

Spatial and temporal shifts in photoperiod with climate change

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1. *Introduction*

- (a) Photoperiod is a critical cue used by organisms to synchronize their activities with seasonal climatic changes (add other citations- there are many possibilities! if you have favorites, please add along with 1-2 words of what the activity is)(e.g., Hsu et al., 2011; Singh et al., 2017).
- (b) As species undergo climate change-induced shifts in space and/or time, the daylength they experience will be altered.
- (c) Many experiments have altered photoperiod, often interacting with temperature changes; however, photoperiod treatments in these experiments are not typically designed to be applied to climate change forecasting.
- (d) Here, we ask:
 - i. How will climate change alter the photoperiod experienced by organisms, given observed climate change-induced biological shifts, both spatially and temporally?
 - ii. What are the implications of these altered photoperiods for forecasts of climate change impacts?
 - iii. Can the large quantity of experiments altering photoperiod be applied to forecasting biological implications of climate change (i.e. do they occur at the appropriate scale)?

2. *How will climate change alter the photoperiod experienced by organisms?*

- (a) Spatial shifts in species ranges and temporal shifts in species phenology and activity will alter the photoperiods experienced by organisms under climate change.
- (b) To date, most work has focused on how spatial range shifts with climate change will affect photoperiod (Saikkonen et al., 2012), but temporal shifts are actually likely to yield bigger changes in experienced photoperiod than spatial shifts (Figures 1).
- (c) Shifts in photoperiod may vary with latitude and time of year (Figure 1), especially since phenology varies with latitude (Figure 3), and species responses to photoperiod vary with latitude (Dan's figure).
- (d) Photoperiod sensitivity can also vary with latitude (cite OSPREE database and perhaps add a table?), so it is unclear how these two things interact. Cat has added a text file to the latitude analysis folder that summarizes papers that have looked at latitudinal effects on photoperiod.

3. *What are the implications of these altered photoperiods for forecasts of climate change impacts?*

- (a) Phenology will be altered, given that daylength is known to affect vegetative growth, cell elongation, and budburst (Linkosalo and Lechowicz, 2006; Erwin, 1998; Sidaway-Lee et al., 2010; Hsu et al., 2011).
- (b) It has been proposed that photoperiod may eventually become a limiting factor, constraining the ability of trees to shift their phenology with warming (Koerner and Basler, 2010; Vitasse and Basler, 2013; Morin et al., 2010).

- (c) Interactions between photoperiod and forcing and chilling could result in muted or exaggerated phenological shifts, compared to what would be expected based on temperature change alone. Say something about crossing thresholds of daylength and the "external coincidence model" for photoperiod control (Bastow and Dean, 2002; Kobayashi and Weigel, 2007; Andrés and Coupland, 2012; Singh et al., 2017)?
 - (d) Effects of photoperiod on forecasting of biological impacts of climate change needs additional investigation. In some forecasting methods (e.g. species distribution modelling), the role of photoperiod is largely ignored (i think this is true? add some citations). In other cases, photoperiod is incorporated into forecasts, along with other variables such as evaporative demand, and temperature (e.g. ED Jolly et al., 2005; Medvigy et al., 2013). These models need to be more widely tested, e.g. in different ecosystems/species, and need to incorporate recent findings about the role of photoperiod in phenology.
4. *Can existing experiments be applied to forecasting?*
- (a) Table of OSPREE experiments that manipulate photoperiod, their daylength treatments, their findings, and perhaps how the treatment corresponds to spatial/temporal shifts? (in supplement, i think)
 - (b) Figure showing magnitude of
 - (c) Most experiments manipulate photoperiod much more dramatically than will occur with climate change (but see (Basler and Körner, 2012)), so it is difficult to extrapolate findings. (This may not be true for all latitudes- for example high latitudes experience more dramatic changes in photoperiod across the year.)
 - (d) There is a great need to better understand exactly how photoperiod acts as a cue (linear response? threshold? how does it interact with temperature to break dormancy?)
5. *Conclusions*
- (a) Organisms may experience large changes to the photoperiod they experience, under climate change, even if they do not shift their ranges spatially.
 - (b) More studies needed with fine-scale changes in photoperiod.

To do:

1. make lines transparent.
2. Make Table of studies testing if photoperiod varies by latitudinal origin- cat started on this.

Random notes that may be useful:

1. Bradshaw and Holzapfel (2001) showed that the pitcher plant mosquito, *Wyeomyia smithii*, has evolved a shorter critical photoperiod in association with a longer growing season. Northern populations of this mosquito now use a shorter day-length cue to enter winter diapause, doing so later in the fall than they did 24 years ago.

