IDE phenology add-on: Global drought-phenology relationship of terrestrial ecosystems

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RESEARCH CHALLENGES: Flowering phenology of plants is sensitive to global environmental changes. The great majority of existing phenological studies focus solely on warming[1–8], while the effects of drought on plant phenology[9–11] are less widely investigated. Yet, the knowledge on how plant phenology of global terrestrial ecosystems responds to drought along an environmental gradient (precipitation, temperature, and elevation) is critical to future understanding of plant species' performance.

The few existing studies that examined drought effects on phenology have inconsistent results, showing drought can advance[9], delay[10], or have no effect[11]. This is probably because the magnitude of drought treatments, environmental gradients, and ecosystems across those studies are not comparable. Therefore, it is timely to investigate responses of major terrestrial ecosystems under a standardized drought event (equivalent to a 1 in 100-years drought) in order to gain a general overview of how plant phenology performs. We will investigate how drought-phenology relationships will differ along the precipitation, temperature and elevational gradient existing within IDE sites.

WORKING HYPOTHESES (more can potentially be addressed):

H1: Earlier shift in phenology at the peak or end of growing season (i.e. advances in mid- and last flowering date) will be influenced by drought stress. We assume that drought will reduce the length of the flowering period.

H2: Flowering phenology of ecosystems dominated by early-flowering species will be less sensitive to drought than those dominated by late-flowering species.

H3: Drought-phenology relationship will differ across a precipitation gradient; xeric and semi-arid ecosystems being less sensitive to drought stress (assuming local adaptation) than mesic and moist systems.

H4: Drought effects on plant phenology will also differ across a temperature gradient. We assume that cool ecosystems will be less sensitive to drought than warmer systems.

H5: Drought stress will alter the well-known "Hopkins' bioclimatic law". We assume that drought stress will decrease elevation-induced phenological shift and leads to more uniform plant phenology across elevations.

RATIONALE: One of the most important determinants of flowering induction, abscisic acid (phytohormone ABA)-mediated signaling, can be influenced by several abiotic factors including increasing temperature[12] and water deficit[13]. Thus, it is highly likely that there is a resemblance between temperature and precipitation effects on flowering phenology[14,15]. Recent studies found that phenology in the early growing season (or spring) mainly depends on temperature[16,17], while precipitation is the predominant factor controlling phenology at the peak or end of growing season[15,18,19]. Hence, it is expected that ecosystems dominated by early-flowering species (flowering during the early growing season) are sensitive to temperature, while systems dominated by late-flowering species (flowering during peak growing season) are sensitive to drought. Generally, drought stress builds up faster and stronger in warmer conditions[20]. Therefore, higher drought effects in warmer ecosystems (subtropics, tropics, and Mediterranean) are anticipated than those in cool systems (arctic to temperate).

The timing of plant phenological phases further differs along elevational gradients[21]. Hopkins hypothesized in 1920 a progressive delay in leaf-phenology with increasing elevation, a phenomenon referred to as "Hopkins' bioclimatic law"[21]. A recent study[22] reported that global warming has significantly declined the elevation-induced phenological shift from 34 $d \cdot 1{,}000 m^{-1}$ to 22 $d \cdot 1{,}000\ m^{-1}$. We do not know whether precipitation reduction across an elevational gradient will alter the well-known bioclimatic law and therefore seek to quantify these effects with this add-on.

GUIDELINES FOR PARTICIPATION: To participate in this add-on, each site should complete the protocol by December 31, 2019. If you are interested to join, please let us know.

MANUSCRIPT AUTHORSHIP: By contributing data to this add-on study, participants (site pi) will be automatically included as a co-author in all papers, as long as they remain engaged and in contact with the lead authors. As phenological observation is a labour-intensive study, we'll offer an additional co-authorship (data collector) for each site.

TENTATIVE WORKLOAD: Around 30-60 person-hours per site (3c+3d or 5c+5d plots) in a complete year.

METHODS

We would require weekly phenological observation during the entire growing season in a year. As phenological phases develop sequentially and are distributed throughout the whole growing season, we kindly ask for the following response parameters.

Short-stature vegetation (grassland and shrubland)

- ***Plot cover (0-100%)***: Measure bare ground, moss, litter and vegetation cover. Separate the **vegetation** cover by **green tissue** and by **senesced tissue** (either yellowish, brown, dead or not green). We need this observation through-out the year. From this continuous observation, we'll be able to determine the onset (e.g. the first DOY of 30% greenness), peak (maximum greenness) and the beginning of dormancy (the first DOY of 50% vegetation senescence will indicate the beginning of dormancy).
- ***Flowering (F):*** Sign of open flowers with visible anthers. Please record the DOY of open flowers per species per plot. We need this observation continuously (throughout the year), from which we'll be able to determine the first flowering date, last flowering date, length of flowering period, and the number of flowering seasons in a year.

Plot:		**Site:**			**Investigator:**				
Responses: DOY (Day Of Year) of **F**-Flowering (record continiously); (1= Yes, 0=No)									
DOY (date)	**92**(02.04)	**99**(09.04)	**106**(16.04)	**113** (23.04)	**120** (30.04)	**127** (07.05)	**134** (14.05)	**141** (21.05)	**148** (28.05)
Bare ground (%)	10	10	10	10	5	5	5	1	1
Moss (%)	50	40	30	10	5	5	5	1	1
Litter (%)	0	0	0	0	0	0	0	0	0
Veg_cover (%)	40	50	60	80	90	90	95	98	98
Veg_green (%)	30	40	55	75	85	85	90	95	95
Veg_senescence (%)	10	10	5	5	5	5	5	3	3
Species / Response	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**	**F**
Festuca_rubra	0	0	1	1	1	1	1	0	0
Luzula_campestris	0	0	1	1	1	1	1	1	1
Plantago_lanceolata	0	0	1	0	0	0	0	1	1

Example of **field-data-collection sheet** for short-stature vegetation.

Tall-stature vegetation (Forest)

- ***New leaf (NL)***: First sign of developing new (fresh) and fully developed (open) green leaves. Please record only the first DOY per species per plot from which plot average (DOY) will be calculated. If the number of growing seasons in a year is more than one, then record the first DOY per species per plot for each season.
- ***Flowering (F):*** Sign of open flowers with visible anthers. Please record the DOY of open flowers per species per plot. We need this observation continuously (throughout the year) from which we'll be able to determine the first flowering date, last flowering date, length of flowering period, and the number of flowering seasons in a year.
- ***Leaf shedding (LS) / ripe fruits start to fall or harvest (FSF)***: Leaf shedding (50% of leaves discolored or fallen) will be monitored for deciduous trees, while the DOY of ripe fruit (indicated through loss of turgidity) or when mature seed starts to fall or harvest date will be monitored for evergreen trees. Please record only the first DOY per species per plot from which a plot average (DOY) will be calculated. This will indicate the beginning of dormancy or end of growing season. If the number of growing seasons in a year is more than one, then repeat the procedure for each season.

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