Phenology Lab

e-phenology

"Time is everything: Phenology, Climate Change and Conservation in highly diverse ecosystems"

"El tiempo lo es todo: Fenología, Cambio Climático y Conservación en ecosistemas muy diversos"

unesp

Patrícia Morellato

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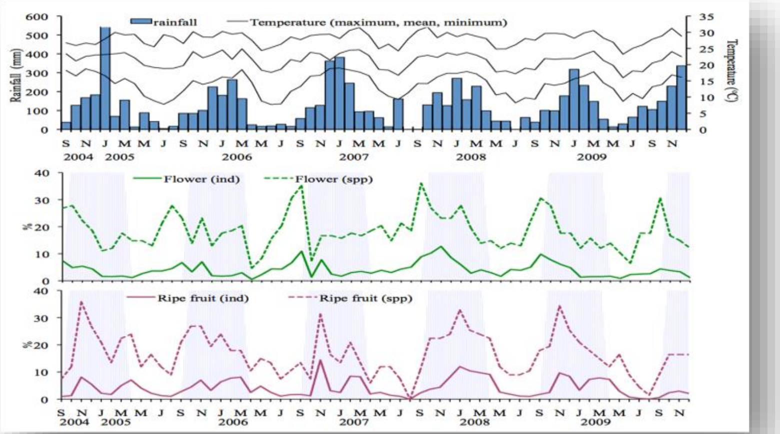
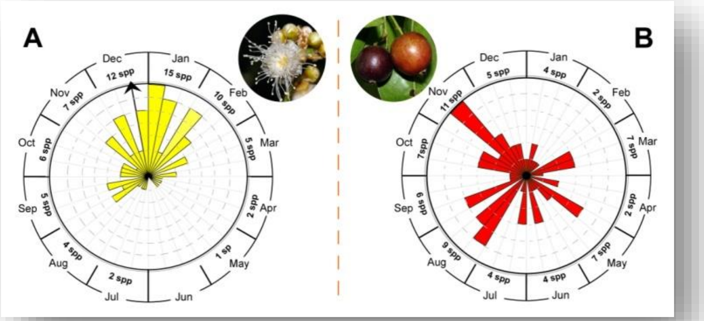
unesp - São Paulo State University
Rio Claro, São Paulo – Brazil
patricia.morellato@unesp.br





GLOBAL ALLIANCE BIODIVERSITY and CLIMATE CHANGE
BioGATe - A multidisciplinary approach on tropical biodiversity

CAPES

unesp PrInt PROJECT

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

FAPESP

FAPESP MUDANÇAS CLIMATICAS

Phenology Lab

Phenology, Climate Change and Conservation in highly diverse ecosystems

1. Phenology in highly diverse ecosystems
2. Phenology and climate change
3. Phenological responses to climate change in the tropics
4. Practical implications: phenology conservation, restoration, and management
5. Challenges to detect temporal responses and shifts in highly diverse ecosystems
6. Final remarks

1. Phenology in highly diverse ecosystems

Phenology Lab

- ✓ Definition

Phenology – greak“φαίνεσθαι” (phainesthai), meaning “to show up”

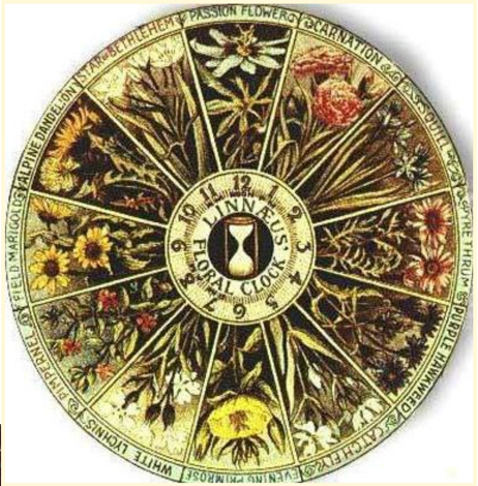
Timing of recurring biological events and its relation to climate

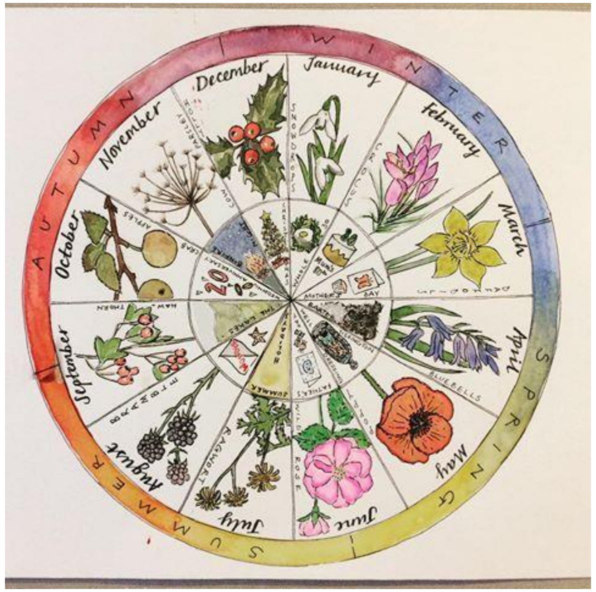

- ✓ **Long history .....**

Modern phenology - Carolus Linnaeus - 1751.

Charles Morrem 1853 - Phenology

Phenology + Climate ~ 2000



1. Phenology in highly diverse ecosystems

Phenology is the study of recurring life cycle events on plants and animal and its relation to climate.

Phenology has a prominent position in the current scenario of **global change research**, considered: ***the easiest and simplest way to monitor and detect plant responses and shifts to global warming***.

Listed as a **EBV** and linked to Sustainable Development Goals

nature ecology & evolution | PERSPECTIVE
https://doi.org/10.1038/s41559-018-0667-3
OPEN

Towards global data products of Essential Biodiversity Variables on species traits

W. Daniel Kissling[1*], Ramona Walls[2], Anne Bowser[3], Matthew O. Jones[4], Jens Kattge[5,6], Donat Agosti[7], Josep Amengual[8], Alberto Basset[9], Peter M. van Bodegom[10], Johannes H. C. Cornelissen[11], Ellen G. Denny[12], Salud Deudero[13], Willi Egloff[7], Sarah C. Elmendorf[14,15], Enrique Alonso García[16], Katherine D. Jones[14], Owen R. Jones[17], Sandra Lavorel[18], Dan Lear[19], Laetitia M. Navarro[6,20], Samraat Pawar[21], Rebecca Pirzl[22], Nadja Rüger[6,23], Sofia Sal[21], Roberto Salguero-Gómez[24,25,26,27], Dmitry Schigel[28], Katja-Sabine Schulz[29], Andrew Skidmore[30,31] and Robert P. Guralnick[32]

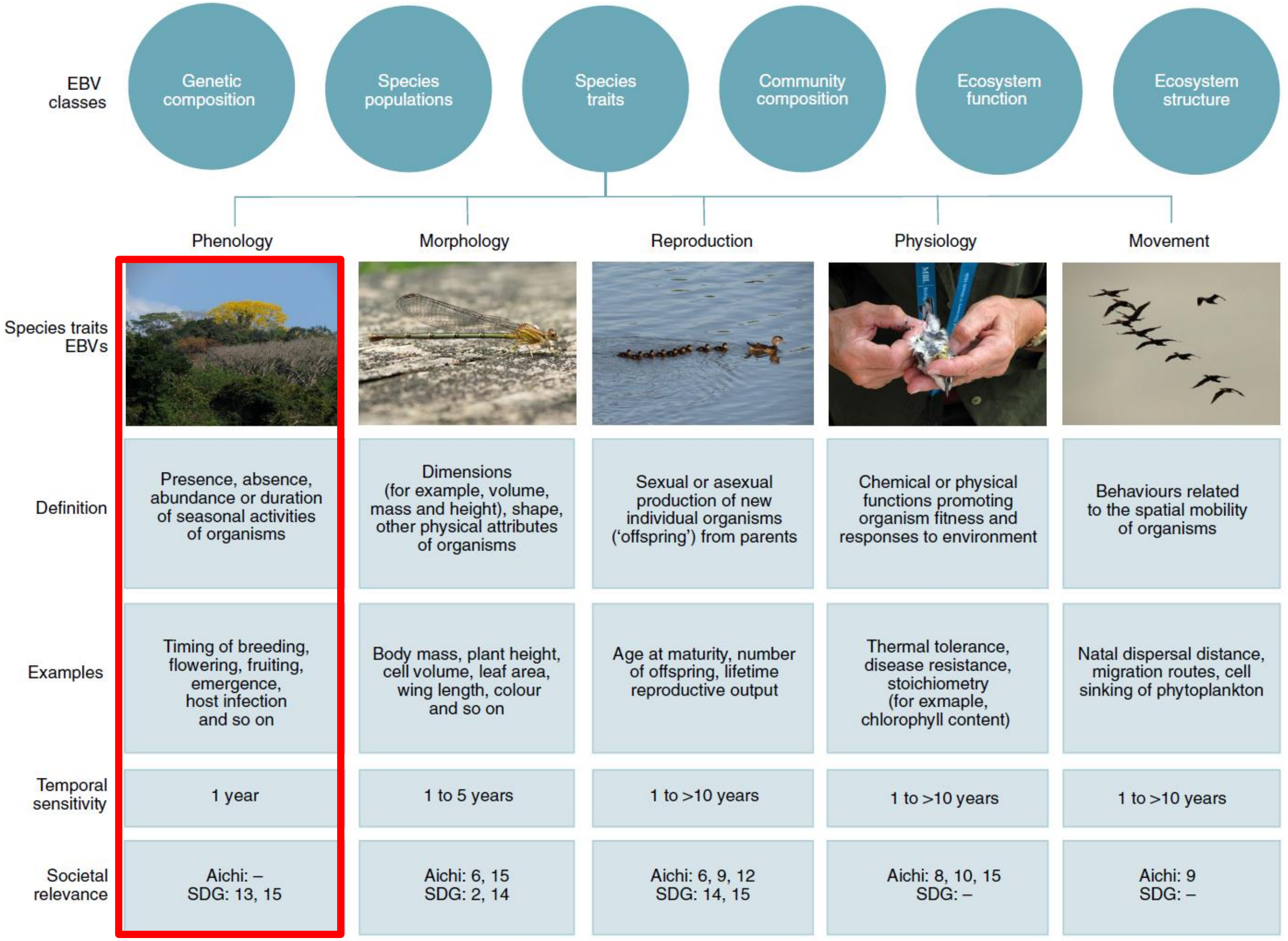
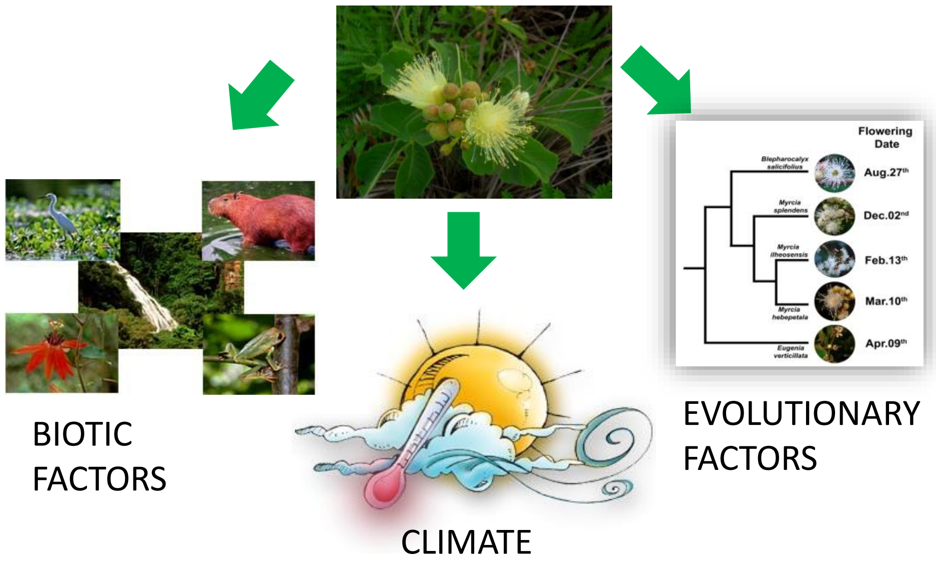


