Warming differentially affects vegetative and reproductive phenology and drives reproductive fitness in a changing Arctic

Courtney G. Collins
Ministry of Forests (BC Gov)
ITEX meeting
April 8, 2024

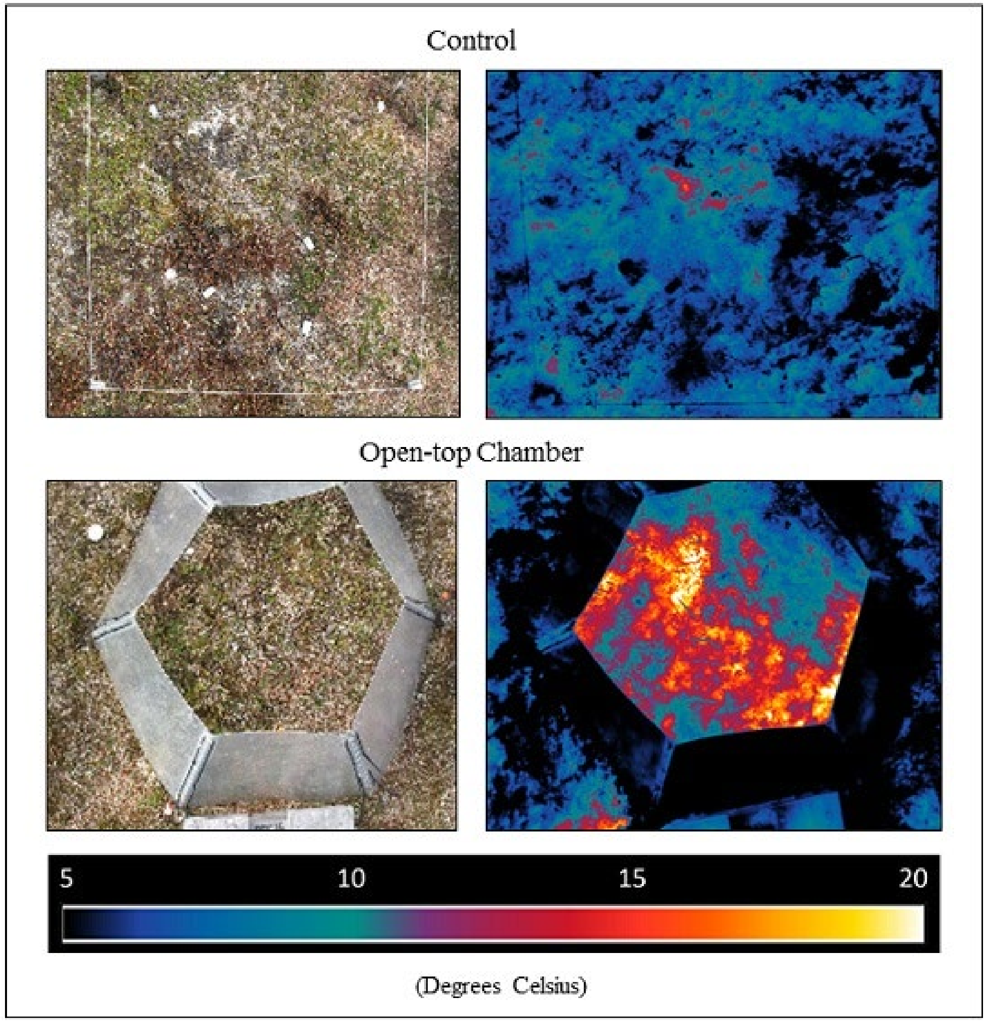
Tundra Ecosystems are changing

- Warming much faster than the global average
- Changes in plant phenology key indicator of these shifts
- Consequences for plant-pollinator interactions, herbivory, and above/belowground C

Photo by Logan Berner

Experimental approaches are critical

- Mechanistic understanding of the impacts of different global change drivers
- Warming is the most consistent global change impact to Tundra ecosystems
- OTCs widely used to isolate the role of warming on plant phenology
- Create 1-3°C of warming above ambient on average



Healy *et al.* 2016

Phenological responses to experimental warming are varied

Arft *et al.* 1999

- Ecosystem type, plant functional type and years of warming influence plant responses to experimental warming.

Wolkovich *et al.* 2012

- Experimental warming underestimates the effects of climate warming on plant flowering and leaf out.

Prevey *et al.* 2019

- Warming advances flowering for later versus earlier flowering species. Experimental and observational warming predict similar shifts.

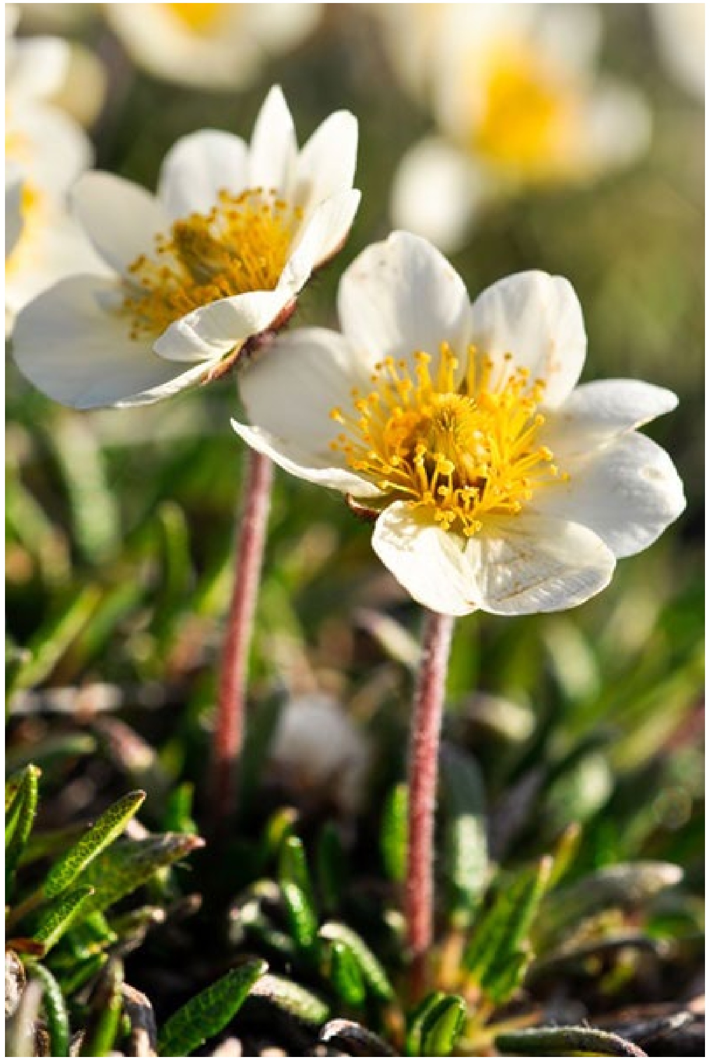


Photo by Anne Bjorkman

Critical unresolved questions

Does experimental warming:

