

Ref ID	Authors	Year	Journal
1	Pantelidis et al.	2023	Scientia Horticulturae
2	Pantelidis et al.	2022	Acta Horticulturae
3	Cifuentes-Carvajal et al.	2023	Agronomy
4	Drogoudi et al.	2023	Plants
5	Chuine et al.	2016	Global change biology
6	Atagul et al.	2022	Agronomy
7	Schwartz et al.	1997	HortScience
8	Marra et al.	2002	Acta Horticulturae
9	Vanalli et al.	2021	Agricultural and Forest Meteorology
10	Kwon et al.	2020	Agricultural and Forest Meteorology
11	Mauli3n et al.	2014	Scientia Horticulturae
12	Lu et al.	2012	Acta Horticulturae
13	Miranda et al.	2013	Agricultural and Forest Meteorology
14	Kamyun et al.	2014	Acta Horticulturae
15	Huret et al.	2017	International Journal of Climatology
16	Bonhomme et al.	2010	Acta Horticulturae
17	Kwon et al.	2020	Acta Horticulturae
18	Borgini et al.	2024	Scientia Horticulturae
19	Guerrero et al.	2024	Frontiers in Plant Science
20	Hamdani et al.	2024	Theoretical and Applied Climatology
21	Guerrero et al.	2022	Acta Horticulturae
22	Fraga et al.	2021	Frontiers in Plant Science
23	Borgini et al.	2024	Scientia Horticulturae
24	Orjuela-Angulo et al.	2022	Revista Colombiana de Ciencias Hort3colas
25	Kumawat et al.	2023	Erwerbs-Obstbau
26	Orozco et al.	2024	Scientific Reports
27	Naseri et al.	2023	Theoretical and Applied Climatology
28	Degrandi-Hoffman et al.	1996	Journal of Applied Ecology
29	Alonso et al.	2005	Journal of the American Society for Horticultural Science
30	Ram3rez et al.	2010	Acta Horticulturae
31	Freitaset al.	2023	Climatic Change
32	Lorite et al.	2020	Agricultural and Forest Meteorology
33	Ruml et al.	2020	Acta Horticulturae
34	Benmoussa et al.	2017	Agricultural and Forest Meteorology
35	Prudencio et al.	2019	Acta Horticulturae
36	Gaeta et al.	2018	European Journal of Agronomy
37	Prudencio et al.	2018	Scientia Horticulturae

38	Parker et al.	2018	Climatic Change
39	Parker et al.	2017	International Journal of Biometeorology
40	Prudencio et al.	2018	Acta Horticulturae
41	Gaeta et al.	2018	Acta Horticulturae
42	Santoset al.	2017	Climatic Change
43	Pantelidis et al.	2023	Scientia Horticulturae
44	Korsakova et al.	2023	Inventions
45	Vávraet al.	2022	Acta Horticulturae
46	Mesterházy et al.	2022	Diversity
47	Chuine et al.	2016	Global change biology
48	Andreini et al.	2014	Agricultural and Forest Meteorology
49	García et al.	1999	Acta Horticulturae
50	Legave et al.	2006	Acta Horticulturae
51	Valentini et al.	2004	Acta Horticulturae
52	Legave et al.	2010	Acta Horticulturae
53	Hangyu et al.	2021	Proceedings-ISCIPT 2021
54	Ruiz et al.	2007	Environmental and Experimental Botany
55	Ruml et al.	2012	Acta Horticulturae
56	Campoyet al.	2012	European Journal of Agronomy
57	Bartolini et al.	2019	Scientia Horticulturae
58	Černá et al.	2012	Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis
59	Guo et al.	2015	Scientia Horticulturae
60	Gao et al.	2012	HortScience
61	Bartolini et al.	2020	Acta Horticulturae
62	Zhuang et al.	2016	European Journal of Agronomy
63	Ruml et al.	2018	Acta Horticulturae
64	Kwon et al.	2020	Acta Horticulturae
65	Borgini et al.	2024	Scientia Horticulturae
66	Ruml et al.	2010	International journal of biometeorology
67	Ortega-Farias et al.	2023	Proceedings-IEEE CHILEAN
68	Fadón et al.	2023	Agricultural and Forest Meteorology
69	Fadón et al.	2022	Acta Horticulturae
70	Chmielewski et al.	2023	Horticulturae
71	Litschmann et al.	2022	Acta Horticulturae
72	Imperiale et al.	2022	Acta Horticulturae
73	Chmielewski et al.	2022	Plants
74	Fadón et al.	2023	European Journal of Agronomy
75	Campillay-Llanos et al.	2024	Scientia Horticulturae
76	Sugiura et al.	2006	Acta Horticulturae
77	Fadón et al.	2021	Agricultural and Forest Meteorology

