Spatial and temporal shifts in photoperiod with climate change

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1. *Introduction*
   (a) Photoperiod is a critical cue used by organisms, and many studies exist demonstrating this. (could focus just on phenology or on other things too?)
   (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 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; **?**).
   (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.
   (d) Photoperiod should be incorporated into foreacasts of biological impacts of climate change (species distribution modelling, ED).

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

Basler, D., and C. Körner. 2012. Photoperiod sensitivity of bud burst in 14 temperate forest tree species. Agricultural and Forest Meteorology 165:73–81.

Erwin, J. E. 1998. Temperature and light effects on stem elongation (plant growth regulation by physical and mechanical stimuli, for further development of horticulture in east asia). Journal of the Japanese Society for Horticultural Science 67:1113–1120.

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Morin, X., J. Roy, L. Sonié, and I. Chuine. 2010. Changes in leaf phenology of three european oak species in response to experimental climate change. New Phytologist 186:900–910.

Saikkonen, K., K. Taulavuori, T. Hyvönen, P. E. Gundel, C. E. Hamilton, I. Vänninen, A. Nissinen, and M. Helander. 2012. Climate change-driven species' range shifts filtered by photoperiodism. Nature Climate Change 2:239.

Sidaway-Lee, K., E.-M. Josse, A. Brown, Y. Gan, K. J. Halliday, I. A. Graham, and S. Penfield. 2010. Spatula links daytime temperature and plant growth rate. Current biology 20:1493–1497.

Vitasse, Y., and D. Basler. 2013. What role for photoperiod in the bud burst phenology of european beech. European Journal of Forest Research 132:1–8.

Tables

Table 1: Growth chamber experiments and their photoperiod treatments.

study	lat	long	daylength	delta	spatial	temporal
ashby62	42.988	-89.412	8			
ashby62	42.988	-89.412	12			
ashby62	42.988	-89.412	16			
basler12	46.200	7.033	shortday			
basler12	46.850	9.530	longday			
basler14	46.315	8.265	16			
basler14	46.315	8.265	9.2			
basler14	46.315	8.265	10.2			
bernier81			8			
bernier81			10			
bernier81			12			
bernier81			14			
bernier81			16			
bernier81			18			
bernier81			20			
bernier81			22			
biasi12	-23.380	-49.130	16			
biran73	31.890	34.819	16			
biran73	31.890	34.819	11			
biran73	31.890	34.819	10.5			
boyer	37.000	-76.000	14			
bradford10	42.700	-75.968	9			
bradford10	42.700	-75.968	16			
caffarra11a	52.320	-6.934	16			
caffarra11a	52.320	-6.934	8			
caffarra11b	52.320	-6.934	10			
caffarra11b	52.320	-6.934	12			
caffarra11b	52.320	-6.934	14			
caffarra11b	52.320	-6.934	16			
calme94	46.500	-78.833	16			
campbell75	45.370	-124.500	16			
charrier11	45.772		16			
cook00b	-34.150	19.040	24			
cook05	-34.076	18.842	24			
dantec14	43.750	0.220	16			
devries82	51.984	5.664	8			
durner84	37.227	-80.423	16			
durner84	37.227	-80.423	9			
ellis97			11			
ellis97			12.5			
falusi03	43.732	11.557	12			
falusi90	46.033	10.750	9			
falusi90	46.033	10.750	13			
falusi96	38.267	15.988	9			
falusi96	38.267	15.988	13			
falusi97	43.820	11.960	12			
ghelardini10	43.717	11.367	8			
ghelardini10	43.717	11.367	16			
granhus09	60.580	11.000	24			
guerriero90	43.706	10.331	12			
gutterman88	30.850	34.770	8			
gutterman88	30.850	34.770	12			
gutterman88	30.850	34.770	14			
gutterman88	30.850	34.770	24			
gutterman88	30.850	34.770	9			
gutterman88	30.850	34.770	15			
gutterman88	30.850	34.770	18			

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

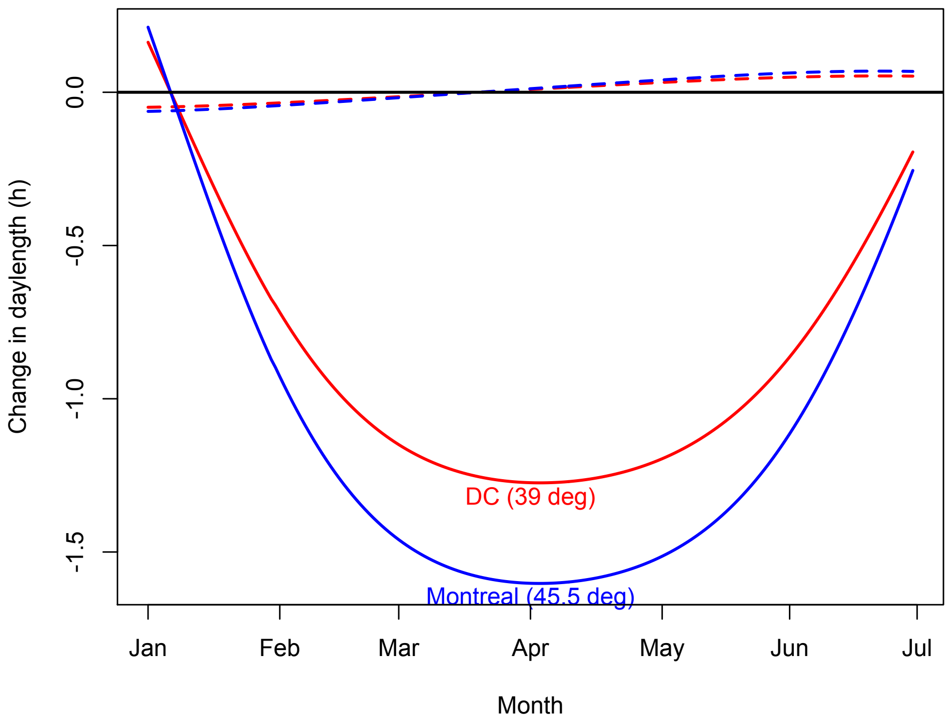

Figure 1: **Shifts in the photoperiod organisms will experience with climate change, at two latitudes (Washington, DC and Montreal).** With warming, species are likely to shift their ranges poleward and/or shift their spring activity earlier, resulting in alterations to the photoperiod they experience.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

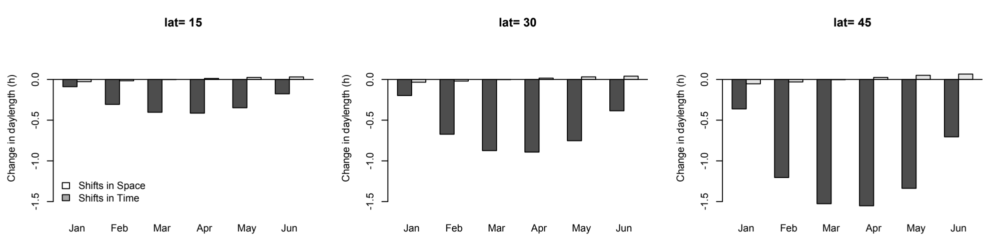

Figure 2: **Shifts in the photoperiod organisms will experience with climate change, across latitude.** With warming, species are likely to shift their ranges poleward and/or shift their spring activity earlier, resulting in alterations to the photoperiod they experience. We compare changes to photoperiod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