

Electronic Supplemental Material (ESM)

Phenological mismatch between alpine flowers and bumble bees: Its mechanism and impacts on the population dynamics of bumble bees. G. Kudo et al. *Oecologia* (2025)

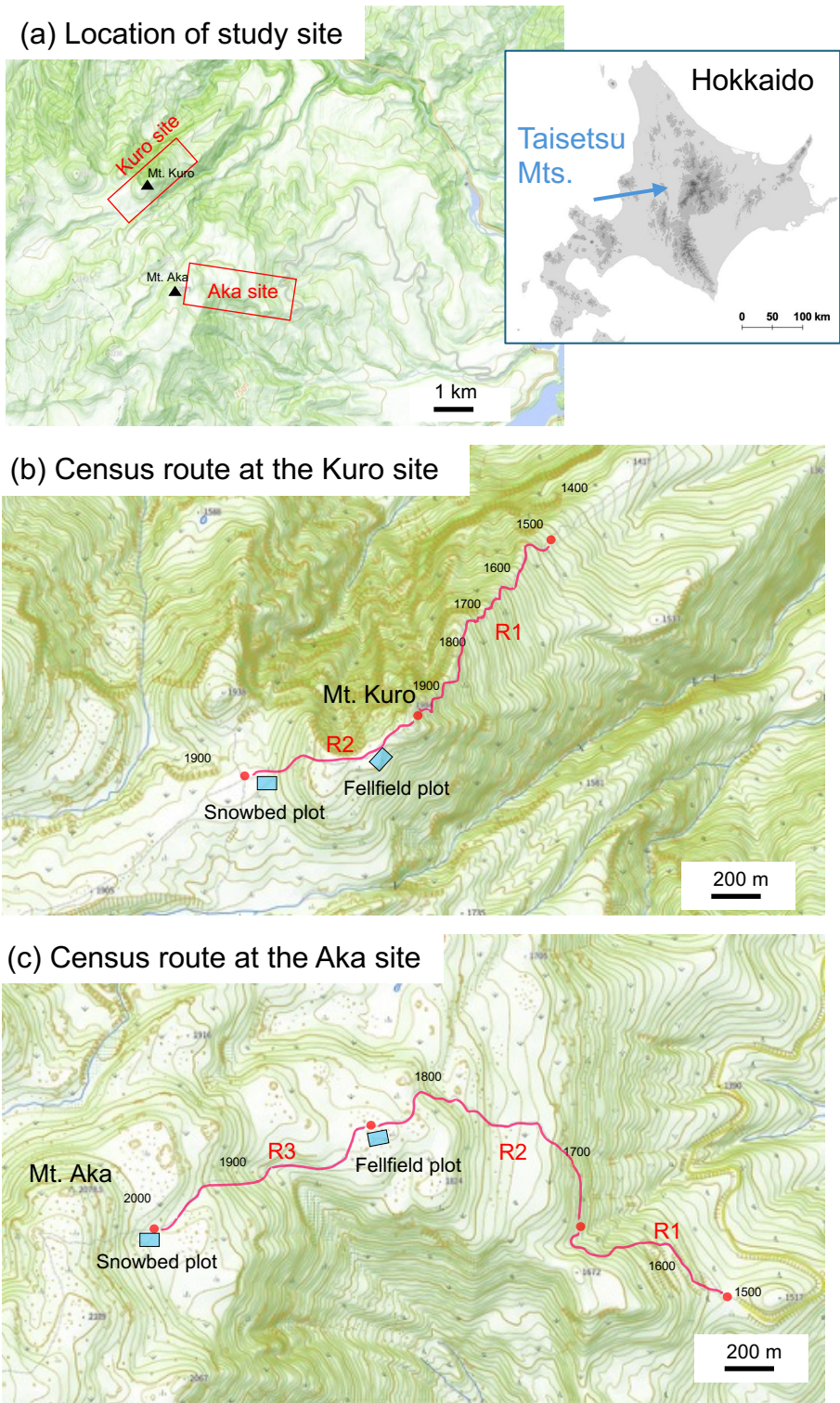


Fig. S1. (a) Location of study sites in the Taisetsu Mountain of Hokkaido. (b) and (c) The census route of bumble bees and the monitoring plots of flowering phenology in the fellfield and snowbed communities at the Kuro and Aka sites. Census routes were set along hiking trails (from 1500 m to 2000 m a.s.l.) and divided into two (Kuro site) or three (Aka site) parts.