Fig. 1 | A framework for EBVs on species traits. We suggest five EBVs within the EBV class 'species traits', comprising (1) phenology, (2) morphology, (3) reproduction, (4) physiology and (5) movement. For each EBV, a definition, examples of species trait measurements, temporal sensitivity and societal relevance are given. Societal relevance refers to those Aichi Biodiversity Targets and SDGs to which the specific EBV is of highest relevance (for details on societal relevance see Supplementary Note 2 and Supplementary Table 2). Photo credits: Katja-Sabine Schulz.

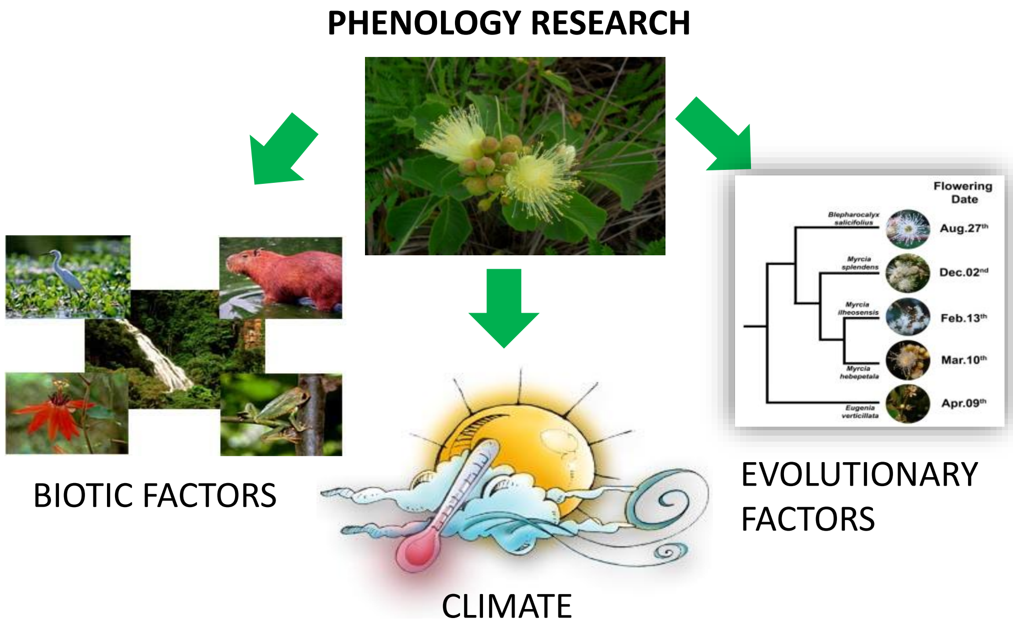
1. Phenology in highly diverse ecosystems

PHENOLOGY RESEARCH



Phenology is a multidisciplinary, Integrative science encompassing biometeorology, ecology, and evolutionary biology, and can also make a key contribution to conservation biology, management and restoration ecology

1. Phenology in highly diverse ecosystems



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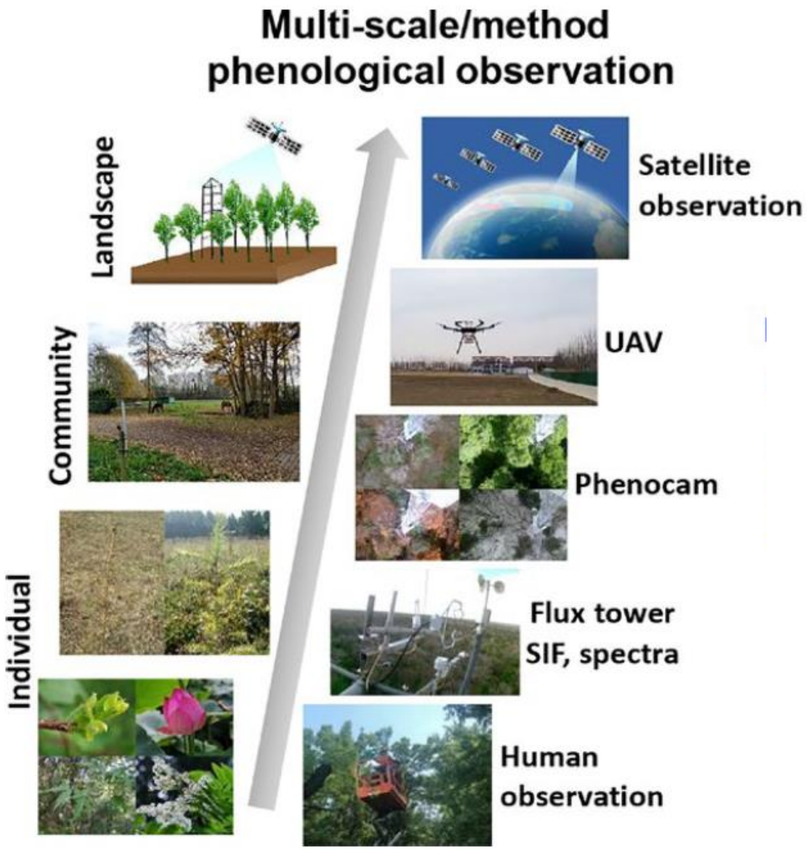



Tracking the rhythm of the seasons in the face of global change: phenological research in the 21st century

Jeffrey T Morisette[1], Andrew D Richardson[2], Alan K Knapp[3], Jeremy I Fisher[4], Eric A Graham[5], John Abatzoglou[6], Bruce E Wilson[7], David D Breshears[8], Geoffrey M Henebry[9], Jonathan M Hanes[10], and Liang Liang[10]

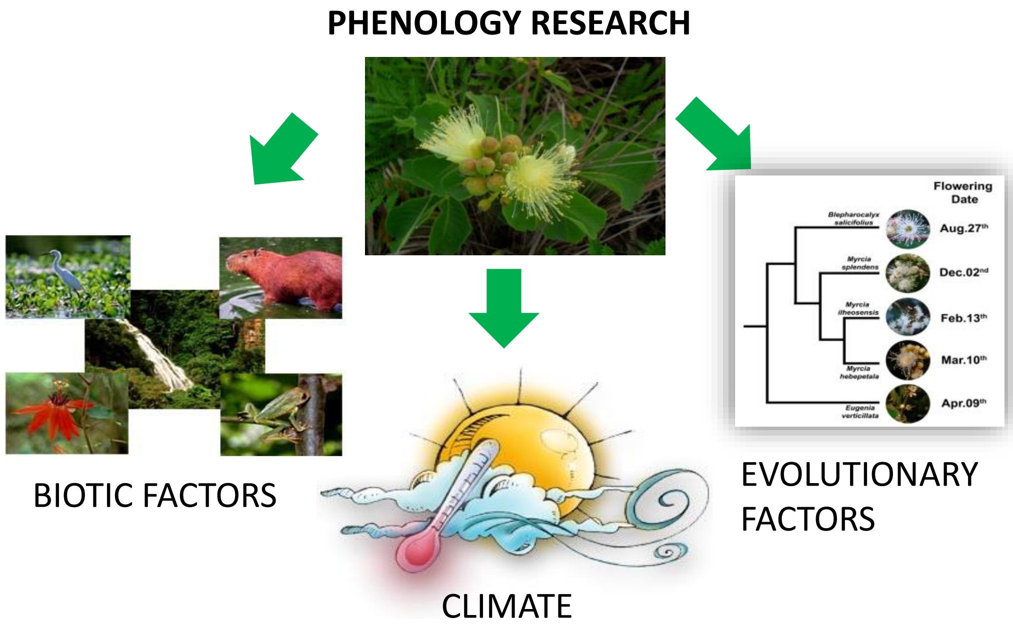

INVITED RESEARCH REVIEW

WILEY Global Change Biology

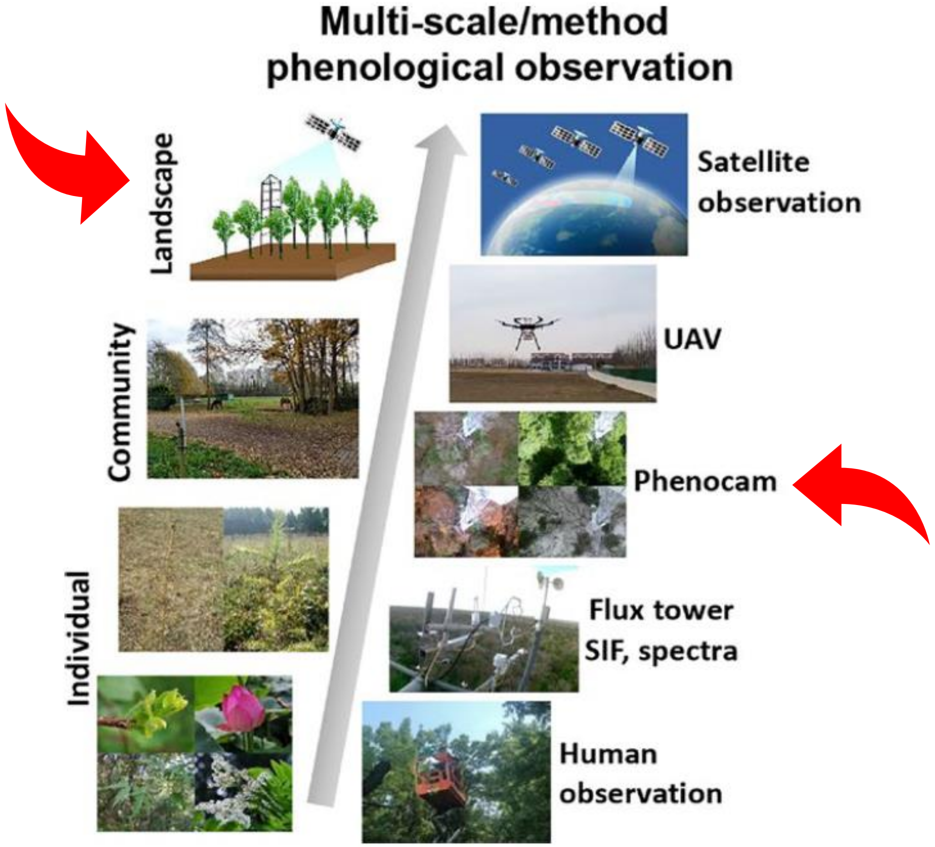
Plant phenology and global climate change: Current progresses and challenges