1. Differentially affect reproductive and vegetative phenology?

2. Shorten, lengthen, or have no effect on the duration of growth, flowering and fruiting periods?

Are plant responses to experimental warming:

3. Variable across spatial and temporal gradients in resource availability and climate?

4. Sustained over very long time periods?

Photo by Anne Bjorkman

International Tundra Experiment (ITEX)

ITEX sites with OTC warming experiments

- Long term monitoring of arctic and alpine tundra plant phenology to climate change
- Ambient observations and experimental treatments
- Passive warming chambers (OTCs)

Collins *et al.* 2021 *Nature Communications*

Recently updated ITEX dataset

Phenophase	Total observations (i)	Spp	Sites	Subsites	Years
Green up	30,361	71	11	28	27
Start of flowering	30,001	106	16	44	28
End of flowering	22,214	80	13	34	28
Fruiting	17,274	53	6	18	28
Seed Dispersal	8,292	48	9	22	28
Leaf Senescence	17,077	61	10	25	27

- 18 sites and 46 experimental locations
- Over 100 plant species
- Observations from 1992-2019
- Six plant phenophases

Photos by Lærke Stewart

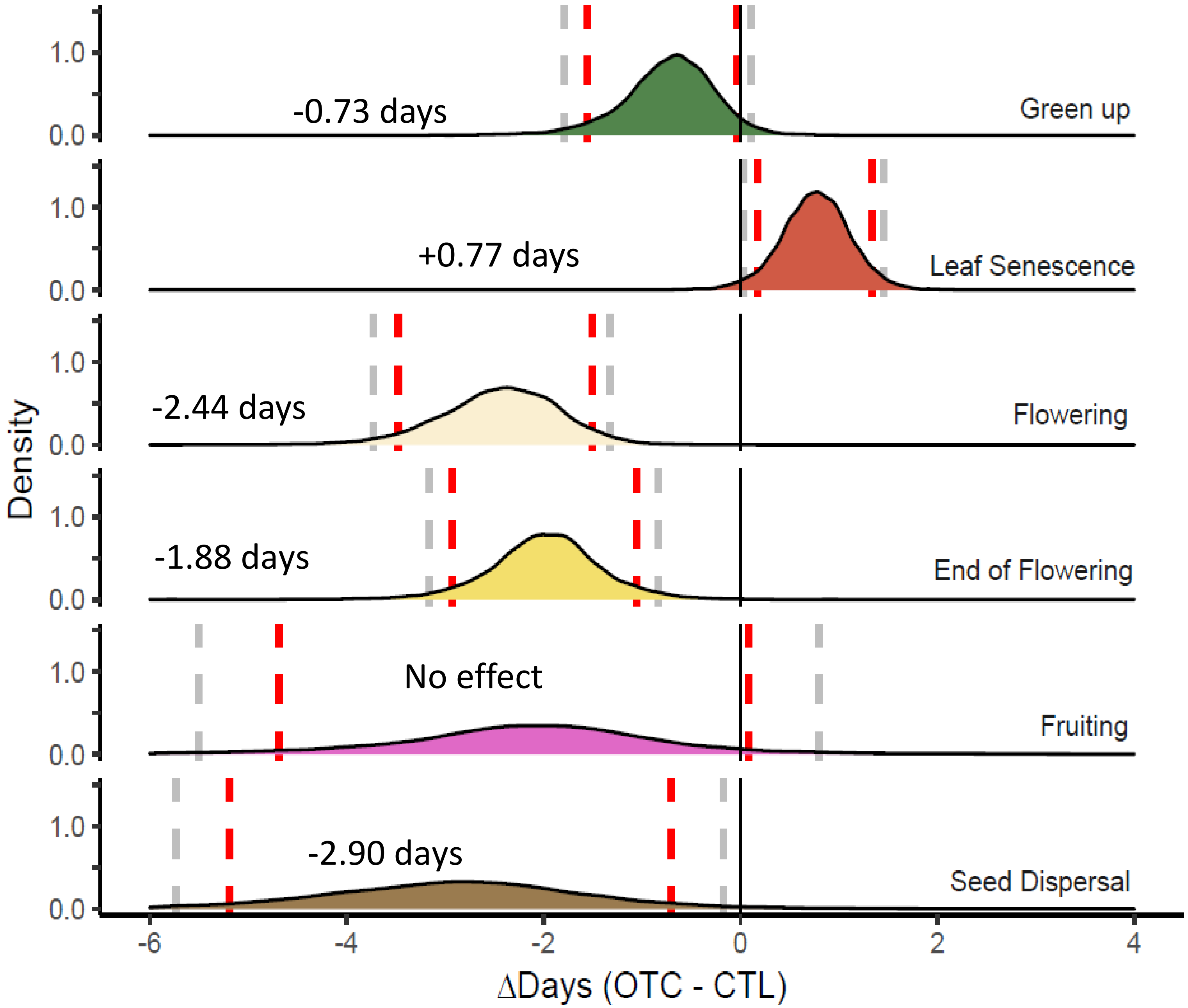
Prevéy *et al.* 2021 *Arctic Science*

Bayesian Hierarchical Modeling

- Response variable- DOY phenology event
  - Interval censored
- Fixed effects-
  - Treatment- warming or control
  - Interaction w/ spatiotemporal predictors
- Random effects-
  - Account for variation across spp, sites, years

$$DOY_{phenology} = Trt + (Trt|species) + (Trt|site) + (Trt|site{:}year) + (Trt|site{:}subsite)$$

