Spatial and temporal shifts in photoperiod with climate change

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December 14, 2017

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 (and forecasted?) biological shifts (both spatial and temporal)?

      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 actually yield bigger changes in experienced photoperiod than spatial shifts (Figures 1,2).

   (c) Shifts in photoperiod may vary with latitude (Figure 2).

   (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.

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 investifation. In some forecasting methods (e.g. species distirbution modelling), the role of photoperiod is largely ignored (i think this is true? add some citations). In other cases, photoperiod is incorporated into foreacasts, 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 given 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?

   (b) 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.)

   (c) 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.

   (b) More studies needed with fine-scale changes in photoperiod

To do:

1. Make a map showing daylength or greenup dates globally
2. Make Table of studies and treatments
3. Make Table of studies testing if photoperiod varies by latitudinal origin

References

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Tables

Table 1: Growth chamber experiments and their photoperiod treatments. ER indicates that the range of photoperiod treatments exceeds the change in daylengths at that latitude. '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
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
worrall67_exp 3	north america	41.31	-72.93	8-16	8.00	ER	ER
heide05_exp1	europe	56.18	-4.32	10-24	14.00	ER	ER
Sanz-Perez09_exp1	europe	40.40	-3.48	10-16	6.00	ER	ER
devries82_exp1	europe	51.98	5.66	8-24	16.00	ER	ER
myking95_exp1	europe	56.10	9.15	8-24	16.00	ER	ER
heide11_exp1	europe	59.67	10.67	10-20	10.00		max NA
falusi90_exp1	europe	46.03	10.75	9-13	4.00	ER	-82
heide93_exp1	europe	59.50	10.77	8-24	16.00	ER	ER
myking97_exp1	europe	59.67	10.77	12-24	12.00	ER	max NA
ghelardini10_exp1	europe	43.72	11.37	8-16	8.00	ER	ER
zohner16_Exp1	europe	48.16	11.50	8-16	8.00	ER	ER
heide08_exp1	europe	48.40	11.72	10-24	14.00	ER	ER
falusi96_exp3	europe	38.27	15.99	9-13	4.00	ER	-111
partanen01_exp1	europe	61.93	26.68	6-16	10.00		-105
ashby62_exp1	north america	42.99	-89.41	8-16	4.00	ER	min NA
heide12_exp1	europe	56.50	-3.06	10-24	5.00		-64
basler14_exp1	europe	46.31	8.27	9.2-16	1.00	ER	-22
laube14a_exp1	europe	48.40	11.71	8-16	4.00	ER	-87
partanen98_exp1	europe	60.03	23.05	8.66-12	3.34		-37
caffarra11b_exp2	europe	52.32	-6.93	10-16	2.00		-30
partanen05_exp1	europe	61.82	29.32	5-20	5.00		-67
heide15_exp2	europe	56.50	-3.06	10-15	1.00		-13
heide93a_exp3	europe	47.50	7.60	13-16	1.00	ER	-18
pettersen71_exp1	europe	59.66	10.77	10-24	2.00		-23
heide93a_exp1	europe	59.67	10.83	8-24	16.00	ER	ER
howe95_exp1	north america	40.55	-124.10	9-24	2.00	ER	-64
viheraaarnio06_exp1	europe	60.45	24.93	16-17	0.00	0	0
viheraaarnio06_exp2	europe	60.45	24.93	15-19	1.00	27.1	-11
viheraaarnio06_exp1	europe	67.73	24.93	20-21	1.00		-5
viheraaarnio06_exp2	europe	67.73	24.93	22-23	-1.00		5
schnabel87_exp1	north america	46.21	-119.77	9.5-14	0.25	35.7	-7

Table 2: **Growth chamber experiments and their photoperiod treatments.** From OSPREE. For now, I used 45.5 lat to estimate spatial and temporal equivalents and Y/N for sensitivity but might be better to have a magnitude of sensitivity found?