78	Chozinski et al.	2008	Acta Horticulturae
79	Hochmaier	2014	Acta Horticulturae
80	Albuquerque et al.	2008	Environmental and Experimental Botany
81	Darbyshire et al.	2020	Agricultural and Forest Meteorology
82	Luedeling et al.	2013	International Journal of Biometeorology
83	Wenden et al.	2018	Acta Horticulturae
84	Guak et al.	2013	Horticulture Environment and Biotechnology
85	Persely et al.	2014	Acta Horticulturae
86	Drogoudi et al.	2020	Euro-Mediterranean Journal for Environmental Integration
87	Kaufmann et al.	2017	Regional Environmental Change
88	Palasciano et al.	2017	Acta Horticulturae
89	Chung et al.	2016	Asia-Pacific Journal of Atmospheric Sciences
90	Marra et al.	2017	Acta Horticulturae
91	Chmielewski et al.	2016	Agricultural and Forest Meteorology
92	Hur et al.	2017	International Journal of Climatology
93	Luedeling et al.	2013	Agricultural and Forest Meteorology
94	Fadón et al.	2021	Acta Horticulturae
95	Schiffers et al.	2021	Acta Horticulturae

Table S1. Literature review of process-based phenological models of *Prunus* species: reference ID, authors, year of publication and journal.

Ref ID	Dormancy break model	Bloom model	Ripe model	Data location	Data period	# Cultivars	Blooming score	Ripening score
1	CH, CU and CP	GDH	-	Greece	2016-2022	49	0.429	-
2	CH, CU and CP	GDH	-	Greece	2020-2022	14	0.429	-
3	CH, CU and CP	GDD	-	USA	2021-2023	3	0.143	-
4	CH, CU and CP	GDH	-	Europe	2020-2022	14	0.429	-
5	Chaine, CH, CU and CP	sigmoid	-	France	1995-2010	1	0.571	-
6	CH	GDH	-	USA	2014-2021	136	0.286	-
7	Auburn	GDH	GDH	USA	-	8	0.428571	0.20
8	-	-	GDH and GDD	USA California	-	5	-	0
9	Chaine	sigmoid	GDD	France,	1987-2008	9	0.714	0.600
10	CH, CU and CP	GDH	-	Korea	2015-2019	5	0.429	-
11	CH, CU and CP	GDH	-	Argentina	7 years	118	0.286	-
12	CU	-	-	Taiwan	1990-2009	10	0.143	-
13	CH, CU and CP	GDH	GDH	Spain	2007-2012	3	0.429	0.200
14	CH, CU and North Carolina	-	-	Thailand	2009-2011	1	0	-
15	-	DTS model	-	Korea	-	-	0.428571	-
16	CH, CU and CP	-	-	France	1973-1978	1	0	-
17	CH, CU and CP	-	-	Korea	2014-2016	3	0.143	-
18	CH, CU and CP	GDH	-	Tunisia	1996-2022	7	0.429	-

Table S2. Literature review of peach phenological models together with model scoring for blooming and ripening. CH=chilling hours, CU=chilling unit, CP=chilling portions, NC= North Carolina model, GDD=Growing Degree Days, GDH=Growing Degree Hours.