Photo by Anne Bjorkman



Collins *et al.* 2021 *Nature Communications*

Summary

- Differential floral and vegetative phenology responses
  - Herbivory and pollinator interactions
- Tundra growing seasons are likely to be longer with warming
  - GPP and C cycling
- Consistent across tundra
  - Few significant interactions with spatiotemporal factors

Photo by Courtney Collins

Acknowledgements

Scientists in ITEX network for data collection

Suding Lab members @ CU

Postdoc funding from INSTAAR and CU Boulder

ARTICLE

Check for updates

https://doi.org/10.1038/s41467-021-23841-2 OPEN

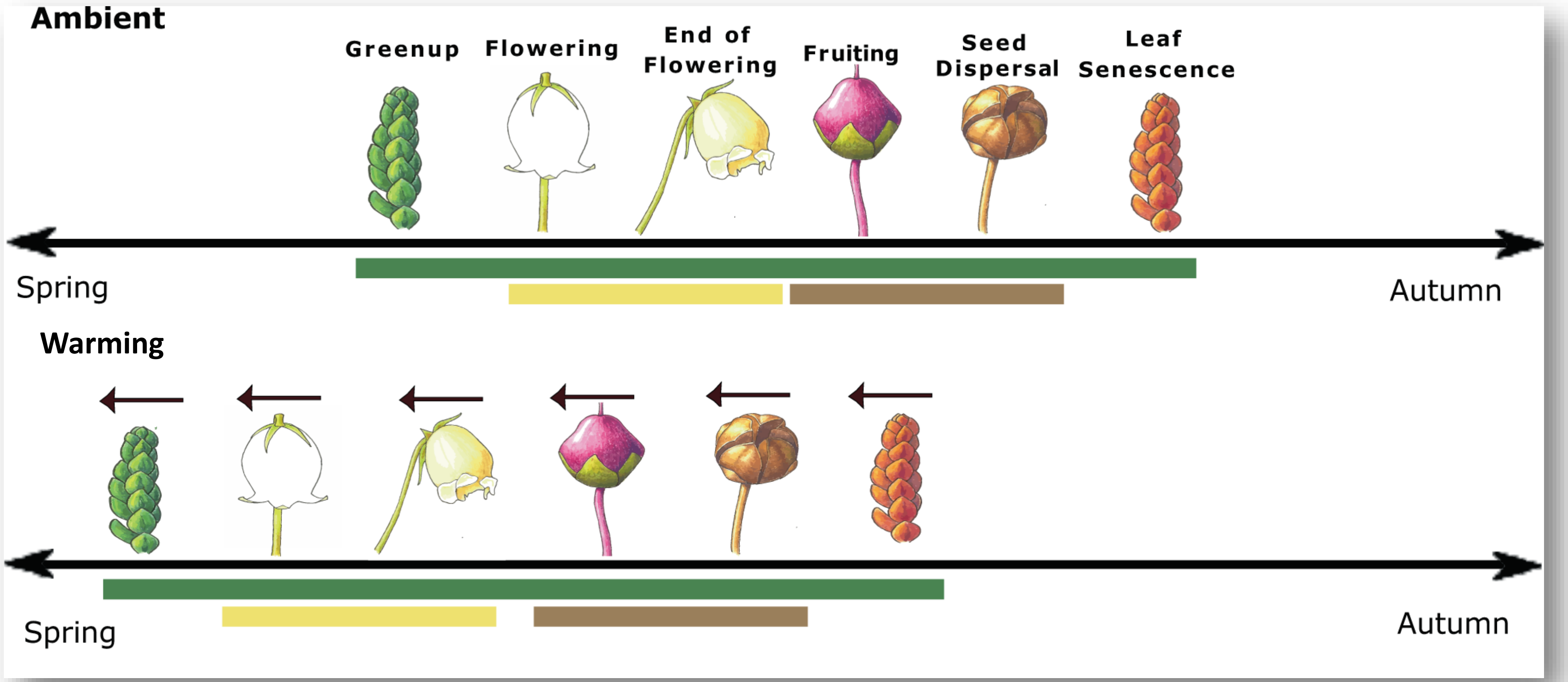
Experimental warming differentially affects vegetative and reproductive phenology of tundra plants

Courtney G. Collins [1✉], Sarah C. Elmendorf[1], Robert D. Hollister [2], Greg H. R. Henry[3], Karin Clark[4], Anne D. Bjorkman [5], Isla H. Myers-Smith [6], Janet S. Prevéy[7], Isabel W. Ashton[8], Jakob J. Assmann [9], Juha M. Alatalo [10], Michele Carbognani [11], Chelsea Chisholm [12], Elisabeth J. Cooper [13], Chiara Forrester[1], Ingibjörg Svala Jónsdóttir [14,15], Kari Klanderud [16], Christopher W. Kopp[17], Carolyn Livensperger [18], Marguerite Mauritz [19], Jeremy L. May[20], Ulf Molau[5], Steven F. Oberbauer[20], Emily Ogburn[1], Zoe A. Panchen[3], Alessandro Petraglia [11], Eric Post [21], Christian Rixen[22], Heidi Rodenhizer [23], Edward A. G. Schuur [23], Philipp Semenchuk [24], Jane G. Smith[1], Heidi Steltzer[25], Ørjan Totland[26], Marilyn D. Walker[27], Jeffrey M. Welker[28,29] & Katharine N. Suding [1]