Study	**Photoperiod treatments (or delta)**	**Spatial equivalent**	**Temporal equivalent**
basler12	9.5, 11 (1.5)	600 km up	30 days earlier
laube14a	8,16 (8)	3200 km up	160 days earlier
other studies			

Figures

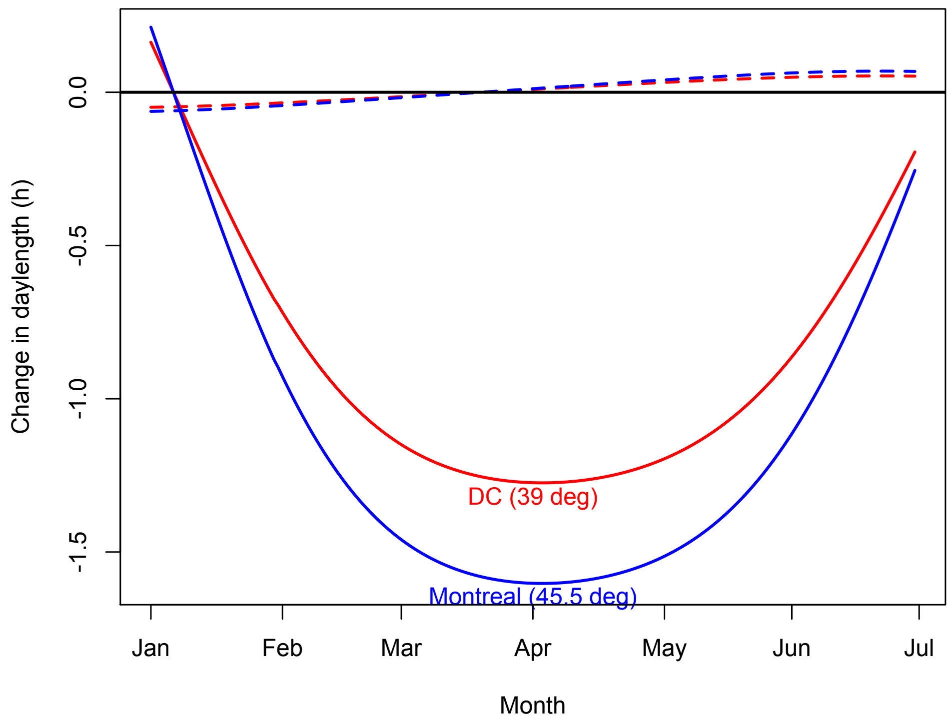

Figure 1: **Shifts in the photoperiod organisms will experience with climate change, at two latitudes (Washington, DC and Montreal).** With warming, species are likely to shift their ranges poleward and/or shift their spring activity earlier, resulting in alterations to the photoperiod they experience. We compare changes to photoperiod in 100 years if species shift spatially (i.e. shifting their ranges 6km,or 0.05 degree, per decade poleward, solid lines) versus temporally (shifting activity earlier 3 days per decade, dashed lines).

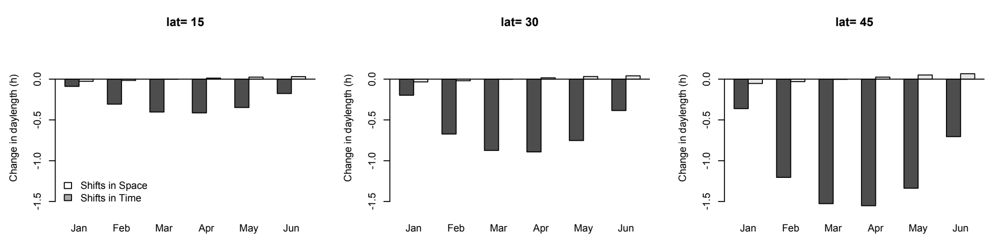

Figure 2: **Shifts in the photoperiod organisms will experience with climate change, across latitude.** With warming, species are likely to shift their ranges poleward and/or shift their spring activity earlier, resulting in alterations to the photoperiod they experience. We compare changes to photoperiod in 100 years if species shift spatially (i.e. shifting their ranges 6km,or 0.05 degree, per decade poleward) versus temporally (shifting activity earlier 3 days per decade).