References

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Tables

Table 1: **Growth chamber experiments and their photoperiod treatments**, compared to the spatial and temporal shifts required for organisms to experiments photoperiod changes equivalent to those treatments. For shifts in space, ‘ER’ indicates that the photoperiod treatments exceeds the change of photoperiod from moving up to 40 degrees latitudinally on June 21. For shifts in time, ‘ER’ indicates that the range of photoperiod treatments exceeds the change in daylengths at that latitude during the entire year. ‘max NA’ indicates that the maximum daylength treatment does not exist at that latitude; ‘min NA’ indicates that the minimum daylength treatment does not exist at that latitude.

idstudy	continent	lat	long	day_range	delta	space	time
ashby62_exp1	north america	42.99	-89.41	8-16	4.00	18.2	min NA (9)
basler14_exp1	europa	46.31	8.27	9.2-16	1.00	6	-22
caffarra11b_exp2	europa	52.32	-6.93	10-16	2.00	7.5	-30
devries82_exp1	europa	51.98	5.66	8-24	16.00	ER	ER
falusi90_exp1	europa	46.03	10.75	9-13	4.00	16	-82
falusi96_exp3	europa	38.27	15.99	9-13	4.00	21.6	-111
ghelardini10_exp1	europa	43.72	11.37	8-16	8.00	21.9	ER
heide05_exp1	europa	56.18	-4.32	10-24	14.00	ER	ER
heide08_exp1	europa	48.40	11.72	10-24	14.00	ER	ER
heide11_exp1	europa	59.67	10.67	10-20	10.00	ER	max NA (6)
heide12_exp1	europa	56.50	-3.06	10-24	5.00	8.9	-64
heide15_exp2	europa	56.50	-3.06	10-15	1.00	3.2	-13
heide93_exp1	europa	59.50	10.77	8-24	16.00	ER	ER
heide93a_exp1	europa	59.67	10.83	8-24	16.00	ER	ER
heide93a_exp3	europa	47.50	7.60	13-16	1.00	5.7	-18
howe95_exp1	north america	40.55	-124.10	9-24	2.00	13.1	-64
laube14a_exp1	europa	48.40	11.71	8-16	4.00	14.3	-87
myking95_exp1	europa	56.10	9.15	8-24	16.00	ER	ER
myking97_exp1	europa	59.67	10.77	12-24	12.00	ER	max NA (6)
nienstaedt66_exp1	north america	44.17	-103.92	8-20	12.00	ER	ER
okie11_exp1	north america	32.12	-83.12	0-12	12.00	ER	ER
partanen01_exp1	europa	61.93	26.68	6-16	10.00	ER	-105
partanen05_exp1	europa	61.82	29.32	5-20	5.00	ER	-67
partanen98_exp1	europa	60.03	23.05	8.66-12	3.34	5.1	-37
pettersen71_exp1	europa	59.66	10.77	10-24	2.00	4	-23
Sanz-Perez09_exp1	europa	40.40	-3.48	10-16	6.00	23.6	ER
schnabel87_exp1	north america	46.21	-119.77	9.5-14	0.25	1.7	-7
viheraaarnio06_exp1	europa	60.45	24.93	16-17	0.00	0	0
viheraaarnio06_exp1	europa	67.73	24.93	20-21	1.00	ER	-5
viheraaarnio06_exp2	europa	60.45	24.93	15-19	1.00	2.1	-11
viheraaarnio06_exp2	europa	67.73	24.93	22-23	-1.00	ER	5
worrall67_exp 3	north america	41.31	-72.93	8-16	8.00	24.3	ER
zohner16_Exp1	europa	48.16	11.50	8-16	8.00	ER	ER