Ref ID	Dormancy break model	Blooming model	Ripening model	Data location	Data period	# Cultivars	Blooming score	Ripening score
19	CH, CU and CP	GDH	-	Spain	1973-2023	21	0.714	-
20	CH, CU and CP	GDH	-	Marocco	2021-2022	28	0.429	-
21	CH, CU and CP	GDH	-	Spain	2018-2020	8	0.571	-
22	CP	GDH	-	Portugal	-	1	0.429	-
23	CP	GDH	-	Tunisia	1996- 2022	11	0.286	-
24	-	-	GDD	Colombia	2015-2016	1	-	0

Table S3. Literature review of plum phenological models together with model scoring for blooming and ripening. See Table 1 caption for abbreviations.

Ref ID	Dormancy break model	Bloom model	Ripe model	Data location	Data period	# Cultivars	Bloom score	Ripe score
25	-	GDD	-	Kashmir	2012–2018	8	0.143	-
26	-	Carbohydrate-temperature	-	California	1982–2022	-	0.143	-
27	CH	GDH	-	Iran	2017	3	0.286	-
28	-	GDD	-	California	1987-1990	5	0	-
29	chilling units	GDH	-	World	1994-2004	44	0.286	-
30	CH, CU, CP, NC, Florida	GDH	-	Chile	2003-2005	3	0.143	-
31	CH and CP	GDH and GDD	-	Portugal	-	9	0.429	-
32	CP	GDH	-	Southern Europe	2004-2015	15	0.429	-
33	CU	GDH	-	Serbia	2011-2014	6	0.286	-
34	CH, CU and CP	GDH	-	Tunisia	1981-2014	37	0.429	-
35	CU and CP	GDH	-	Spain	2014-2016	1	0.286	-
36	CU and CP	GDH	-	Italy	1982–1992	7	0.429	-
37	CU and CP	GDH	-	Spain	2015-2017	3	0.286	-
38	CP	GDH	GDD	USA	1971–2000	-	0.571	0.600
39	CP	GDD	GDD	USA	1971–2000	-	0.571	0.600
40	CU and CP	GDH	-	Spain	2014-2016	4	0.429	-
41	CP	GDH	-	Italy	1991-1993, 2002	5	0.286	-
42	CP	GDH	-	Portugal	-	-	0.286	-

Table S4. Literature review of almond phenological models together with model scoring for blooming and ripening. See Table 1 caption for abbreviations.

Ref ID	Dormancy break model	Bloom model	Ripe model	Data location	Data period	# Cultivars	Bloom score	Ripe score
43	CH, CU and CP	GDH	-	Greece	2016-2022	49	0.429	-
44	Sigmoid, triangular	GDD	-	Russia	1995-2022	15	0.571	-
45	-	GDH and GDD	-	Czech Republic	1998-2018	-	0.286	-
46	Chuine	sigmoid	-	Hungary	1994-2020	3	0.429	-
47	Chuine	sigmoid	-	France	1987–2008	1	0.571	-
48	Sigmoid, CU, GDD, Bidabè	-	-	France, Italy, Spain	1988-2009	23	0.429	-
49	CU	GDH	-	Italy and Spain	1991-1994	-	0.429	-
50	Bidabè	GDH	-	France	1998-2005	5	0.429	-
51	Utah, North Carolina	GDH and GDD	-	Italy	1999-2002	5	0.286	-
52	CH, CU and Bidabé	-	-	France	1997-2007	1	0.143	-
53	-	GDD	-	China	1980-2020	-	0.286	-
54	CH, CU and CP	GDH	-	Spain	2003-2005	10	0.286	-
55	-	GDD	-	Serbia	1995-2004	42	0.143	-
56	CH, CU and CP	GDH	-	Spain, South Africa	2006-2009	14	0.143	-
57	CH	-	-	Italy	1973–2016	40	0.429	-
58	-	sine wave	-	Czech Republic	1927–1960	1	0.429	-
59	CH and CP	GDH	-	China	1963–2010	-	0.286	-
60	CH, CU and CP	GDH	-	China	2009-2012	6	0.286	-
61	CU	-	-	Italy	1991-2016	2	0.429	-
62	CP	GDH	-	China	2009–2011	69	0.286	-
63	CU	GDH	-	Serbia	2011-2013	10	0.429	-
64	CH, CU and CP	GDH	-	Korea	1919-2019	2	0.429	-
65	CH, CU and CP	GDH	-	Tunisia	1996-2022	5	0.286	-
66	-	-	GDD	Serbia	1995-2004	10	-	0.200

