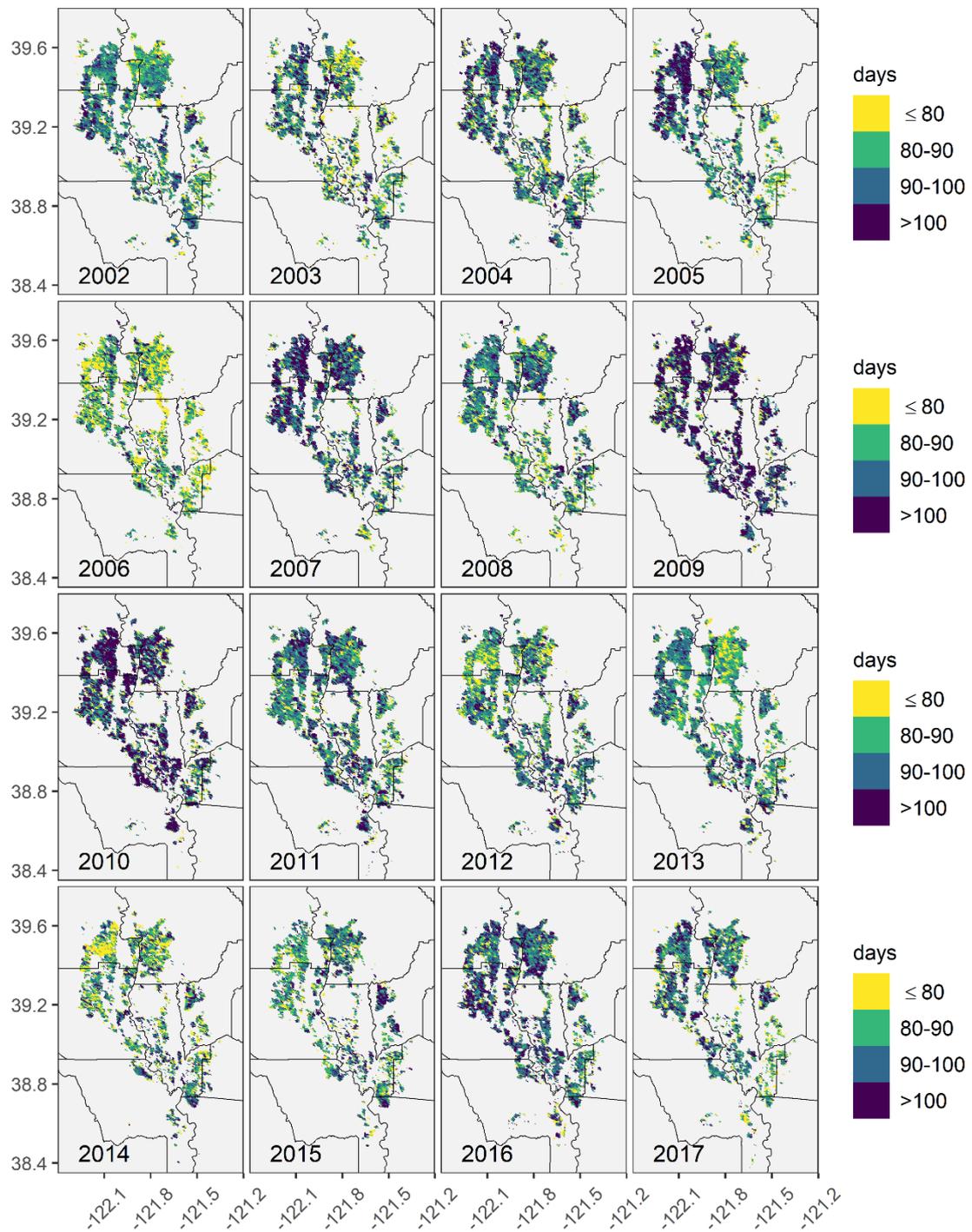
Figure S6d. Spatial maps of growing length from planting to heading during 2002–2017 in Sacramento Valley.