Shilong Piao[1,2,3] | Qiang Liu[1] | Anping Chen[4] | Ivan A. Janssens[5] | Yongshuo Fu[5,6] | Junhu Dai[7] | Lingli Liu[8] | Xu Lian[1] | Miaogen Shen[2,3] | Xiaolin Zhu[9]

1. Phenology in highly diverse ecosystems



Phenology is a multidisciplinary, Integrative science encompassing biometeorology, ecology, and evolutionary biology, and can also make a key contribution to conservation biology, management and restoration ecology

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1. Phenology in highly diverse systems

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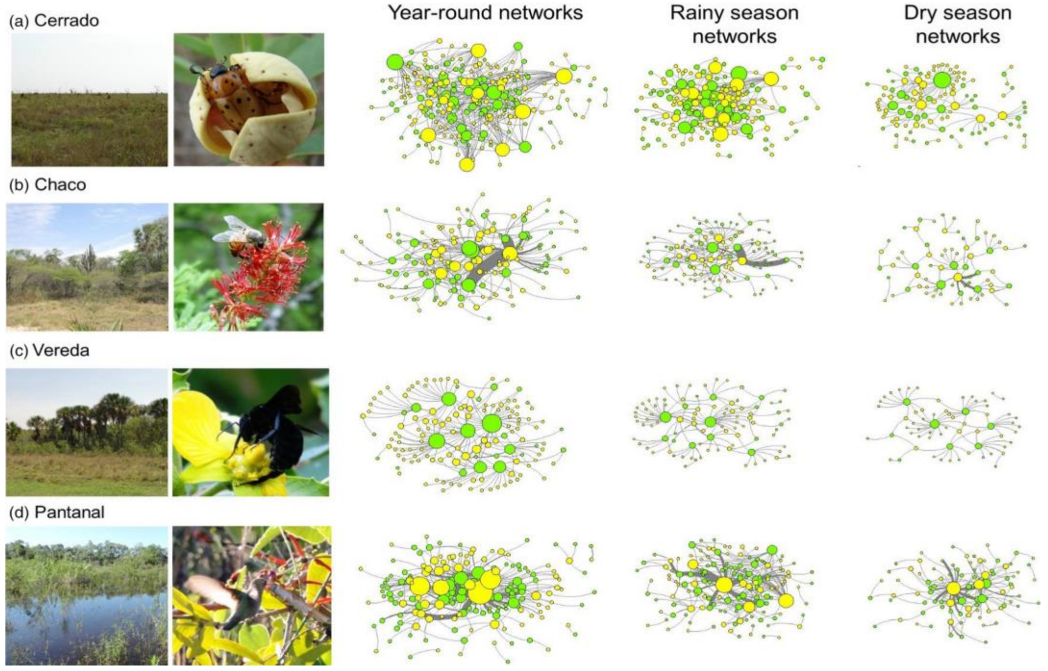
Outstanding Biodiversity

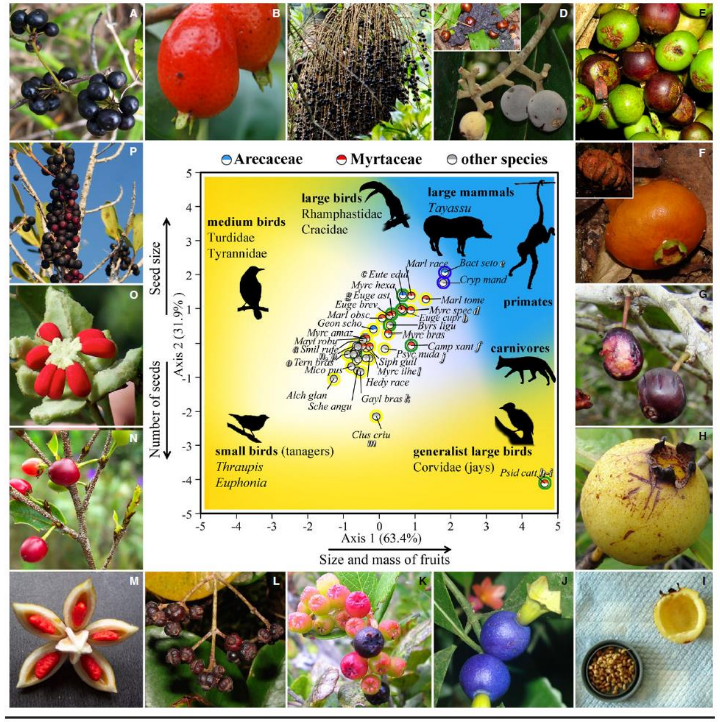
Photo ©: C.E.T. Paine

High dependence on animals for pollination and seed dispersal,

delivering key ecosystems services



Souza et al. 2017. J. Ecology



Staggemeier et al. 2017. Biotropica

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2. Phenology and climate change

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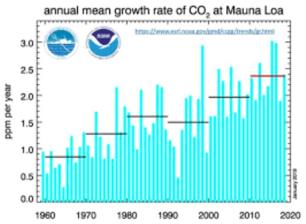
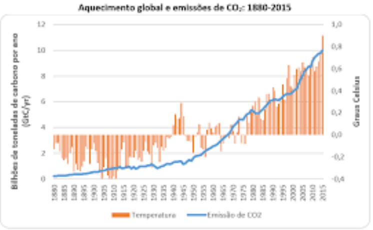




Fonte: Global Carbon Project http://cdiac.ornl.gov/GCP/ e NOAA http://www.ncdc.noaa.gov/

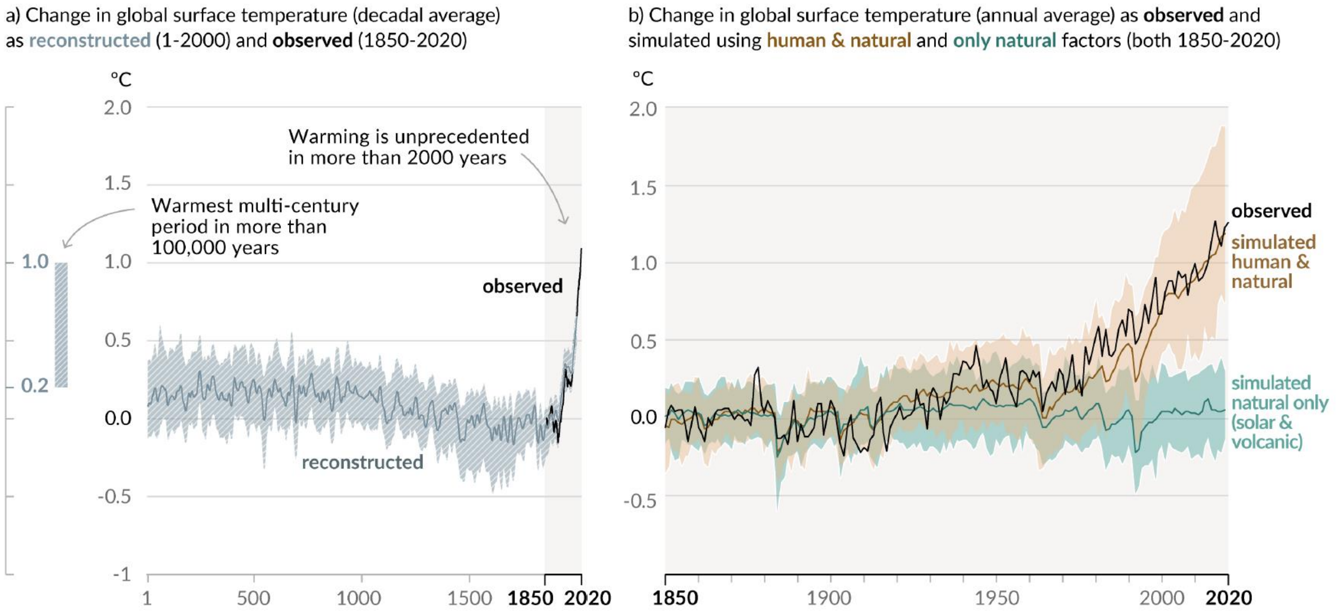
SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

ipcc INTERGOVERNMENTAL PANEL ON climate change — WMO UNEP

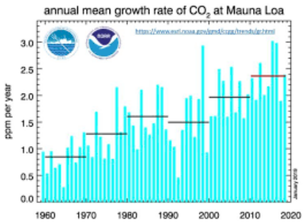
Human influence has warmed the climate at a rate that is unprecedented in at least the last 2000 years

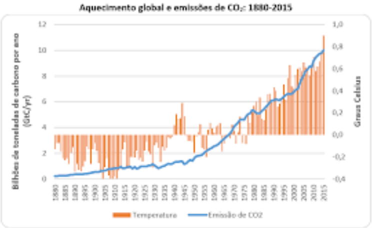
Figure SPM.1

Changes in global surface temperature relative to 1850-1900



2. Phenology and climate change





Fonte: Global Carbon Project http://cdiac.ornl.gov/GCP/ e NOAA http://www.ncdc.noaa.gov/

The great acceleration of plant phenological shifts

Vitasse, Y

NATURE CLIMATE CHANGE | VOL 12 | APRIL 2022 | 300–304 | www.nature.com/natureclimatechange