Table S5. Literature review of apricot phenological models together with model scoring for blooming and ripening. See Table 1 caption for abbreviations.

Ref ID	Dormancy break model	Bloom model	Ripe model	Data location	Data period	# Cultivars	Bloom score	Ripe score
67	-	exponential of GDD	-	Chile	2017-2021	8	0.143	-
68	CP	GDH	-	Germany, Spain	1978-2020	3	0.429	-
69	CP	GDH	-	Spain	-	12	0.429	-
70	CP	GDH	-	Germany	2011-2023	1	0.429	-
71	CH, CU and CP	-	-	Czech Republic	2017-2021	40	0.286	-
72	CU and CP	GDH	-	Italy	2019	6	0.429	-
73	CP	GDH	-	-	2011-2019	1	0.286	-
74	CH, CU and CP	GDH	-	Spain	1991-2022	7	0.571	-
75	-	GDD	-	Chile	2017-2021	7	0.143	-
76	CH	-	-	-	1995-1998	1	0	-
77	CP	GDH	-	Spain	22 years	20	0.571	-
78	-	-	GDH	USA	2003-2004	7	-	0.200
79	CH	GDH	-	Argentina	2002-2007	4	0.286	-
80	CH, CU and CP	GDH	-	Spain	2004-2006	7	0.429	-
81	sequential and overlap CP	GDH	-	Australia	1992-2015	3	0.286	-
82	CH, CU and CP	GDH	-	Germany	1984-2008	1	0.286	-
83	CP	Pope overlap	-	Europe	1970-2018	1	0.429	-
84	CH and CU	-	-	Canada	2009-2010	1	0	-
85	-	GDD	-	Hungary	1984-1991	3	0.143	-
86	CH, CU and CP	-	-	Germany, Greece	1984-2019	4	0.286	-
87	CH, CU and CP	-	-	Germany	2012-2014	3	0.143	-
88	CH, CU and CP	-	-	Italy	-	10	0.286	-
89	chilling days, anti-chilling days	-	-	South Korea	1981-2010	-	0.143	-
90	CH and CU	GDH	-	Italy	1994-2013	4	0.143	-
91	CP	GDD	-	Germany	2001-2015	3	0.429	-
92	-	DTS model	-	Korea	-	-	0.429	-
93	CP	GDH	-	Germany	1984-2008	1	0.429	-
94	CP	GDH	-	Germany	-	1	0.286	-
95	CP	sigmoidal	-	Germany	1984-2018	1	0.429	-

Table S6. Literature review of cherry phenological models together with model scoring for blooming and ripening. See Table 1 caption for abbreviations.