Photo by Anne Bjorkman

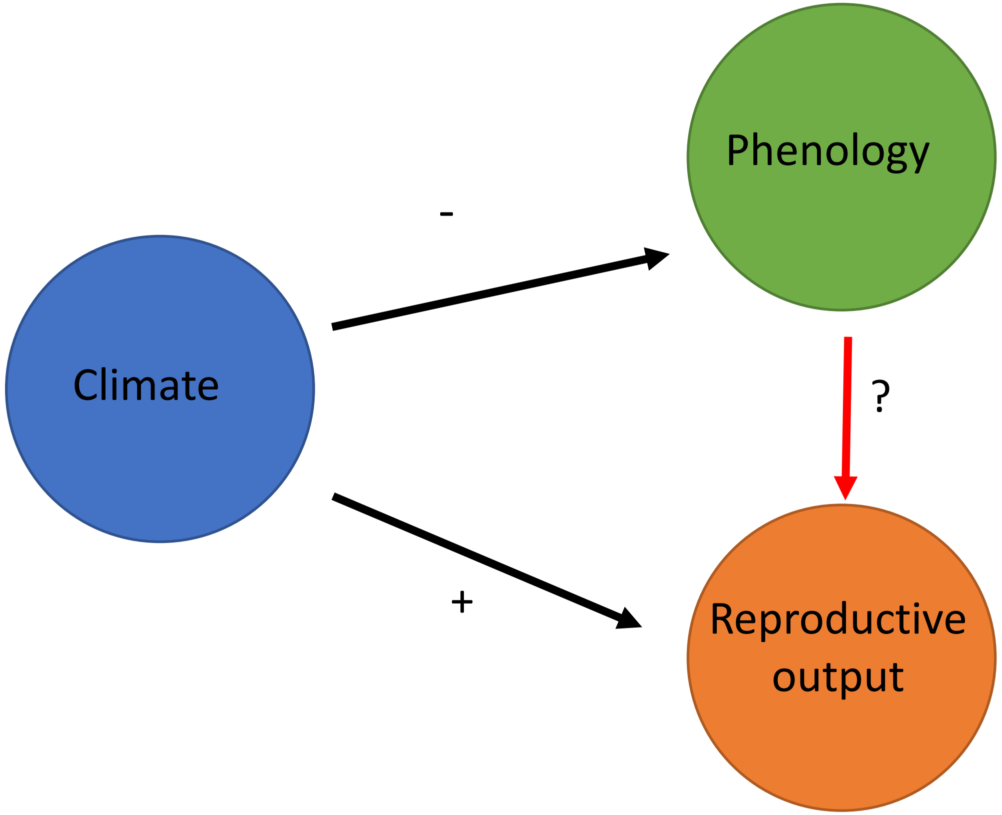
72 citations!

Phenology is shifting with climate change



Collins et al. 2021 modified

Linking phenology shifts to demographic outcomes



ECOLOGY LETTERS
Ecology Letters, (2016) 19: 595–608 doi: 10.1111/ele.12599

IDEA AND PERSPECTIVE

Predicting when climate-driven phenotypic change affects population dynamics

Nina McLean,[1*] Callum R. Lawson,[2] Dave I. Leech[3] and Martijn van de Pol[1,2]

Abstract
Species' responses to climate change are variable and diverse, yet our understanding of how different responses (e.g. physiological, behavioural, demographic) relate and how they affect the parameters most relevant for conservation (e.g. population persistence) is lacking. Despite this, studies that observe changes in one type of response typically assume that effects on population dynamics

ANNUAL REVIEWS
Annual Review of Ecology, Evolution, and Systematics

Demographic Consequences of Phenological Shifts in Response to Climate Change

Amy M. Iler,[1] Paul J. CaraDonna,[1] Jessica R.K. Forrest,[2] and Eric Post[3]

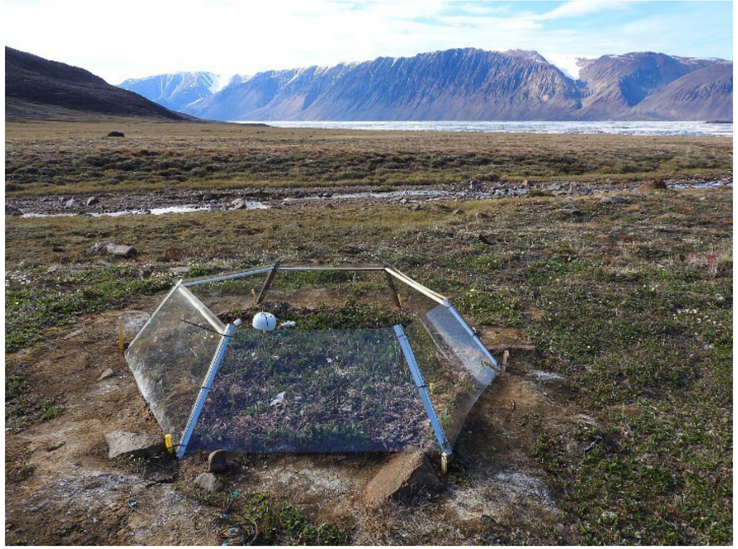
Global Change Biology
Global Change Biology (2015) 21, 3062–3073, doi: 10.1111/gcb.12914

Phenological plasticity will not help all species adapt to climate change

ANNE DUPUTIÉ[1,2*], ALEXIS RUTSCHMANN[2,3*], OPHÉLIE RONCE[4] and ISABELLE CHUINE[2]

Long term (20+ years) experimental plots at 2 Canadian Arctic sites

Qikiqtani Inuit



Tłı̨chǫ (Dogrib) Dene

Daring Lake, NT (64.87, -111.58)
Ambient (climate) warming ~2.3°C
2001-2022 (control plots only)
7 species - flowering time, flower & fruit counts

Alexandra Fiord, NU (78.83-75.80)
Experimental warming ~1.5 °C
1992-2003 (OTC & control)
5 species- flowering time, flower & fruit counts

Questions

1. Do tundra plant species that advance their phenology with warming temperatures have altered (positive or negative) reproductive fitness outcomes?

2. How do the direct effects of warming on reproductive fitness compare to the indirect effects of warming mediated by shifting phenology?

3. How does the relationship between flowering phenology and reproductive fitness shift under future climate warming scenarios?