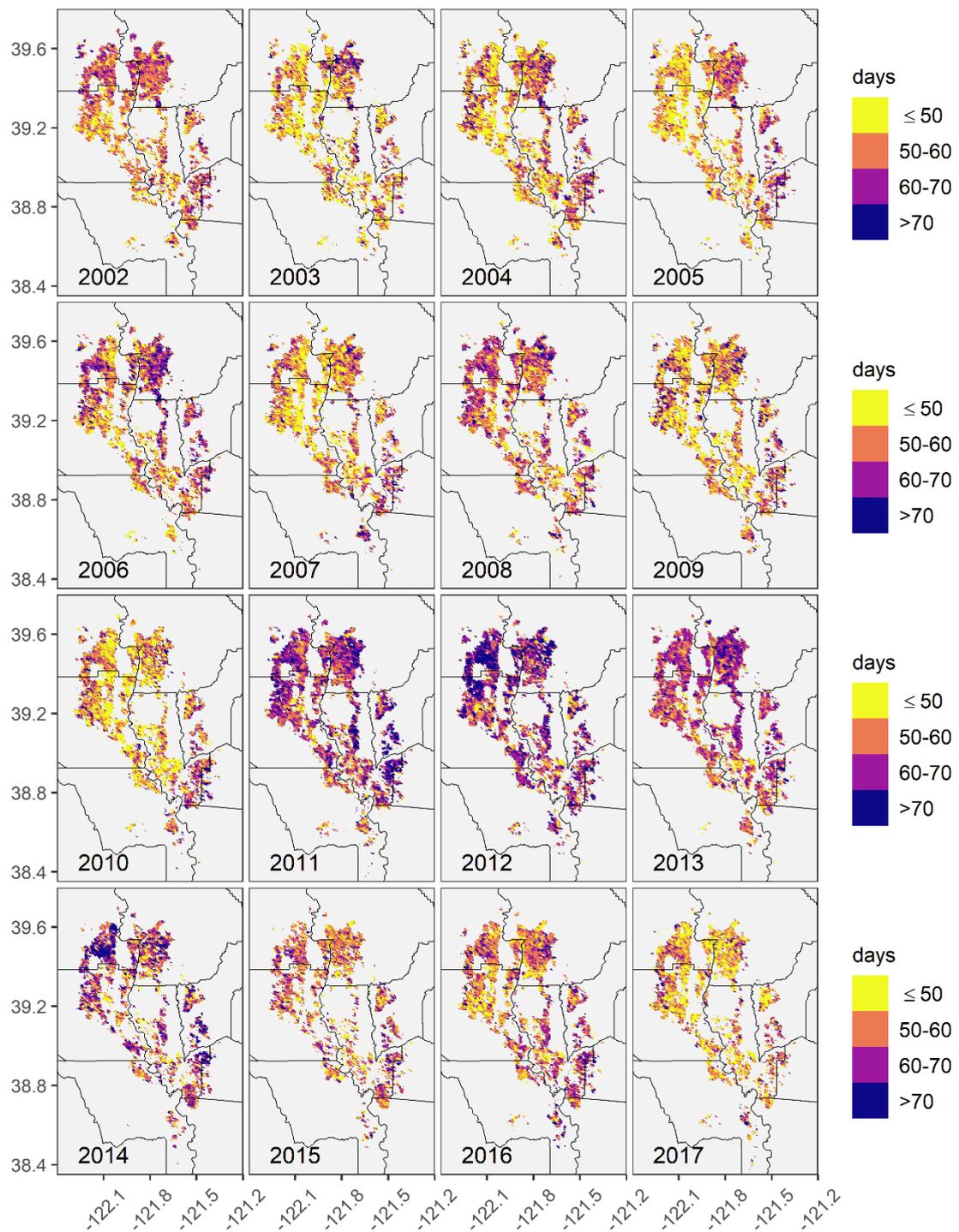
Figure S6e. Spatial maps of growing length from heading to harvest during 2002–2017 in Sacramento Valley.