Species	Dormancy break model	Blooming model	Ripening model
Peach ⁴¹	$S_c(t) = \sum_0^t R_c, S_c(t_c) = C^*$ $R_c(T(t)) = \frac{1}{1 + \exp(a(T - T_c)^2 + b((T - T_c)))}$ $a = 3.53, b = -25.85, T_c = 1.52, C^* = 49.6$	$S_f(t) = \sum_c^t R_f, S_f(t_b) = F^*$ $R_f(T(t)) = \frac{1}{1 + \exp(s(T - T_f))}$ $s = -0.50, T_f = 14.4, F^* = 4.19$	$S_r(t) = \sum_b^t R_r, S_r(t_r) = R^*$ $R_r(T(t)) = \begin{cases} 0 & \text{if } T < T_a \\ T - T_a & \text{otherwise} \end{cases}$ $T_a = 7, R^* = 678$
Plum ^{53,54}	See Chilling Portion model $CP = [26; 51]$	$S_f(t) = \sum_c^t R_f, S_f(t_b) = F^*$ $R_f(T(t)) = \begin{cases} 0 & \text{if } T < 4.5 \\ T - 4.5 & \text{if } 4.5 < T < 25 \\ 20.5 & \text{otherwise} \end{cases}$ $F^* = [4, 343; 9, 525]$	$S_r(t) = \sum_b^t R_r, S_r(t_r) = R^*$ $R_r(T(t)) = \begin{cases} 0 & \text{if } T < T_a \\ T - T_a & \text{otherwise} \end{cases}$ $T_a = 2.9, R^* = [1, 382; 1726]$
Almond ^{50,52}	See Chilling Portion model $CP = 23$	$S_f(t) = \sum_c^t R_f, S_f(t_b) = F^*$ $R_f(T(t)) = \begin{cases} 0 & \text{if } T < T_f \\ T - T_f & \text{otherwise} \end{cases}$ $T_f = 4.5, F^* = 300$	$S_r(t) = \sum_b^t R_r, S_r(t_r) = R^*$ $R_r(T(t)) = \begin{cases} 0 & \text{if } T < T_a \\ T - T_a & \text{otherwise} \end{cases}$ $T_a = 4.5, R^* = 2,450$
Apricot ^{45,55}	$S_c(t) = \sum_0^t R_c, S_c(t_c) = C^*$ $R_c(T(t)) = \frac{1}{1 + \exp(a(T - T_c)^2 + b((T - T_c)))}$ $a = 0.599, b = -14.87, T_c = -3.01, C^* = 130.6$	$S_f(t) = \sum_c^t R_f, S_f(t_b) = F^*$ $R_f(T(t)) = \frac{1}{1 + \exp(s(T - T_f))}$ $s = -0.50, T_f = 14.4, F^* = 4.19$	$S_r(t) = \sum_b^t R_r, S_r(t_r) = R^*$ $R_r(T(t)) = \begin{cases} 0 & \text{if } T < T_a \\ T - T_a & \text{otherwise} \end{cases}$ $T_a = 3, R^* = [1, 246; 1, 606]$
Cherry ^{56,57}	See Chilling Portion model $CP = [42.1; 59.9]$	$S_f(t) = \sum_c^t R_f, S_f(t_b) = F^*$ $R_f(T(t)) = \begin{cases} 0 & \text{if } T < 4.5 \\ T - 4.5 & \text{if } 4.5 < T < 25 \\ 20.5 & \text{otherwise} \end{cases}$ $F^* = [3653; 6993]$	$S_r(t) = \sum_b^t R_r, S_r(t_r) = R^*$ $R_r(T(t)) = \begin{cases} 0 & \text{if } T < 4 \\ 21(1 + \cos(\frac{\pi}{2} + \frac{\pi}{2} \frac{T-25}{11})) & \text{if } T > 25 \\ \frac{21}{2}(1 + \cos(\pi + \pi \frac{T-4}{21})) & \text{otherwise} \end{cases}$ $R^* = 13,367$

Table S7. Model equations and parameters for the temperature-driven phenological stages of endodormancy break, blooming and ripening. When parameters are reported as a range of possible values, the model parameterization is available for multiple cultivars. For chilling portion model equations refer to Luedeling et al. (2009)⁷¹.