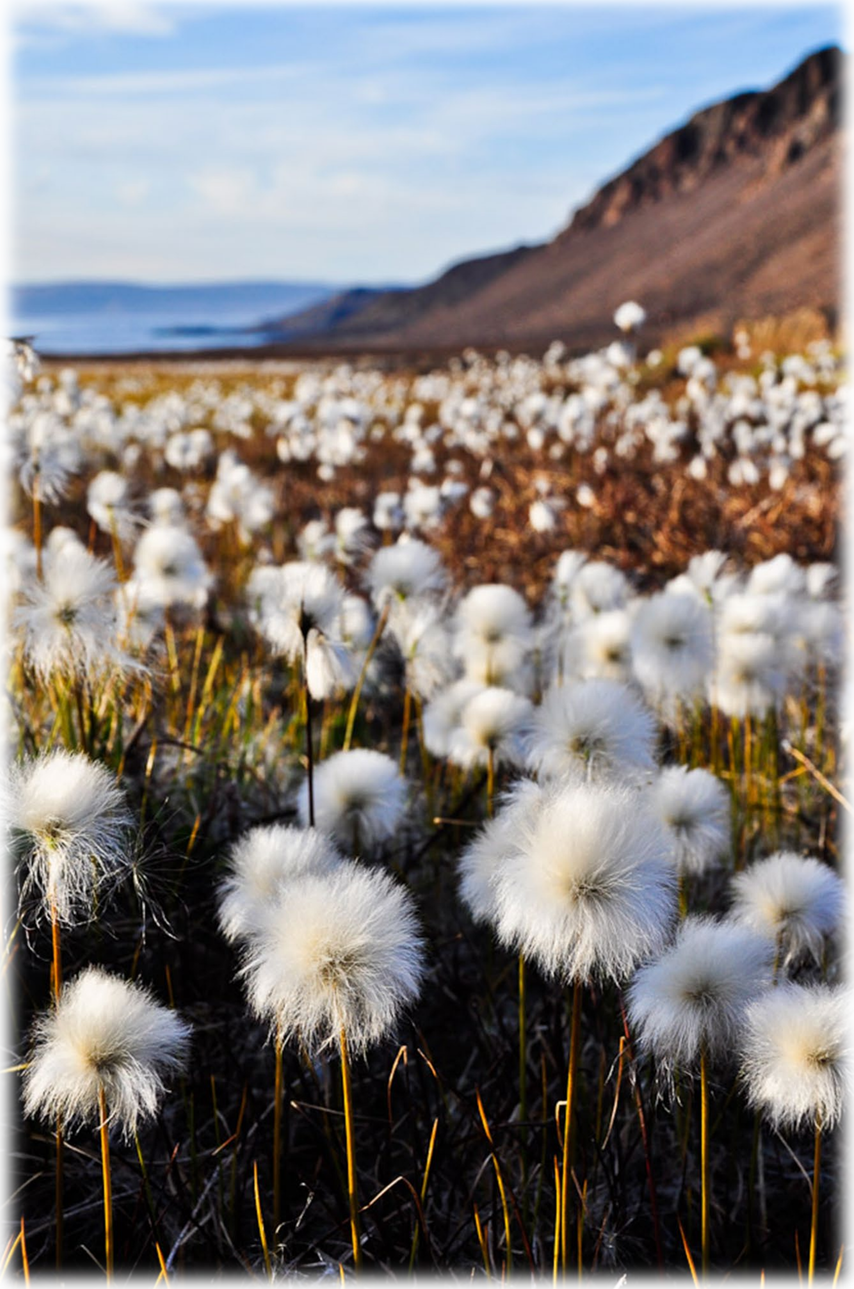
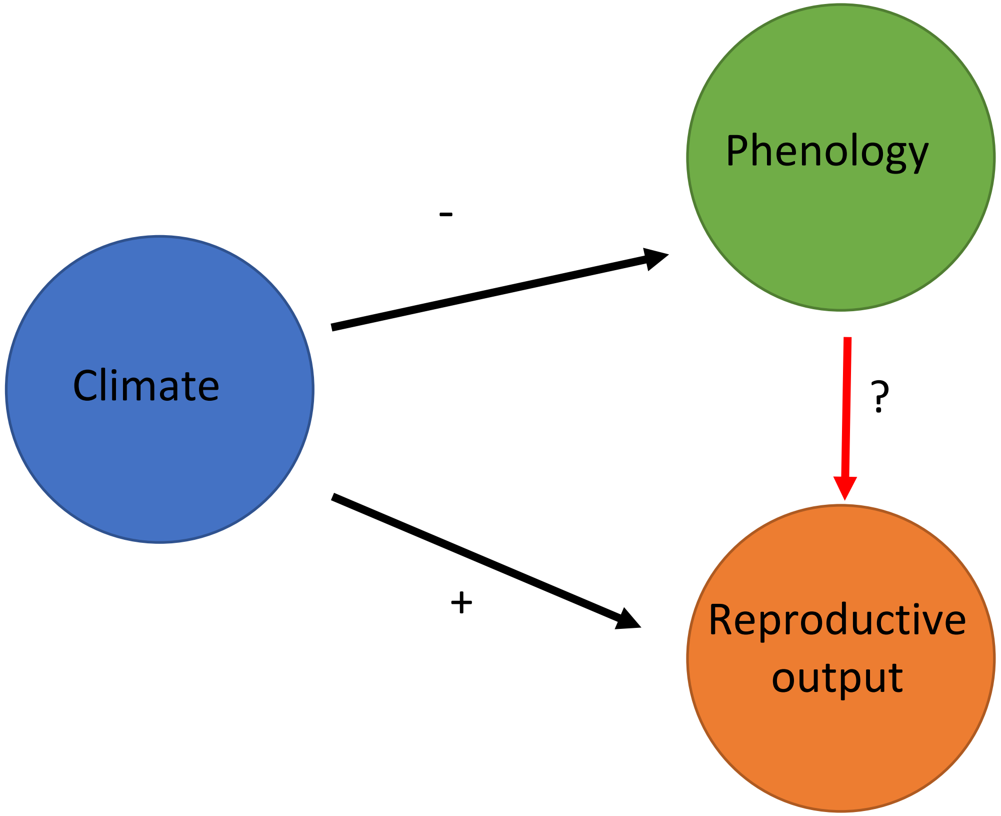


Photo by Anne Bjorkman

Hierarchical SEMs



Eq. 1a Number of flowers

DOY_{flower} ~ Temp + (1|individual) + (1|year) + (1|spp)

Fitness ~ Temp + DOY_{flower} + DOY_{flower}^2+ (1|individual) + (1|year) + (1|spp)