✓ ***Long-term observation data***

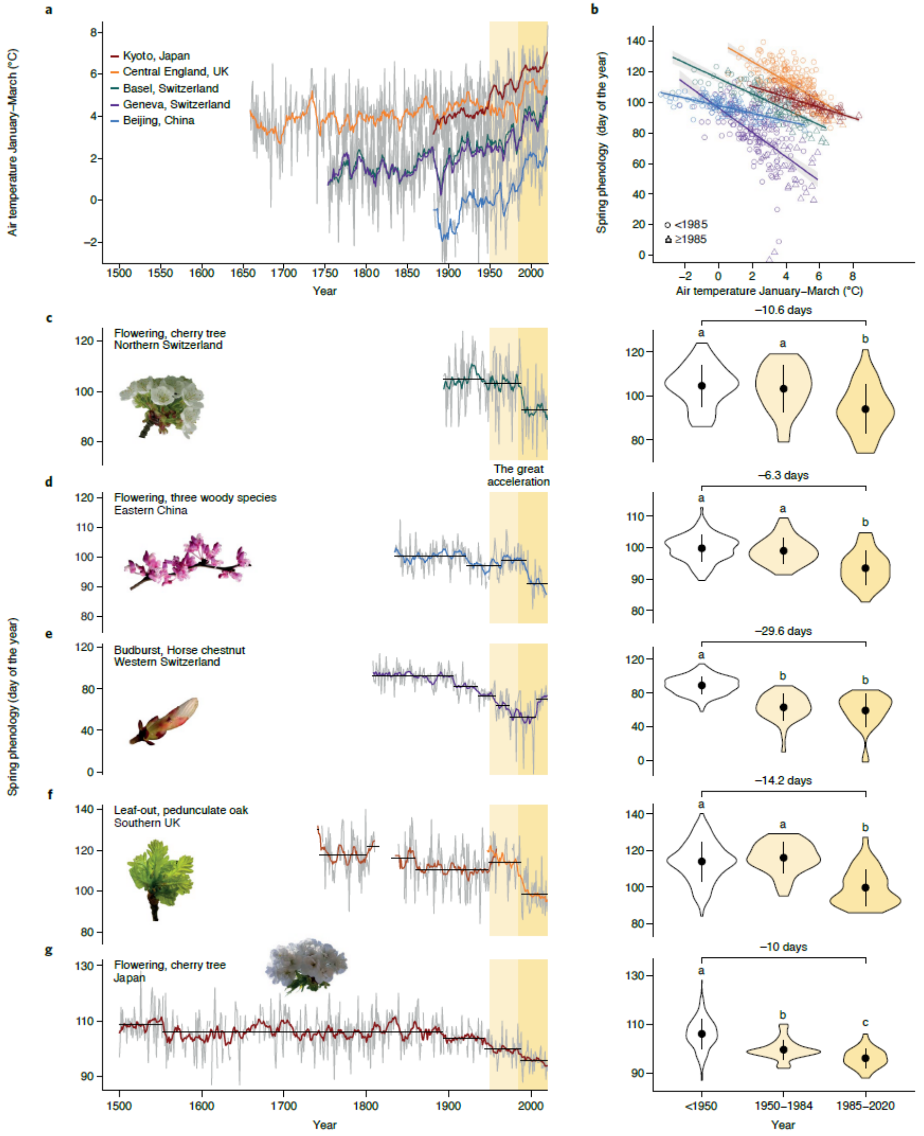


Fig. 1 | The world's longest phenological time series with the associated spring temperatures.

2. Phenology and climate change

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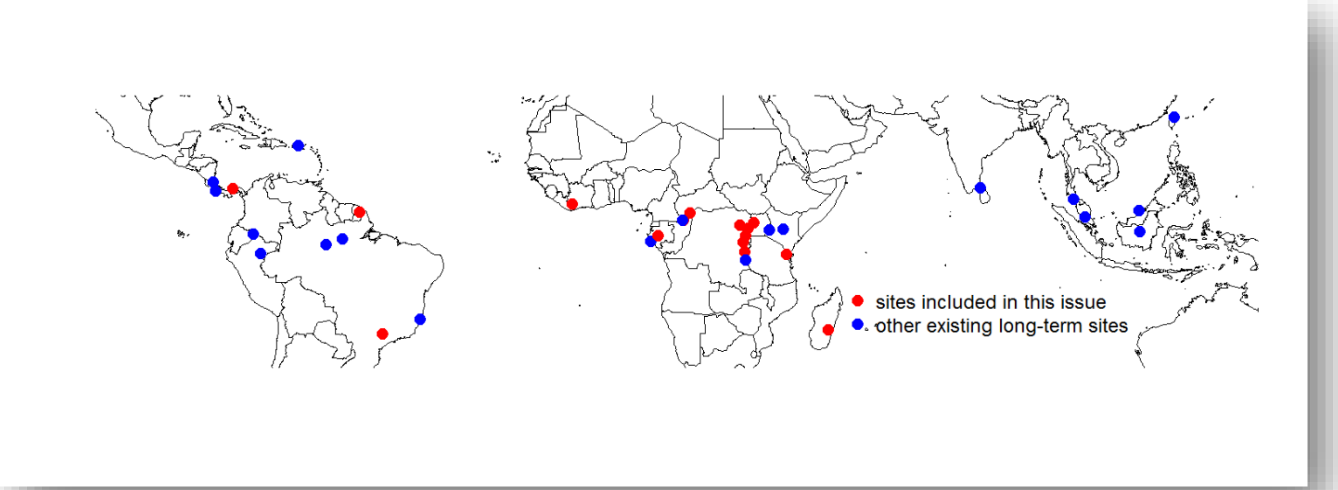
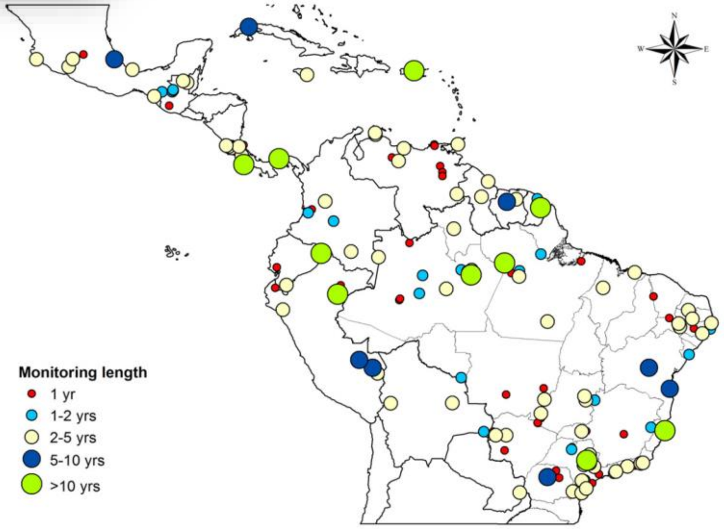
✓Long-term observation programs

However, the bulk of evidence of **phenology** shifts comes from temperate regions.

The **short time series** and the **high species diversity** make it difficult tracking phenology and detect cues and shifts in the tropics.



Albernethy et al. 2018. Biotropica



Mendoza, Peres, Morellato 2017. GPC 148:227-241

2. Phenology and climate change

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SIXTH ASSESSMENT REPORT
Working Group I – The Physical Science Basis

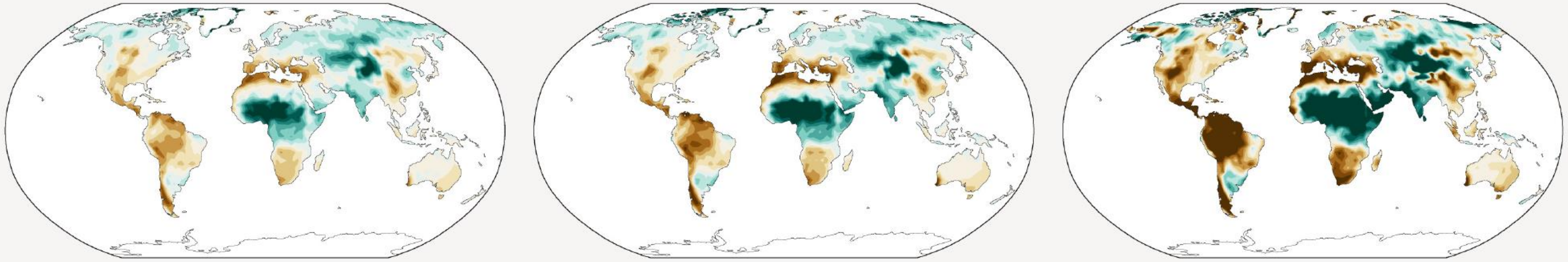
INTERGOVERNMENTAL PANEL ON climate change

With every increment of global warming, changes get larger in regional mean temperature, precipitation and soil moisture

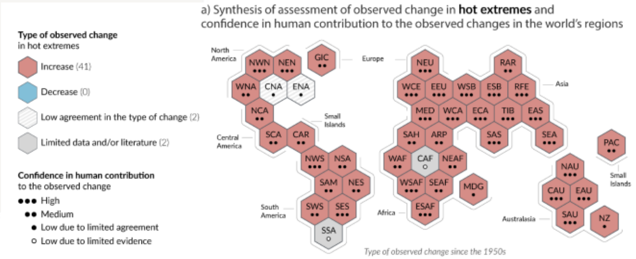
Figure SPM.5

d) Annual mean total column soil moisture change (standard deviation)

Across warming levels, changes in soil moisture largely follow changes in precipitation but also show some differences due to the influence of evapotranspiration.



Relatively small absolute changes may appear large when expressed in units of standard deviation in dry regions with little interannual variability in baseline conditions



2. Phenology and climate change

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Making Peace with Nature

A scientific blueprint to tackle the climate, biodiversity and pollution emergencies

3.1. Relative global impact of direct drivers on major ecosystems

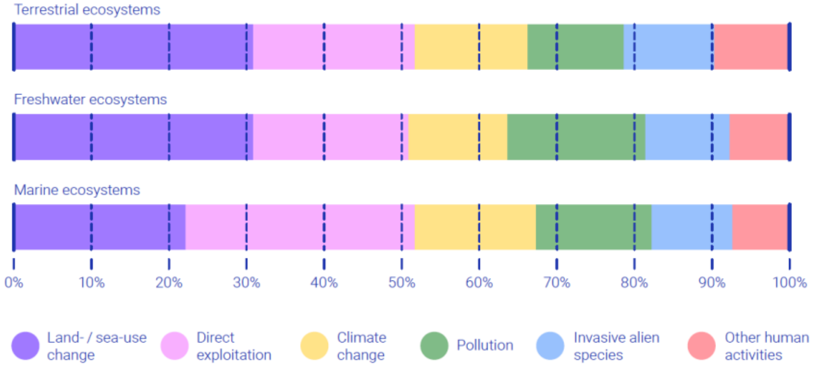

Figure 3.1: Relative global impact of direct drivers on major ecosystems, ranking the past and current causes of declines in biodiversity.
Source: IPBES 2019a, GA SPM, Figure SPM.2