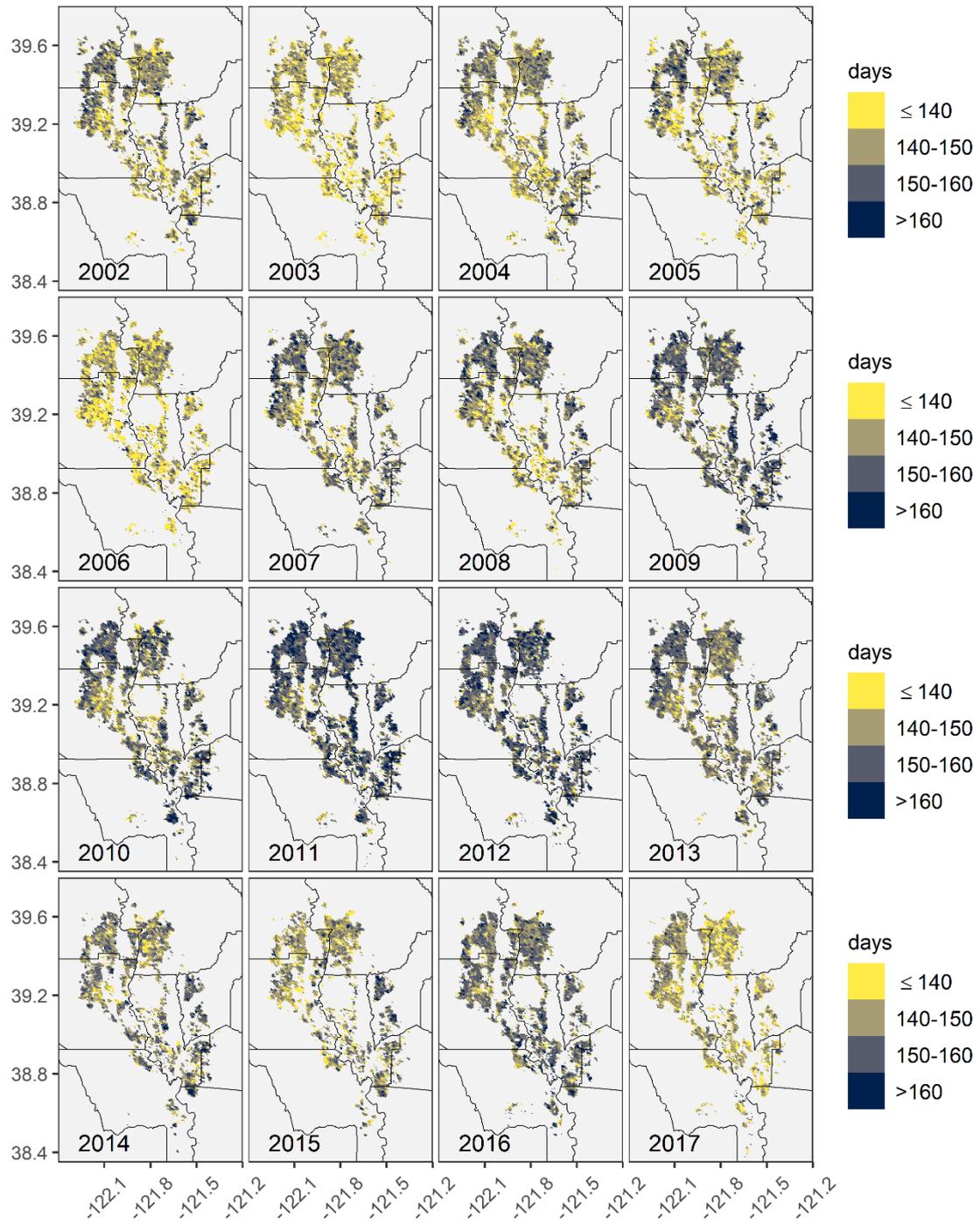
Figure S6f. Spatial maps of total growing length from planting to harvest during 2002–2017 in Sacramento Valley.