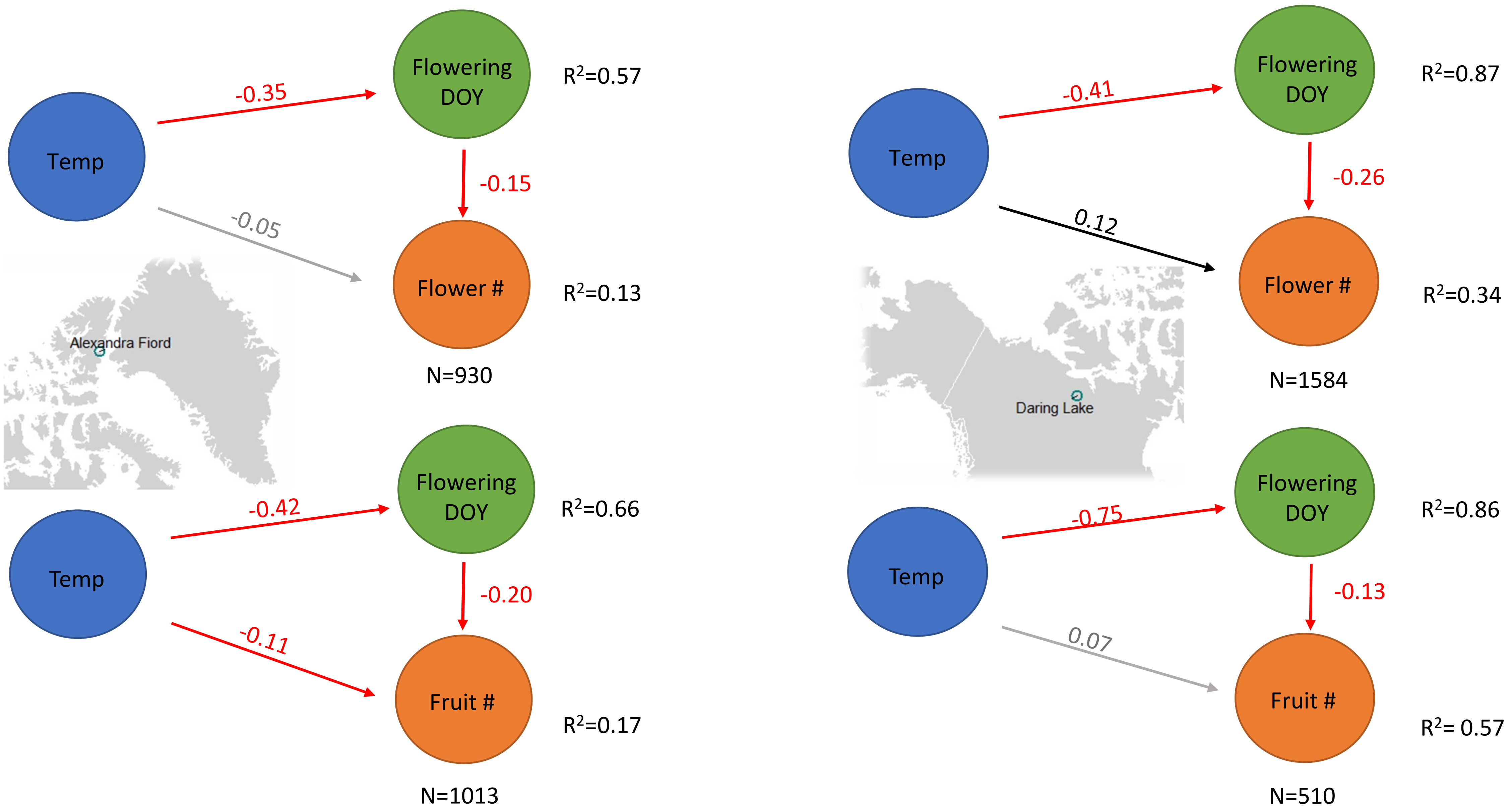
Eq. 1b Number of fruit

DOY_{flower} ~ Temp + $Temp_{y-1}$ + (1|individual) + (1|year) + (1|species)

Fitness ~ $Temp_{y-1}$ + DOY_{flower} + DOY_{flower}^2 + (1|individual) + (1|year) + (1|spp)