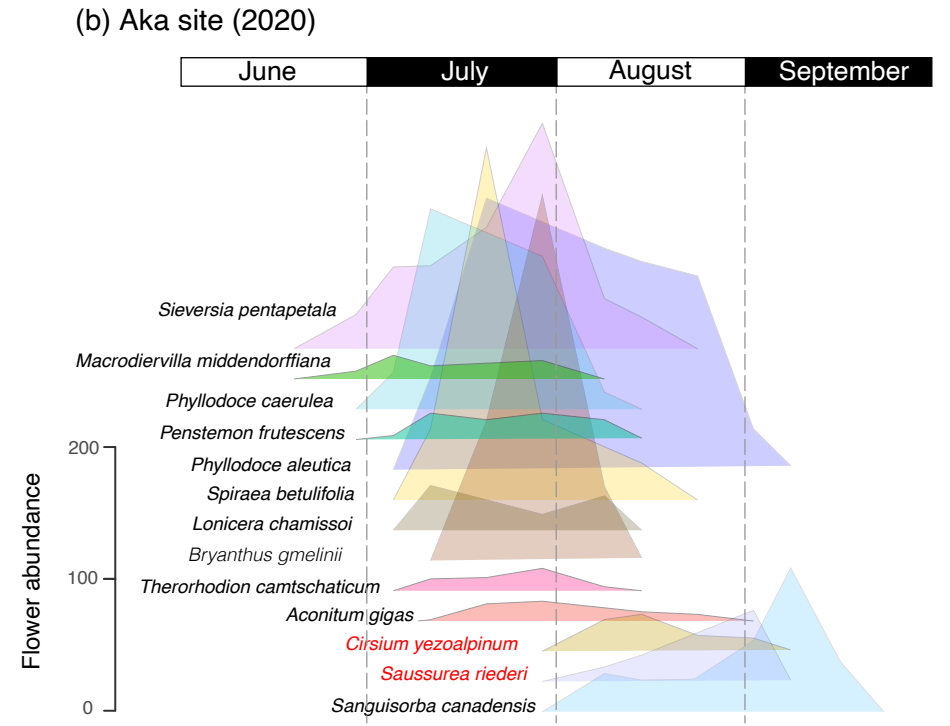
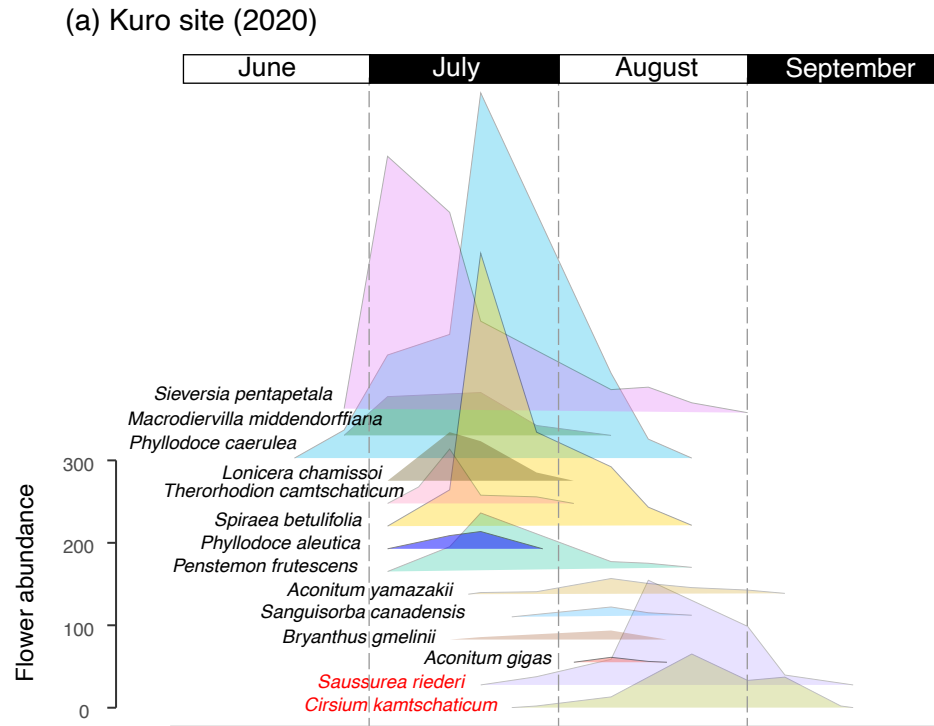


Fig. S2. Seasonal changes in flower abundance of the main plant species visited by bumble bees at the Kuro site (a) and the Aka site (b) in 2020. Flower or inflorescence abundance of each species was recorded at 7–10 days intervals from late June to early September in 40–50 quadrats (1 m x 1 m) placed along the trail to quantify the amount of flower resources for bumble bees at each site. Thistle species are shown in red. (G. Kudo and T. Nagase, unpublished data).