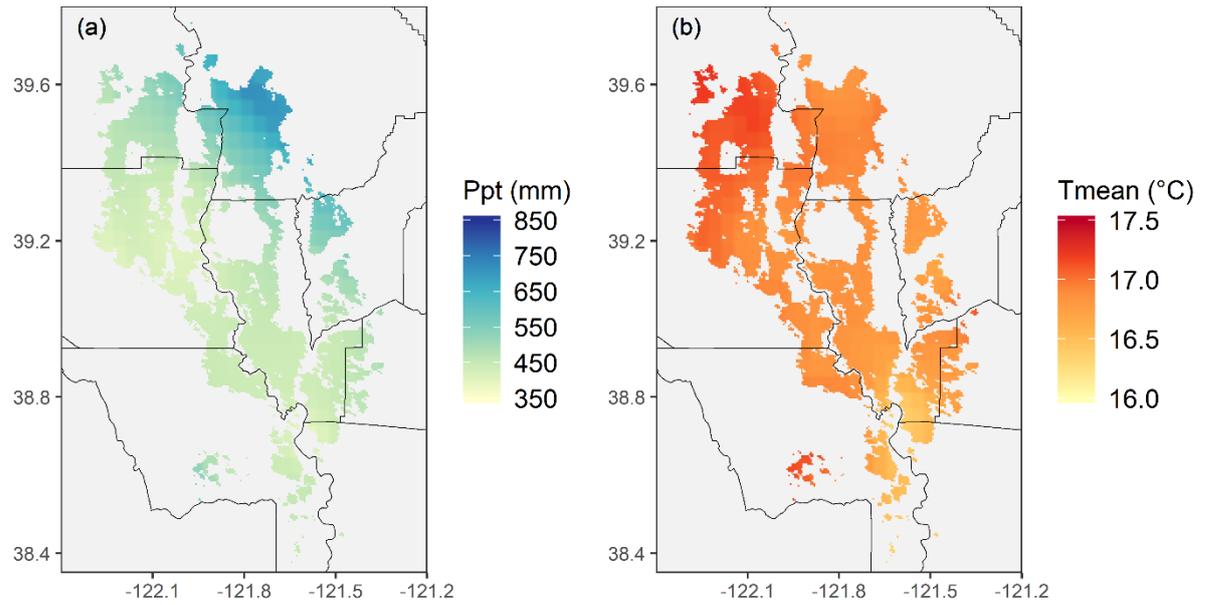
Figure S7. Average (**a**) annual total precipitation and (**b**) mean temperature of rice regions in Sacramento Valley during 2002–2017.
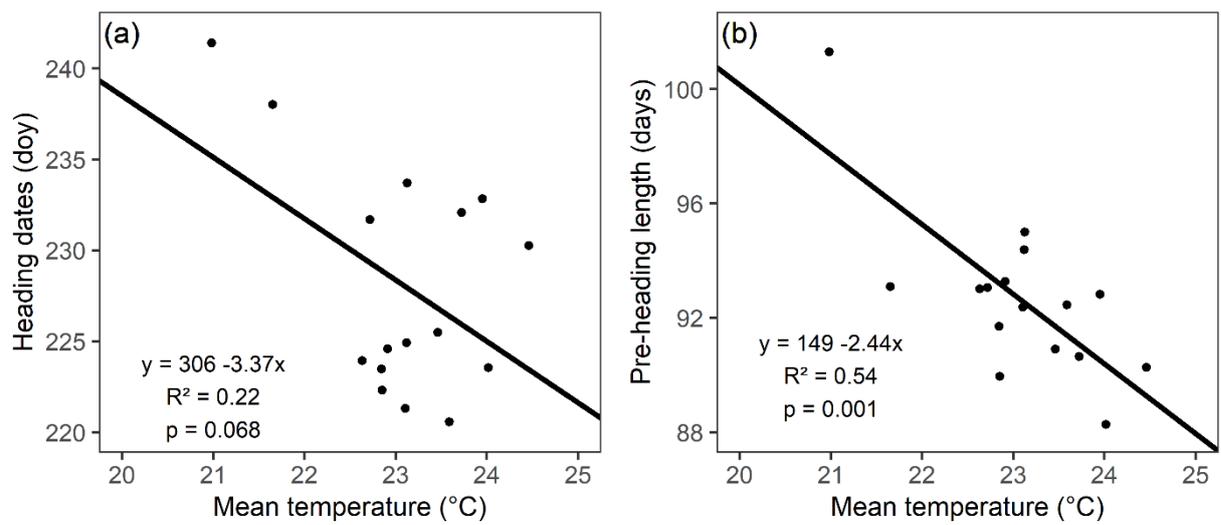

Figure S8. The relationships (**a**) between average mean temperature of pre-heading season and simulated heading dates; (**b**) between the pre-heading season mean temperature and growing length from planting to heading for rice region in California.