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 (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.

study	continent	lat	long	daylength	space	time
howe95	north america	40.548	-124.097	9-24		exceeds range
schnabel87	north america	46.209	-119.766	9.5-14		-86
nienstaedt66	north america	44.166	-103.916	8-20		exceeds range
ashby62	north america	42.988	-89.412	8-16		exceeds range
okie11	north america	32.120	-83.120	0-12		exceeds range
worrall67	north america	41.306	-72.928	8-16		exceeds range
caffarra11a	europe	52.320	-6.934	8-16		-132
caffarra11b	europe	52.320	-6.934	10-16		-94
heide05	europe	56.176	-4.316	10-24		exceeds range
Sanz-Perez09	europe	40.400	-3.480	10-16		exceeds range
heide12	europe	56.500	-3.062	10-24		exceeds range
heide15	europe	56.500	-3.062	10-15		-64
devries82	europe	51.984	5.664	8-24		exceeds range
heide93a	europe	47.500	7.600	13-16		-78
basler14	europe	46.315	8.265	9.2-16		-151
myking95	europe	56.100	9.150	8-24		exceeds range
heide11	europe	59.667	10.667	10-20		
falusi90	europe	46.033	10.750	9-13		-82
heide93	europe	59.500	10.767	8-24		exceeds range
myking97	europe	59.667	10.767	12-24		
pettersen71	europe	59.660	10.770	10-24		exceeds range
heide93a	europe	59.670	10.830	8-24		exceeds range
ghelardini10	europe	43.717	11.367	8-16		exceeds range
zohner16		48.164	11.503	8-16		exceeds range
laube14a		48.403	11.712	8-16		exceeds range
heide08	europe	48.396	11.725	10-24		exceeds range
sogaard08	europe	60.278	12.734	12-24		
falusi96	europe	38.267	15.988	9-13		254
partanen98	europe	60.033	23.050	8.66-12		-37
viheraaarnio06	europe	60.450	24.930	15-19		-62
viheraaarnio06	europe	67.730	24.930	20-23		-13
partanen01	europe	61.933	26.683	6-16		-105
partanen05	europe	61.817	29.317	5-20		exceeds range

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

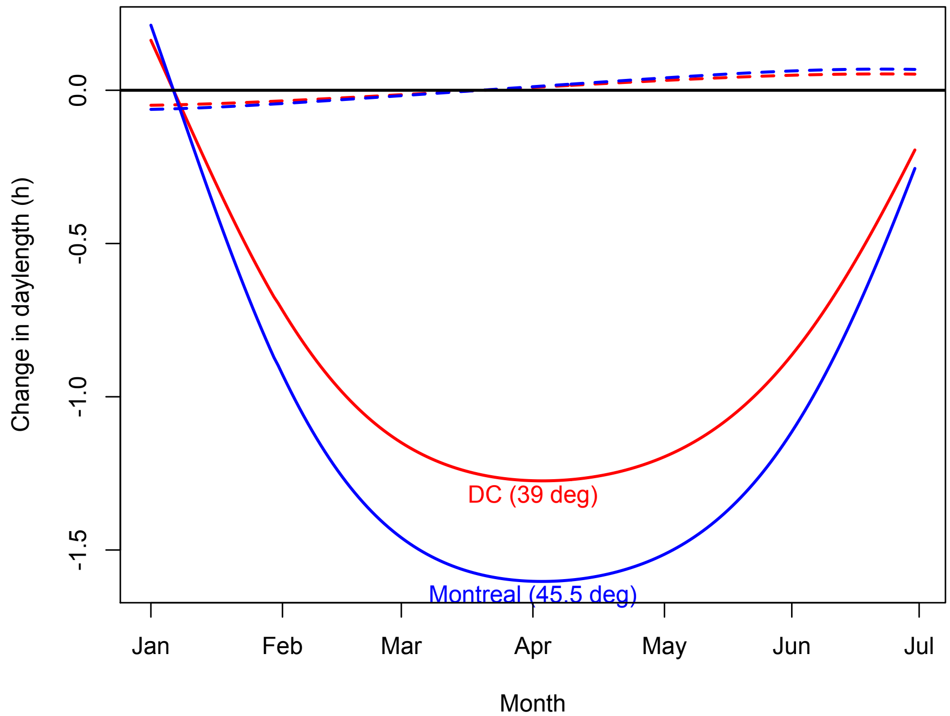

Figure 1: **Shifts in the photoperiod organisms will experience with climate change, at two latitudes (Washington, DC and Montreal).** With warming, species are likely to shift their ranges poleward and/or shift their spring activity earlier, resulting in alterations to the photoperiod they experience. 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).

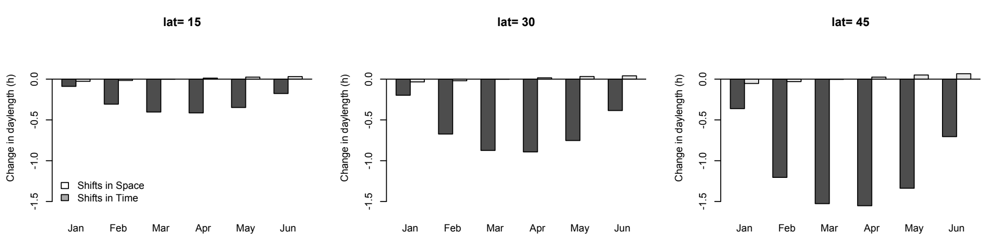

Figure 2: **Shifts in the photoperiod organisms will experience with climate change, across latitude.** With warming, species are likely to shift their ranges poleward and/or shift their spring activity earlier, resulting in alterations to the photoperiod they experience. We compare changes to photoperiod 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).