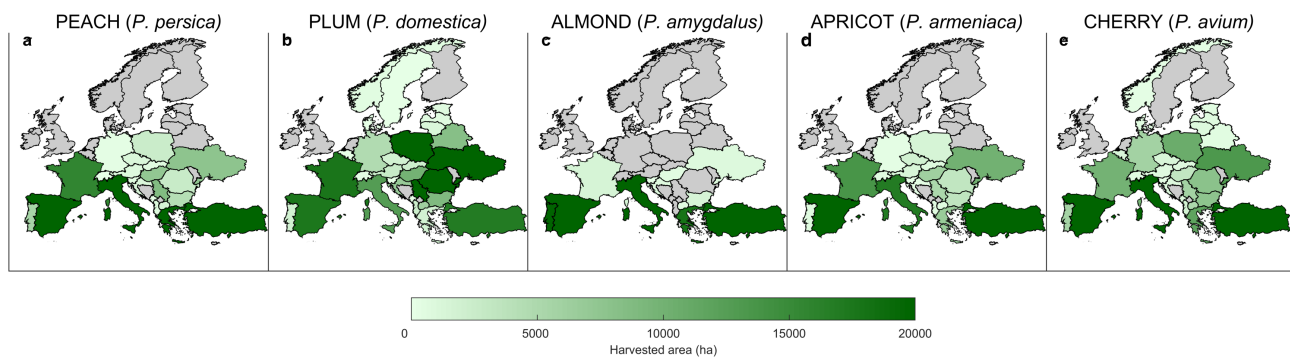


Figure S1. Average yearly (1995-2024) harvested area (ha) by country in the European territory for (a) peach, (b) plum, (c) almond, (d) apricot and (e) cherry production.

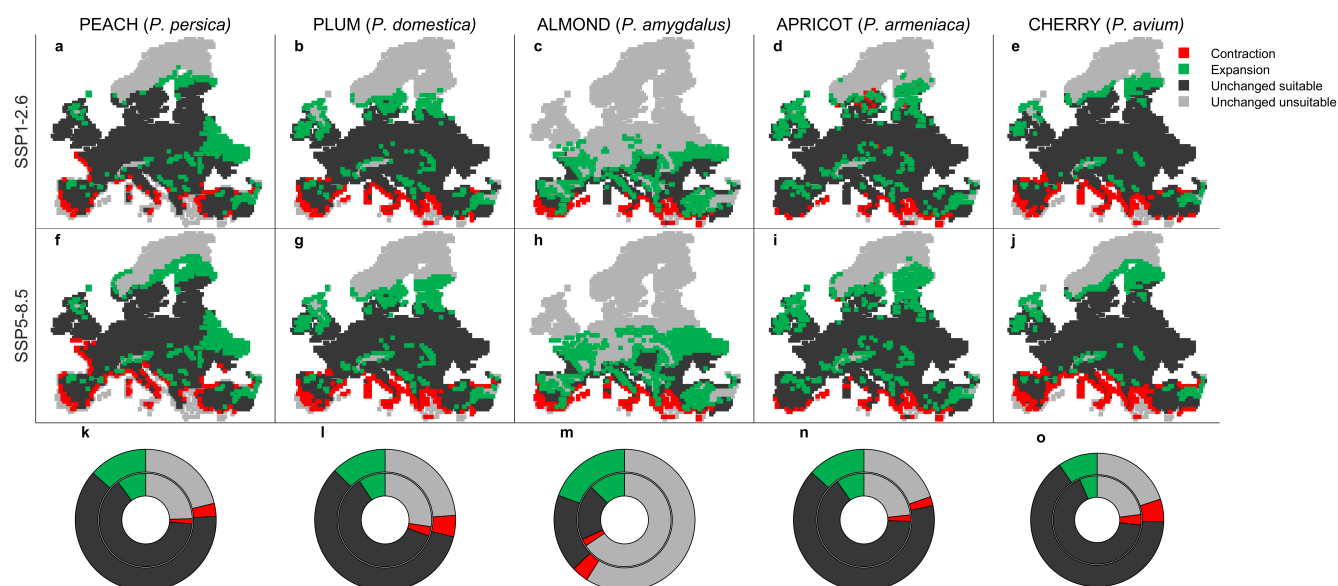


Figure S2. Future shifts of the ecological niche at the middle of the XXI century (2041-2060), compared to the historical period (1995-2014) under a sustainability scenario of climate change SSP1-2.6 (a-e) and a fossil-fuel development scenario SSP5-8.5 (f-j). Red areas represent a future niche contraction, green areas a future expansion, light gray areas are unchanged unsuitable areas and dark gray areas represent no niche change compared to the historical period. (k-o) Composition of the European territory between areas of contraction, expansion and unchanged in the future under the SSP1-2.6 scenario (inner donuts) and under the SSP5-8.5 scenario (outer donuts), compared to the historical period.