3.4. Land degradation world maps

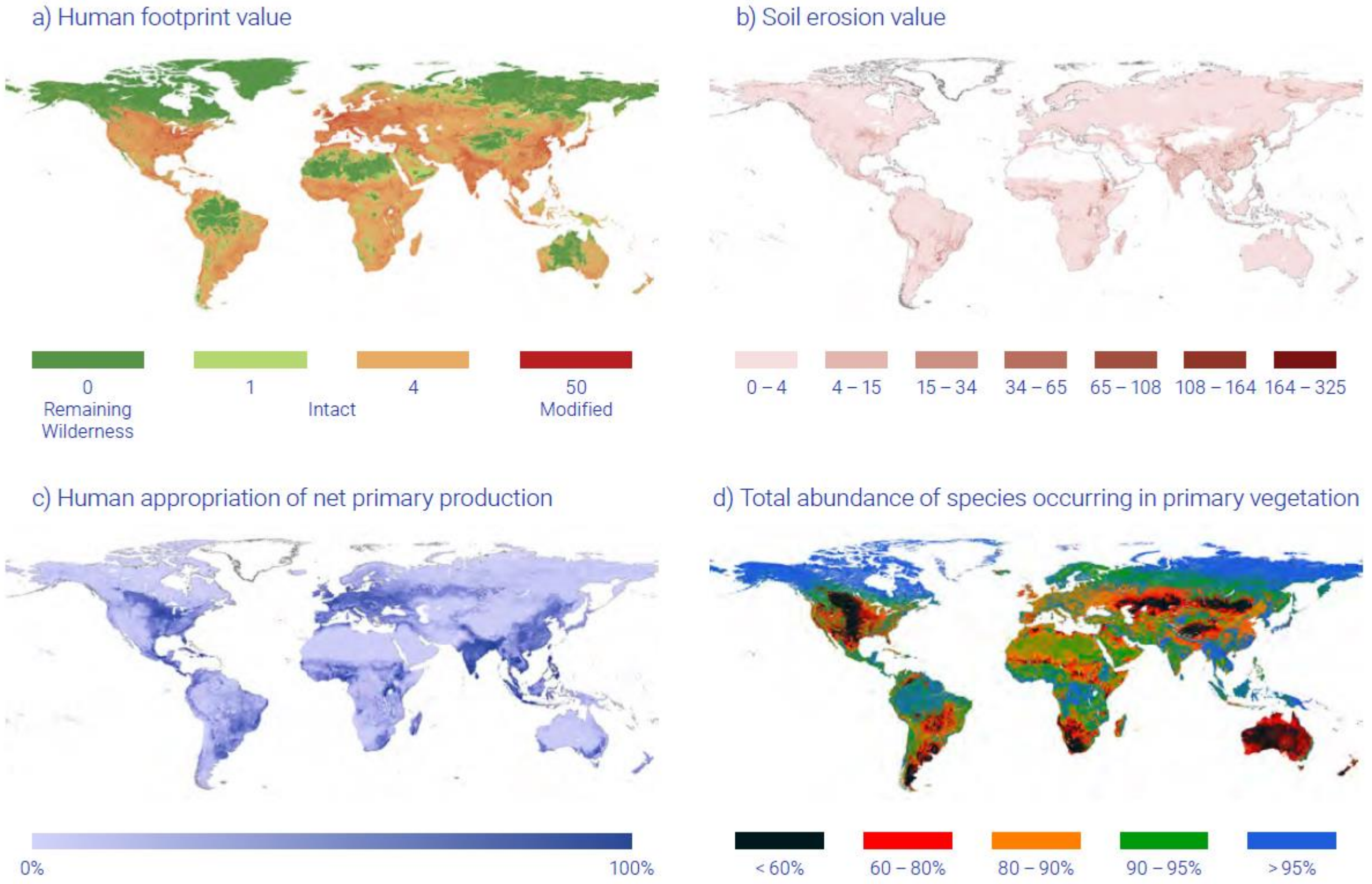

Figure 3.4: Human activities have modified the land surface of the planet as shown through the human footprint value indicating the intactness of terrestrial ecosystems (panel a) the soil erosion value (panel b), the human appropriation of net primary production (panel c) and the total abundance of originally occurring species as a percentage of their total abundance in minimally disturbed primary vegetation, expressed as the Biodiversity Intactness Index (panel d).

Data sources: a) Brooke, *et al.* (2020), b) Borrelli *et al.* (2007), c) Newbold *et al.* (2016), d) Haberl *et al.* (2007)

Data compiled and plotted by Emily Zhang

2. Phenology and climate change

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Making Peace with Nature

A scientific blueprint to tackle the climate, biodiversity and pollution emergencies

"Climate change and biodiversity loss are two of the most pressing issues of the Anthropocene. While there is recognition in both scientific and policy-making circles that the two are interconnected, in practice they are largely addressed in their own domains." *IPPC-IPBES Report 2021*

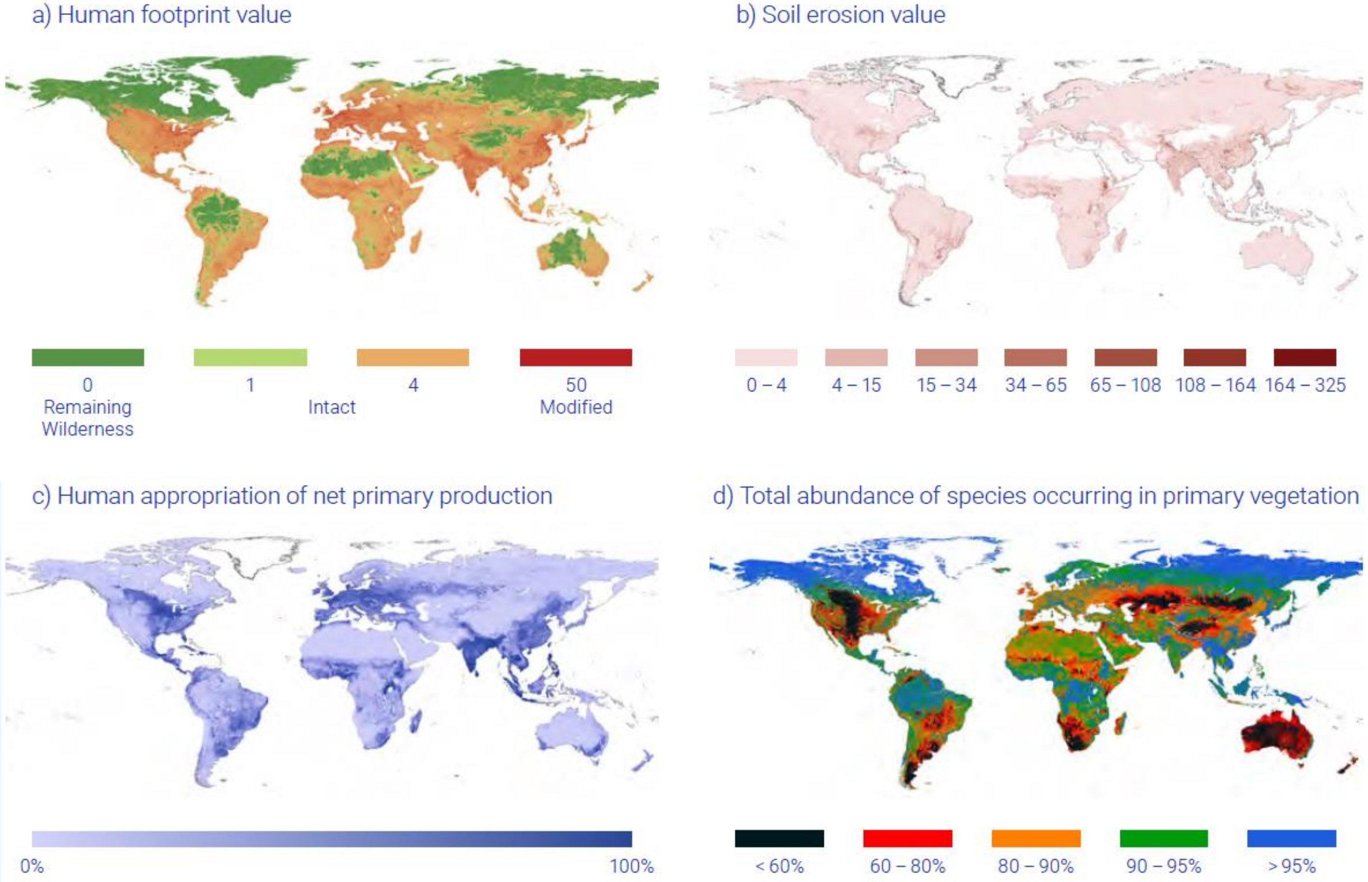
Source: IPBES 2019a, GA SPM, Figure SPM.2

IPBES-IPCC CO-SPONSORED WORKSHOP

BIODIVERSITY AND CLIMATE CHANGE

WORKSHOP REPORT

3.4. Land degradation world maps



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3. Phenological responses to climate change in the tropics