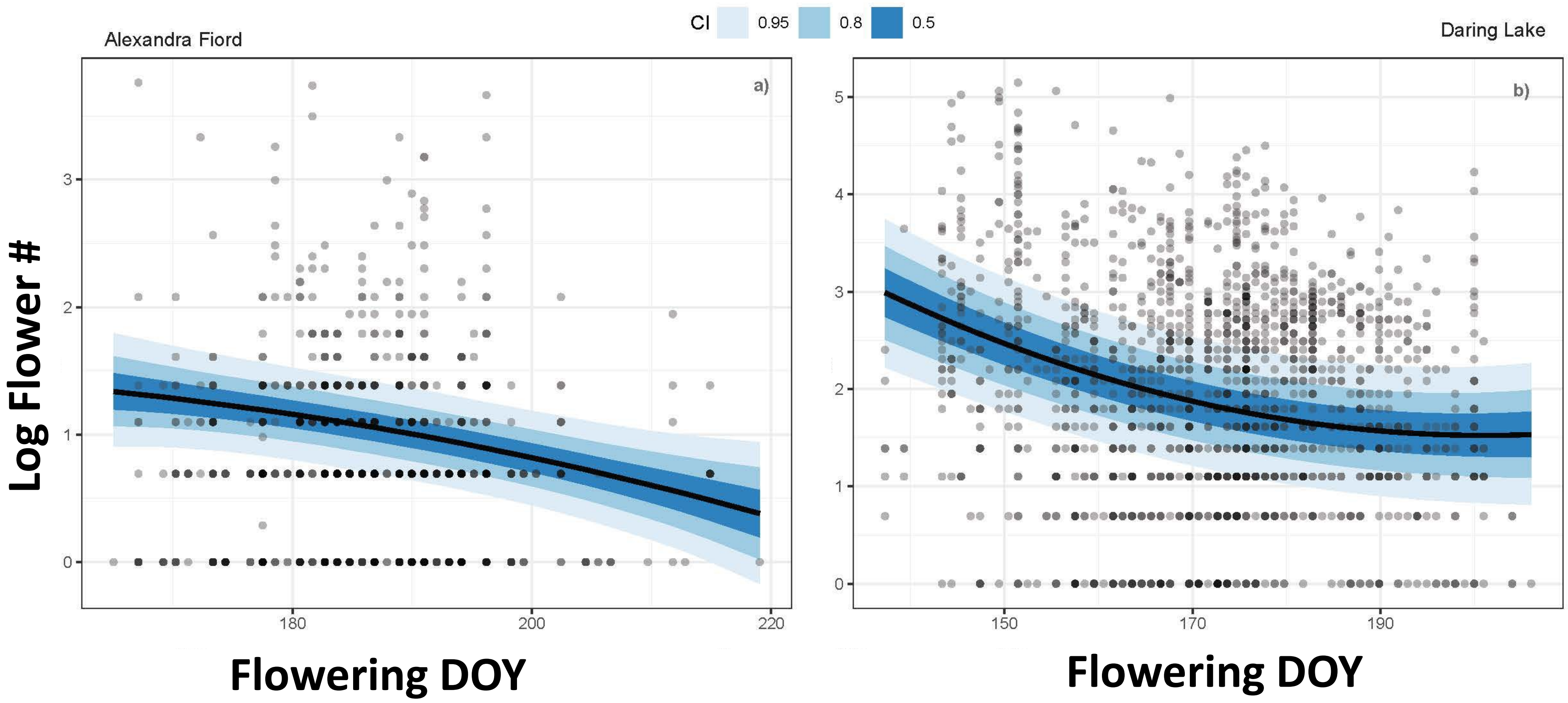
Collins et al. 2024 *Annals of Botany*

Warming affects reproductive fitness primarily through phenology



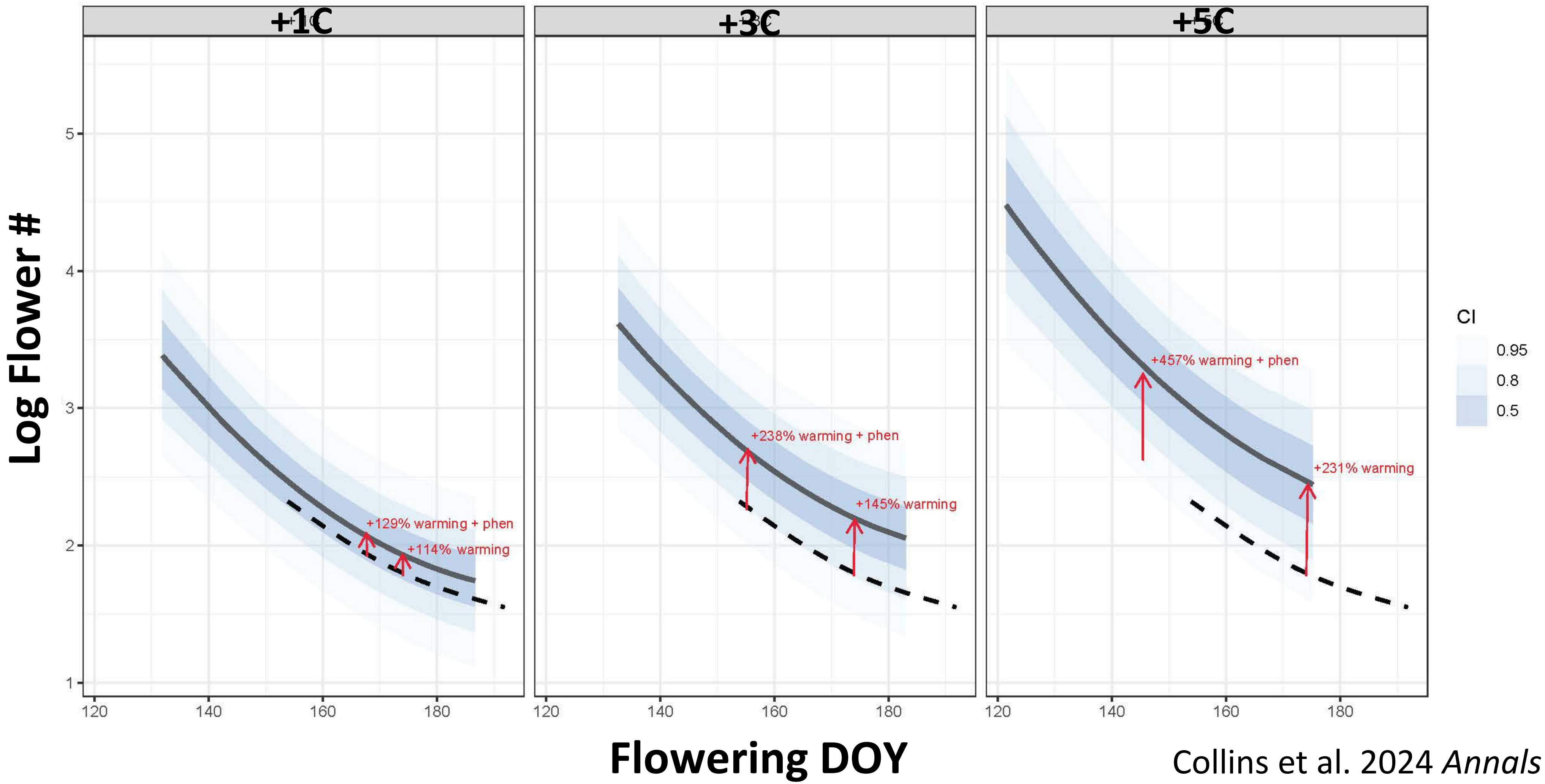
Collins et al. 2024 *Annals of Botany*

Warming effects reproductive fitness primarily through phenology



Collins et al. 2024 *Annals of Botany*

Large increases in reproductive fitness under future climate if phenology continues to advance



Collins et al. 2024 *Annals of Botany*

Summary

1. Warming (both experimental and ambient), drove earlier flowering across species, which lead to higher numbers of flowers and fruits produced.

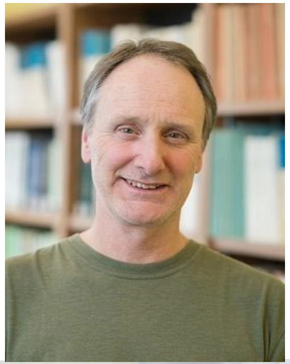
2. Indirect effect of warming mediated through phenology was ~2-3x stronger than the direct effect of warming on reproductive fitness.

3. Under future climate scenarios, individual plants showed a ~2 to 4.5 fold increase in their reproductive fitness (flower counts) with advanced flowering phenology.