Table S1. Species list observed in the monitoring plots of flowering phenology. Plant group is classified as early-flowering fellfield plants (FE), late-flowering fellfield plants (FL), and snowbed plants (S). Plant species growing at both fellfield and snowbed habitats are separately listed in each category. Circles mean the occurrence of flowering in each year (2010-2023).

(a) Kuro site

[illegible]

[illegible][illegible]

<i>Harrimanella stelleriana</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Potentilla matsumurae</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Phyllodoce caerulea</i> var. <i>yezoensis</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Sieversia pentapetala</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Phyllodoce aleutica</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Vaccinium uliginosum</i>	S															○
<i>Gentiana nipponica</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Veronica stelleri</i> var. <i>longistyla</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Pedicularis chamissonis</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Loiseleuria procumbens</i>	S															○
<i>Peucedanum multivittatum</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Solidago virgaurea</i> subsp. <i>leiocarpa</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Anemone narcissiflora</i> var. <i>sachalinensis</i>	S										○	○	○			
<i>Sanguisorba stipulata</i>	S		○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Parnassia palustris</i>	S					○				○					○	○
<i>Cirsium kamtschaticum</i> ssp. <i>alpinum</i>	S	○	○	○	○	○	○	○	○	○	○	○	○	○	○	○
<i>Saxifraga merkii</i>	S		○	○			○				○	○	○	○	○	

Table S2. The results of linear models conducted for the peak time (day of year) of worker bees of four *Bombus* species. Explanatory variables in the full models were deviations in snowmelt time, early summer (June) and mid-summer (July–August) temperatures, and site (Kuro, Aka). Best-fit models based on AICc values are shown. AICc value of full model is shown in parenthesis.

	Coeff.	SE	<i>t</i> value	<i>P</i> value
(a) <i>B. hypocrita</i> AICc = 149.9 (160.2)				
Intercept	100.7	1.04	96.7	< 0.0001 ***
(b) <i>B. beaticola</i> AICc = 154.5 (172.6)				
Intercept	104.4	1.15	91.1	< 0.0001 ***
(c) <i>B. yezoensis</i> AICc = 148.8 (164.7)				
Intercept	107.3	1.00	106.9	< 0.0001 ***
ΔSnowmelt time	0.25	0.12	2.02	0.056 ⁺
(d) <i>B. hypnorum</i> AICc = 144.5 (164.2)				
Intercept	93.5	1.50	62.2	< 0.0001 ***

Full model: Peak DOY ~ (ΔSnowmelt time + ΔEarly summer temp + ΔMid-summer temp) × Site

Table S3. The results of linear models conducted for phenological mismatch (day), i.e., difference between peak flowering time of snowbed plants and peak time of worker bees of four *Bombus* species. Explanatory variables in the full models were deviations in snowmelt time, early summer (June) and mid-summer (July–August) temperatures, and site (Kuro, Aka). Best-fit models based on AICc values are shown. AICc value of full model is shown in parenthesis.

	Coeff.	SE	<i>t</i> value	<i>P</i> value
(a) <i>B. hypocrita</i> AICc = 166.1 (183.2)				
Intercept (Kuro site)	6.40	1.94	3.30	0.0034
ΔSnowmelt time	-0.68	0.17	-4.06	0.0006 ***
Aka site	-8.41	2.72	-3.09	0.0055 **
(b) <i>B. beaticola</i> AICc = 164.2 (191.7)				
Intercept (Kuro site)	12.78	1.87	6.84	< 0.0001 ***
ΔSnowmelt time	-0.71	0.16	-4.36	0.0003 ***
Aka site	-13.83	2.62	-5.28	< 0.0001 ***
(c) <i>B. yezoensis</i> AICc = 148.4 (165.4)				
Intercept (Kuro site)	13.92	1.35	10.34	< 0.0001 ***
ΔSnowmelt time	-0.52	0.12	-4.43	0.0002 ***
Aka site	-10.56	1.89	-5.60	< 0.0001 ***
(d) <i>B. hypnorum</i> AICc = 137.6 (163.3)				
Intercept (Kuro site)	0.10	2.26	0.05	0.97
ΔSnowmelt time	-0.92	0.20	-4.54	0.0003 ***
Aka site	-12.99	3.41	-3.81	0.0015 **

Full model: mismatch ~ (ΔSnowmelt time + ΔEarly summer temp + ΔMid-summer temp) × Site