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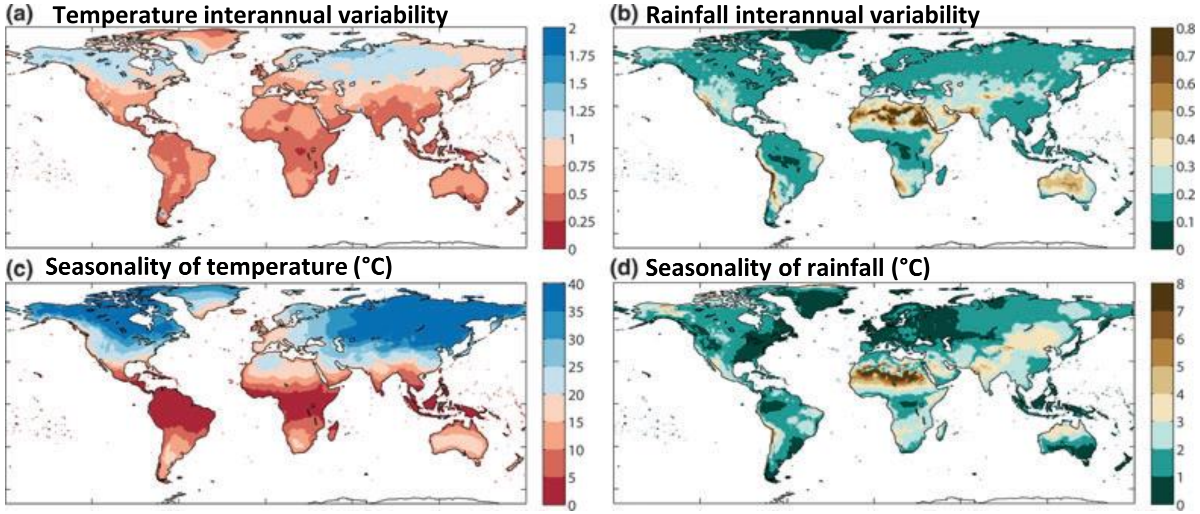
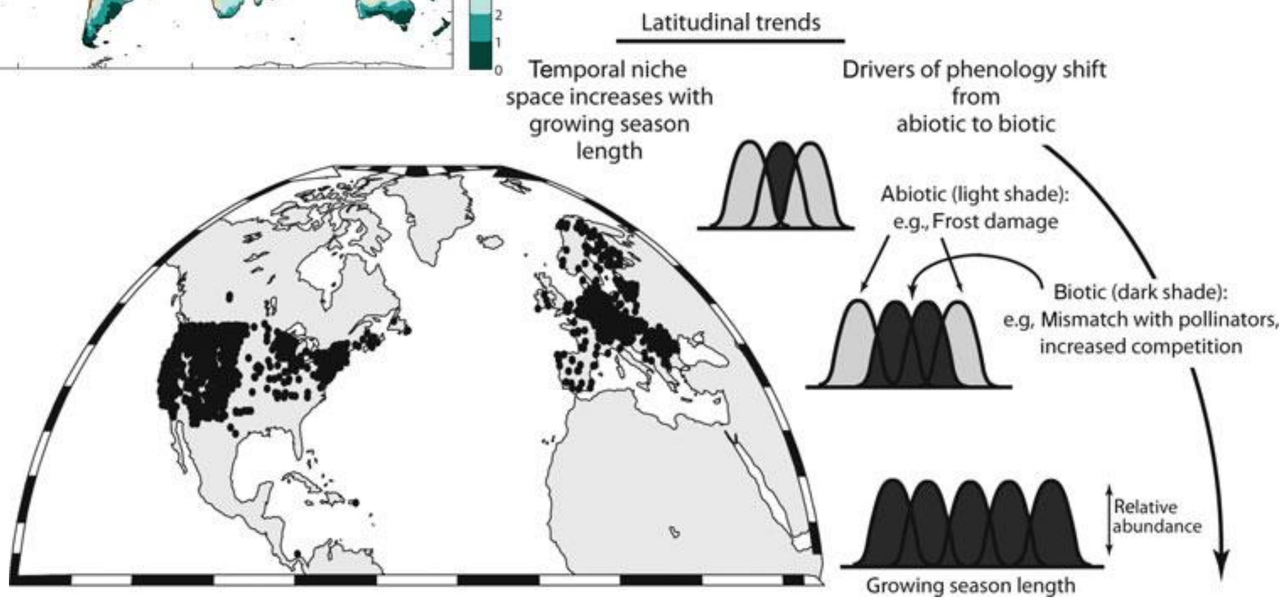
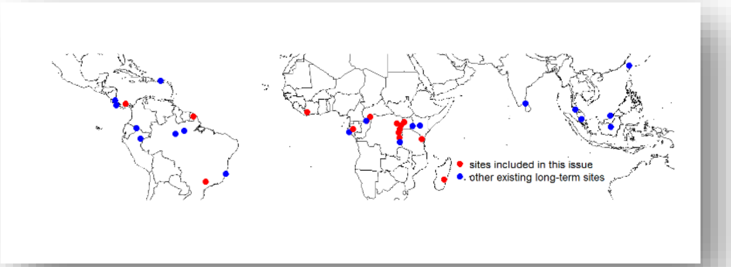
Some predictions can be made considering variability in **temperature**, **precipitation** and **length of growing season**

Phenology responses and shifts should differ depending on the length of growing season - ***Long-term observations***





Pau et al, 2011. GCB



Albernethy et al. 2018. Biotropica

3. Phenological responses to climate change in the tropics

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✓Long-term observation programs

OPEN ACCESS Freely available online PLOS | ONE

Phenological Changes in the Southern Hemisphere

Lynda E. Chambers[1*], Res Altwegg[2,15], Christophe Barbraud[3], Phoebe Barnard[2,16], Linda J. Beaumont[4], Robert J. M. Crawford[5], Joel M. Durant[6], Lesley Hughes[4], Marie R. Keatley[7], Matt Low[8], Patricia C. Morellato[9], Elvira S. Poloczanska[10], Valeria Ruoppolo[11,12], Ralph E. T. Vanstreels[12], Eric J. Woehler[13], Anton C. Wolfaardt[14]

October 2013 | Volume 8 | Issue 10 | e75514

The El Nino Southern Oscillation, Variable Fruit Production, and Famine in a Tropical Forest

S. Joseph Wright;

Ecology, Vol. 80,

LETTERS
PUBLISHED ONLINE: 7 JULY 2013 | DOI: 10.1038/NCLIMATE1934
nature climate change

Clouds and temperature drive dynamic changes in tropical flower production

Stephanie Pau[1,2*], Elizabeth M. Wolkovich[3], Benjamin I. Cook[4,5], Christopher J. Nytch[6], James Regetz[2], Jess K. Zimmerman[6] and S. Joseph Wright[7]

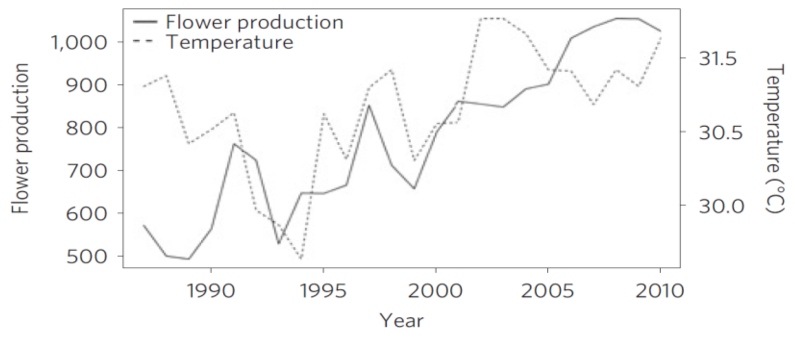
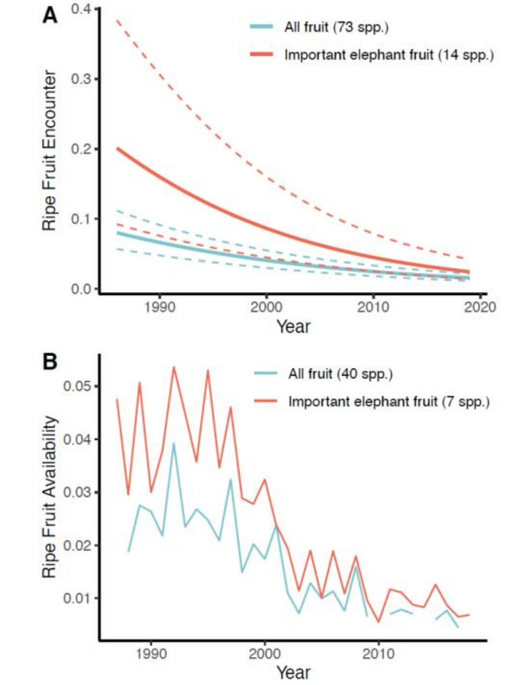
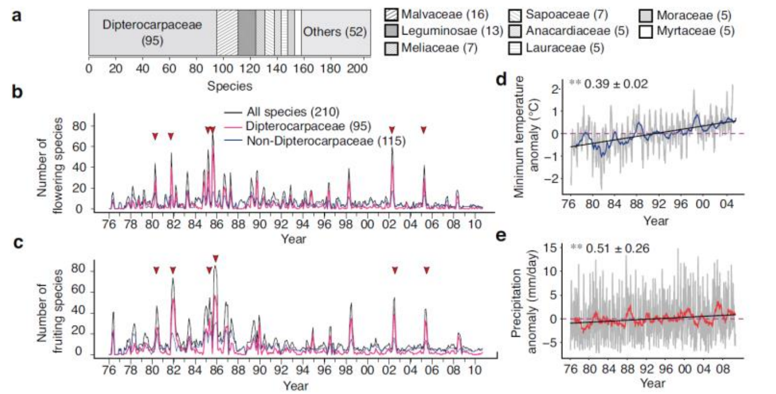


Figure 2 | Long-term trends in flower production (solid line) and maximum temperature (dotted line) at BCI from 1987 to 2009. Flower



Long-term collapse in fruit availability threatens Central African forest megafauna§

Emma R. Bush1,2†, Robin C. Whytock1,3*†, Laila Bahaa-el-din4, Stephanie Bourgeois3, Nils Bunnefeld1, Anabelle W. Cardoso5,6, Jean Thoussaint Dikangadissi3, Pacome Dimbonda3,Edmond Dimoto3, Josue Edzang Ndong3, Kathryn J. Jeffery1, David Lehmann3, Loic Makaga3,
hite1,8,9,



bioTROPICA
THE SCIENTIFIC JOURNAL OF THE ATBC

Special Section 2018: Long-term trends of tropical plant phenology: consequences for plants and consumers

communications biology
ARTICLE
https://doi.org/10.1038/s42003-022-03245-8 OPEN
Check for updates

Impacts of climate change on reproductive phenology in tropical rainforests of Southeast Asia

Shinya Numata[1✉], Koharu Yamaguchi[2], Masaaki Shimizu[2], Gen Sakurai[3], Ayaka Morimoto[1], Noraliza Alias[4], Nashatul Zaimah Noor Azman[4], Tetsuro Hosaka[5] & Akiko Satake[6✉]