Photo by Karin Clark

Acknowledgements

Greg Henry (UBC)



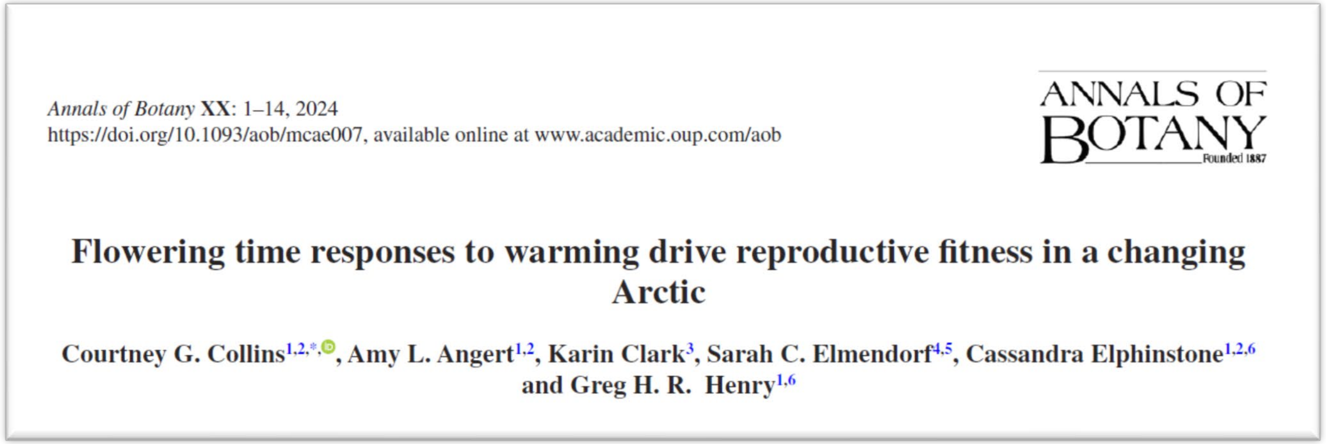
Karin Clark (Gov. NWT)

Cassandra Elphinstone (UBC)

Amy Angert (UBC)

Sarah Elmendorf (CU Boulder)

- Coauthors
- ITEX network
- Qikiqtani Inuit Association
- Yellowknives Dene Tlicho (Dogrib) First Nation
- Numerous field assistants, (under)graduate students and postdocs for collecting data



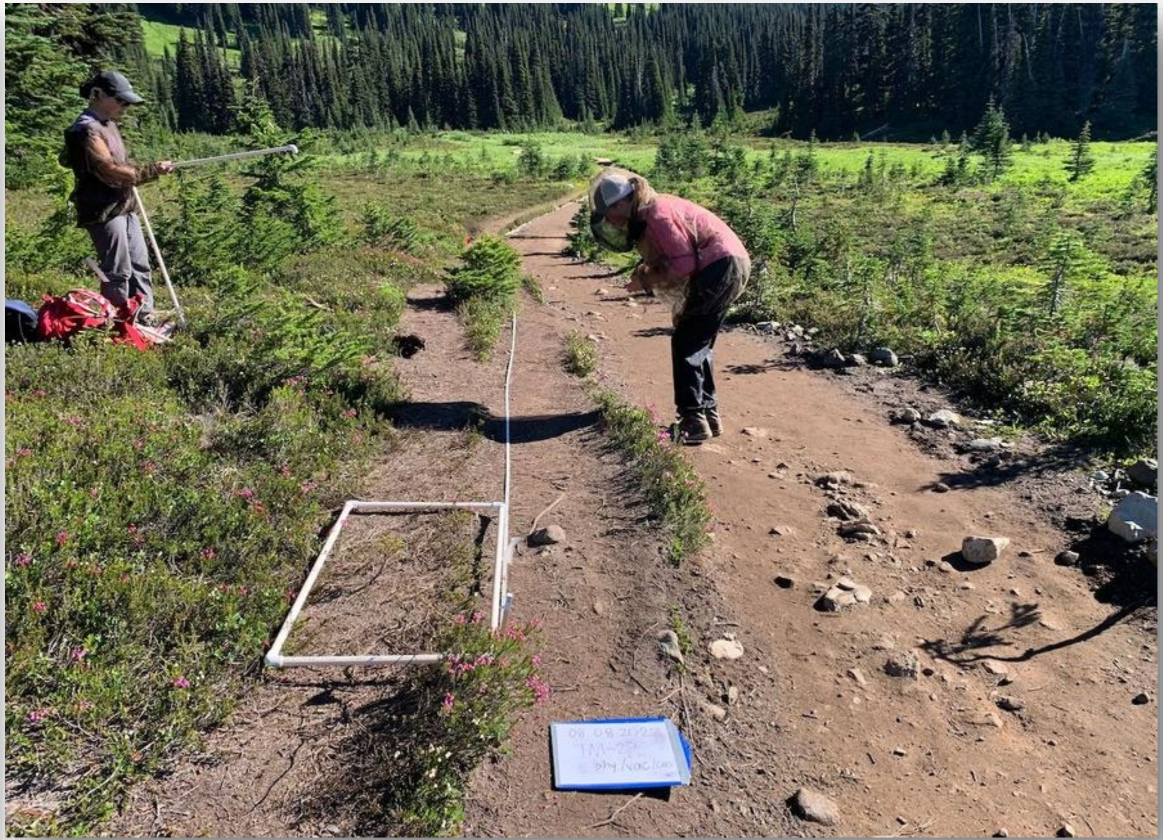
Annals of Botany XX: 1–14, 2024
https://doi.org/10.1093/aob/mcae007, available online at www.academic.oup.com/aob
ANNALS OF BOTANY Founded 1887

Flowering time responses to warming drive reproductive fitness in a changing Arctic

Courtney G. Collins[1,2,*], Amy L. Angert[1,2], Karin Clark[3], Sarah C. Elmendorf[4,5], Cassandra Elphinstone[1,2,6] and Greg H. R. Henry[1,6]

New ITEX Site in BC Coast Mountains!!
Nch’kay (Garibaldi Lake)

Experimental warming



Human trampling

https://garibaldialpine.wixsite.com/garibaldialpine