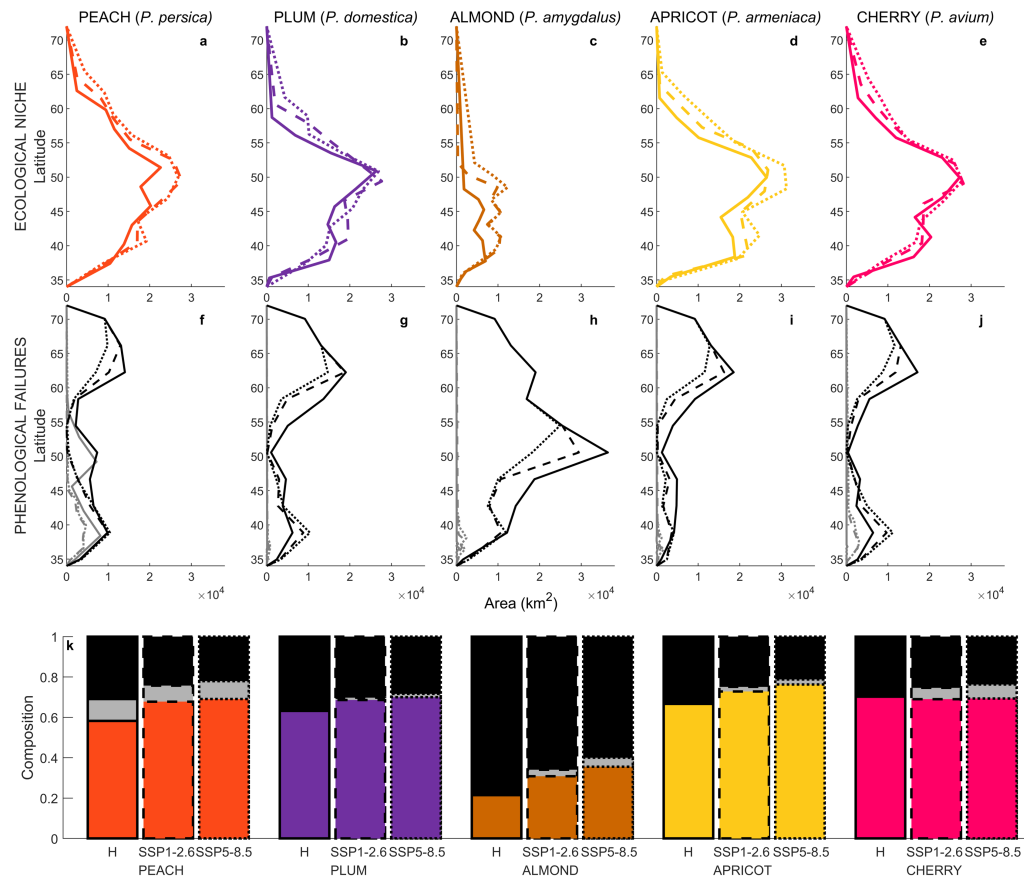


Figure S3. Latitudinal gradient of *Prunus* (a-e) ecological niche and (f-j) phenological failures (in gray chilling failures and in black forcing failures) in the historical period (1995-2014, solid line), at the middle of the century under SSP1-2.6 scenario (2041-2060, dashed line), and at the middle of the century under SSP5-8.5 scenario (2041-2060, dotted line). (k) Barplot represents the composition of the European territory between suitable areas (colored in orange for peach, purple for plum, brown for almond, yellow for apricot and magenta for cherry) in gray chilling failures and in black forcing failures, during the historical period (H, solid edge) and at the end of the century under the two scenarios (SSP1-2.6 scenario dashed bar edge, SSP5-8.5 scenario dotted bar edge).