3. Phenological responses to climate change in the tropics

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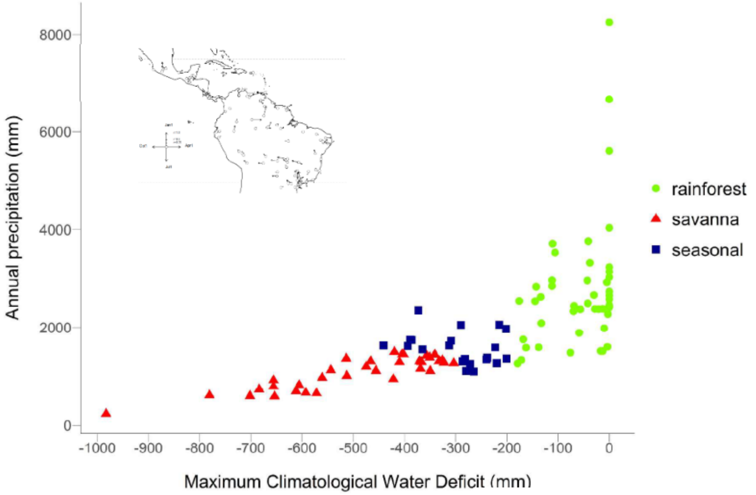
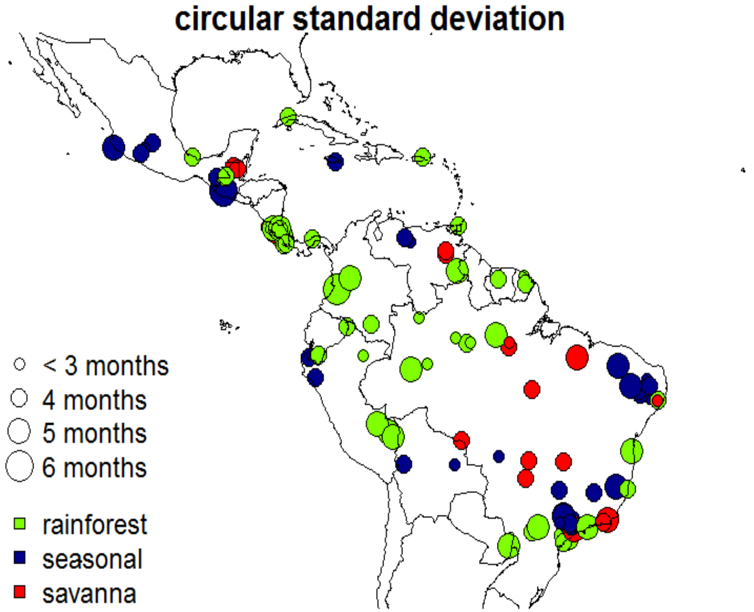
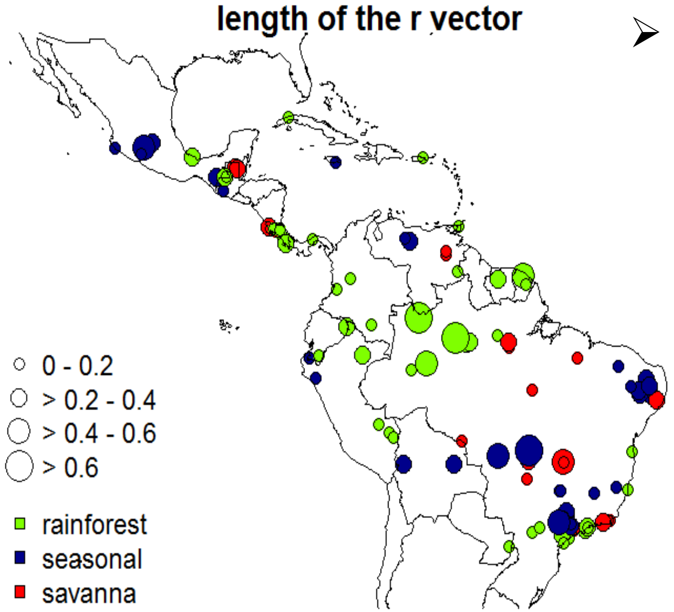


Fruiting availability is sensible to climate change scenarios.

- Reduced fruiting season length as consequence of future climatic conditions may have a very detrimental effect for resident frugivores.





- Half of analyzed Neotropical sites were subjected to some degree of fruiting seasonality.

Mendoza, I., Peres, C. A., Morellato, L.P.C. in prep. Large-scale climatic predictors of fruiting seasonality across the Neotropics.

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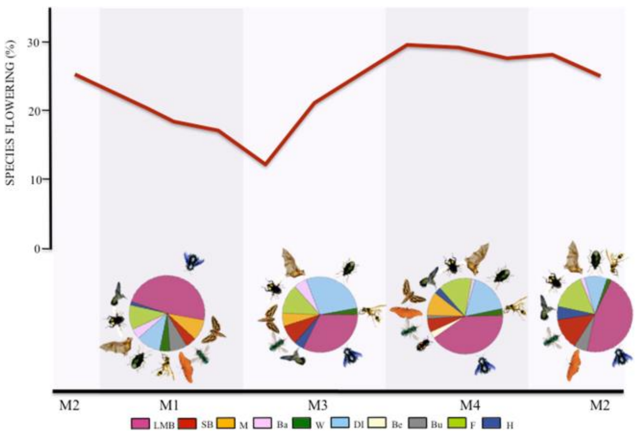
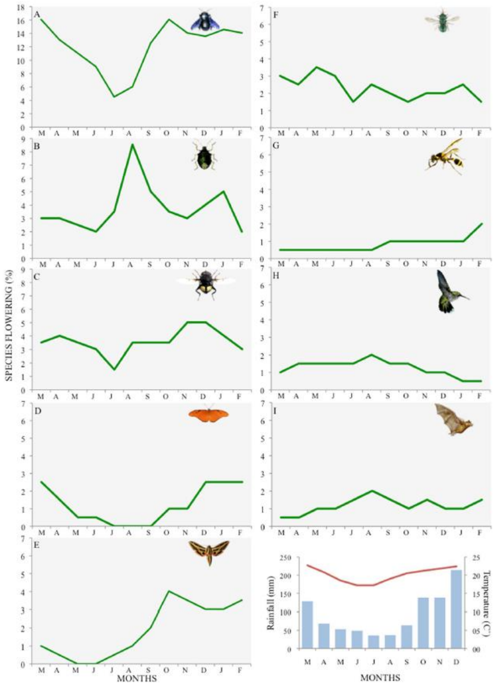
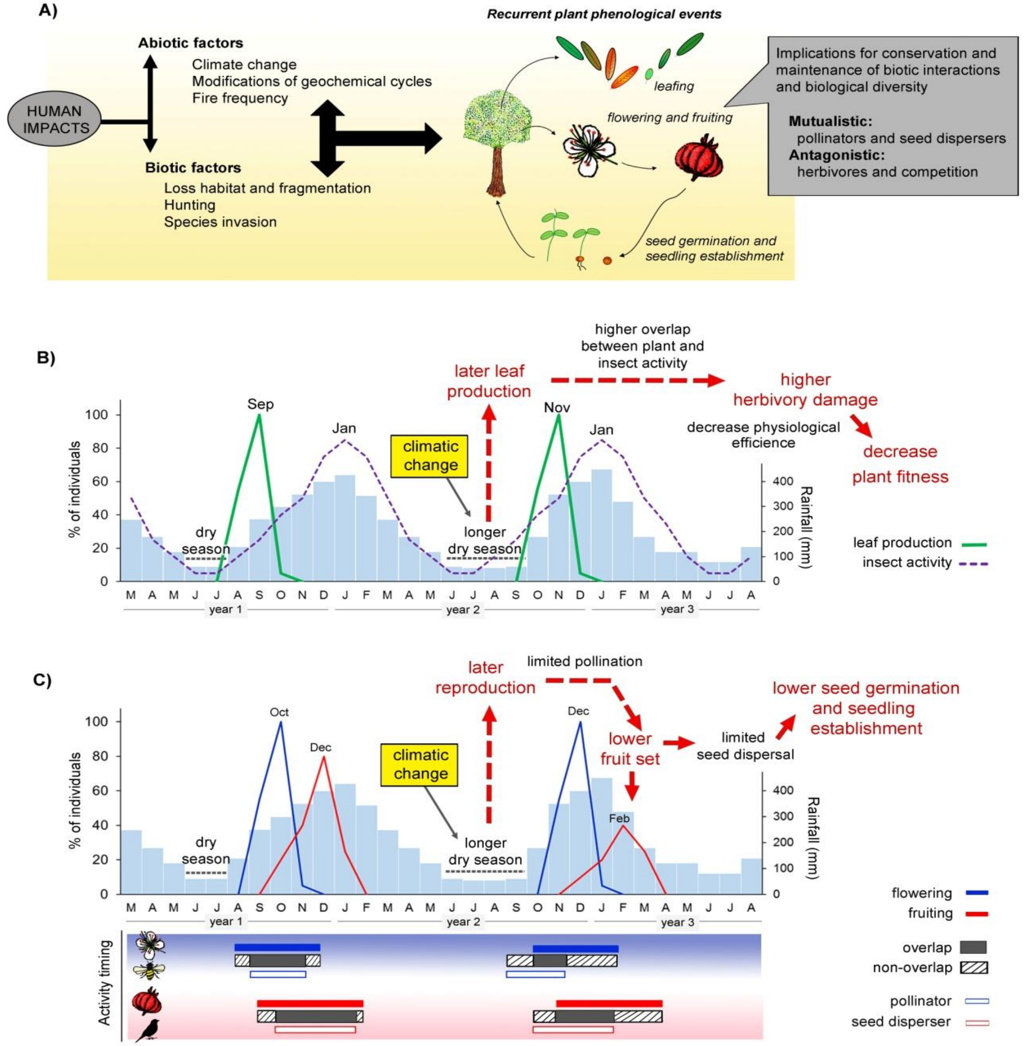
Conservation

The organization of flowering and fruiting phenology directly affects the structure and availability of plant resources over time and the maintenance of pollinators and seed dispersers





Genini et al. 2021 The Sience of Nature



Morellato et al. 2016 Biol. Cons

4. Practical implications: phenology conservation, restoration, and management

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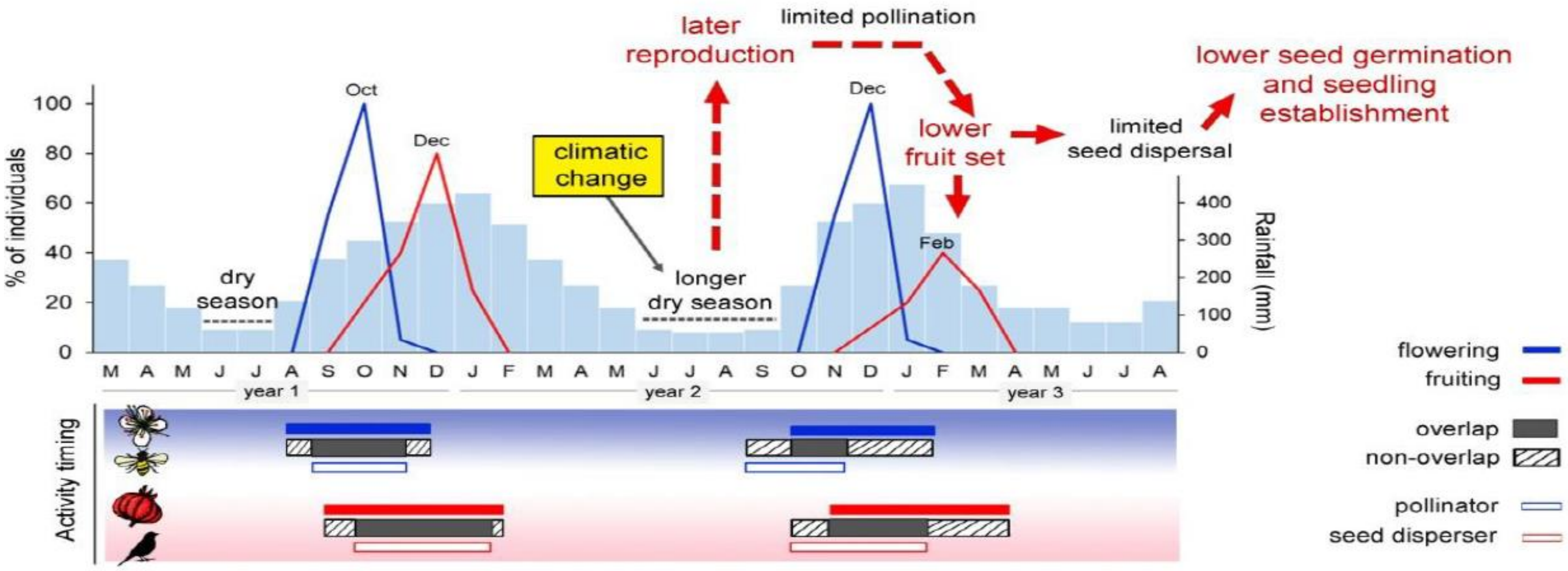
Phenological shifts and mismatches