Figures

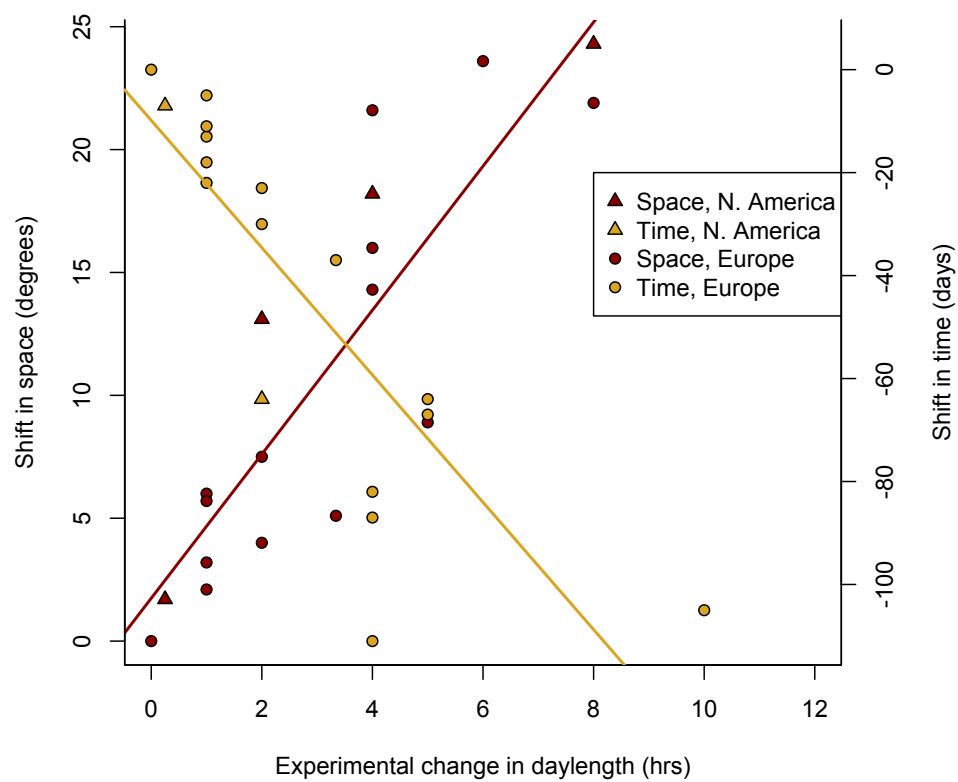


Figure 1: Shifts in the daylength in OSPREE treatments, and their equivalent spatial and temporal shifts).

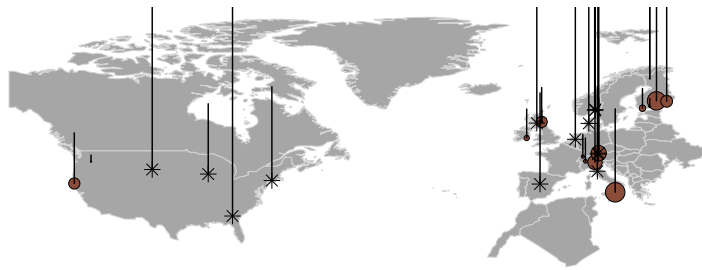


Figure 2: **OSPREE** experiments that manipulate photoperiod, and their equivalent spatial and temporal shifts).

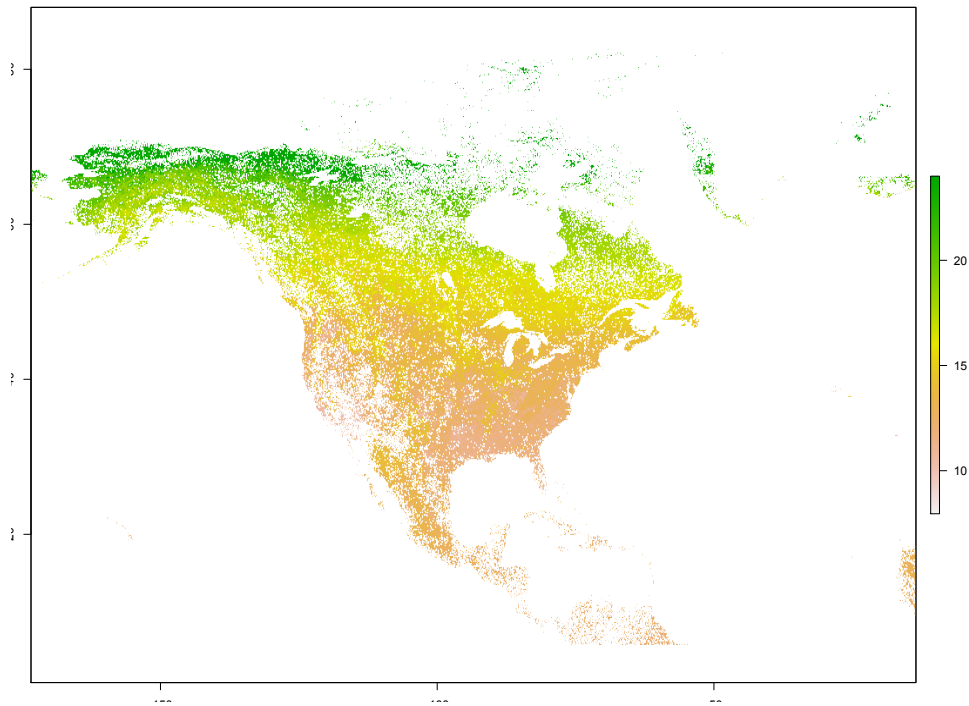


Figure 3: **Green-up date varies with latitude.**