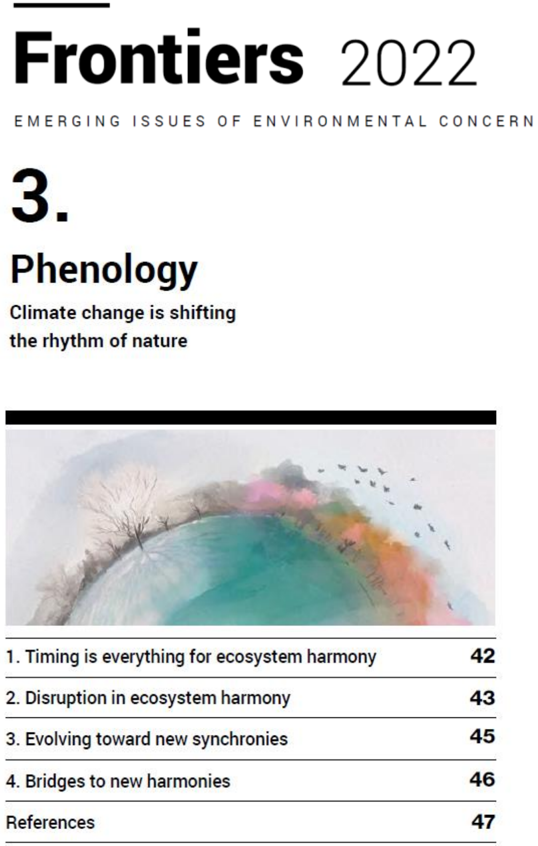
Flowering and pollinators

Fruiting and frugivory


Phenology

Climate change is shifting the rhythm of nature




Frontiers 2022

EMERGING ISSUES OF ENVIRONMENTAL CONCERN

3.

Phenology

Climate change is shifting the rhythm of nature

4. Practical implications: phenology conservation, restoration, and management

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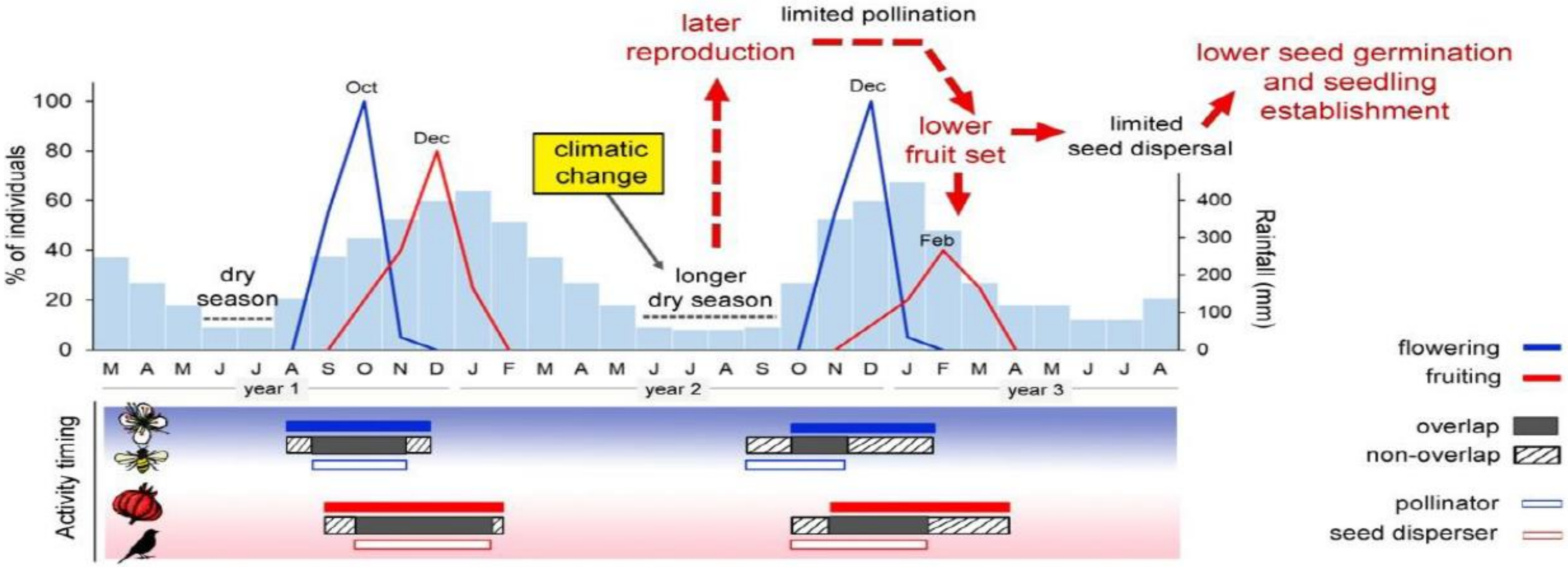
Flowering and pollinators

Fruiting and frugivory

Phenology

Climate change is shifting the rhythm of nature



Ecology Letters, (2007) **10**: 710–717 doi: 10.1111/j.1461-0248.2007.01061.x

LETTER

Global warming and the disruption of plant–pollinator interactions

Ecology Letters, (2009) **12**: 184–195 doi: 10.1111/j.1461-0248.2008.01269.x

REVIEW AND SYNTHESES

How does climate warming affect plant-pollinator interactions?

Variable flowering phenology and pollinator use in a community suggest future phenological mismatch

Theodora Petanidou [a,*], Athanasios S. Kallimanis [b], Stefanos P. Sgardelis [c], Antonios D. Mazaris [c], John D. Pantis [c], Nickolas M. Waser [d]

Frontiers 2022

EMERGING ISSUES OF ENVIRONMENTAL CONCERN

3.

Phenology

Climate change is shifting the rhythm of nature

4. Practical implications: phenology conservation, restoration, and management

Phenology Lab

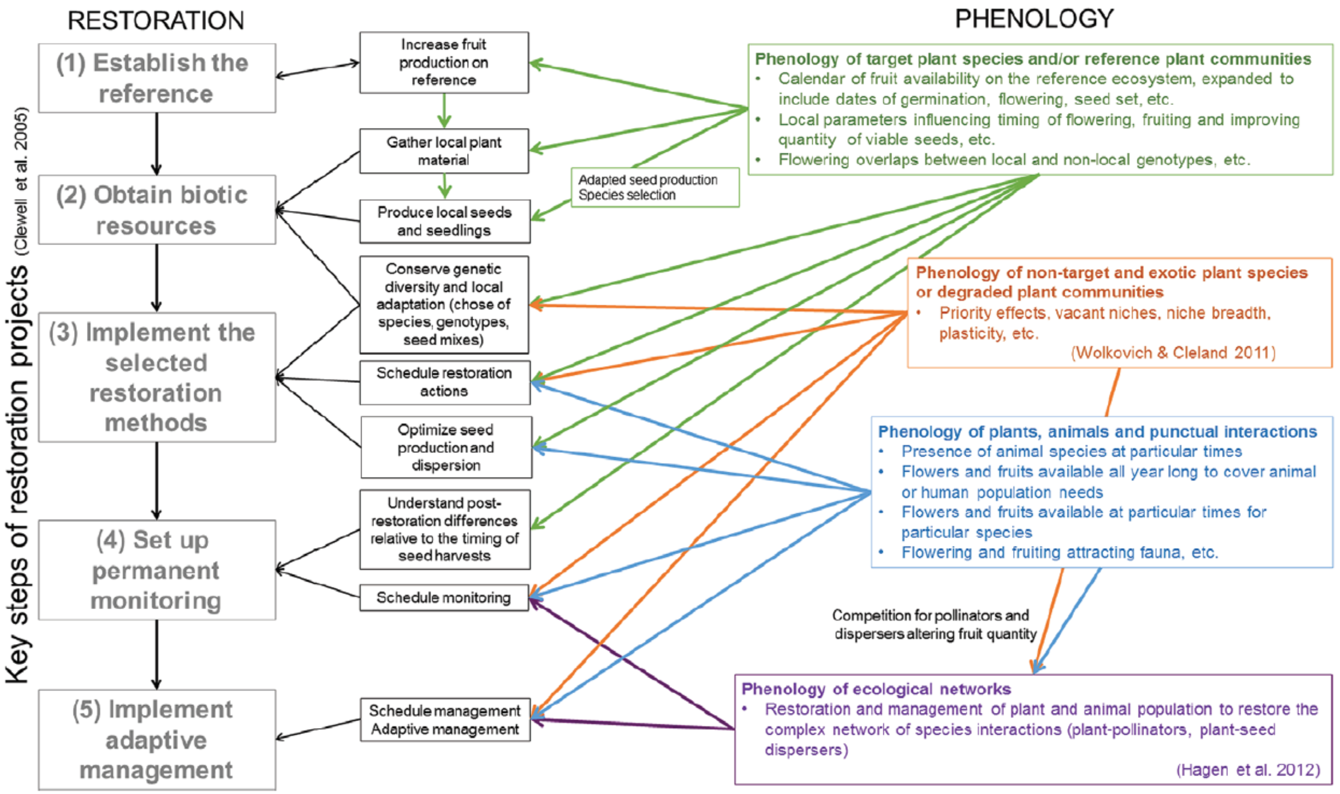


Figure 1. Conceptual framework showing where phenology can contribute to restoration. Numbers 1–5 are five major key steps of restoration projects (Clewell et al. 2005). Phenological information that may be collected for restoration projects are found in boxes on the right-hand side of the figure. Arrows show how specific phenological information can contribute to specific restoration steps.

Implications for Practice

- Phenology is an integrative environmental science which should be incorporated in ecological restoration project guidelines. Concurrently, restoration can provide new insights into phenological drivers and patterns.
- Restoration often requires the use of plants, and phenological data helps identify which species is most suitable and when and where locally adapted seeds can be acquired.
- Phenological information helps select species with important ecosystem functions (e.g. early germination and establishment to reduce soil erosion), and helps improve the fine-tuning of postrestoration management regimes (e.g. fire, grazing, mowing intensity/frequency, control of invasive species)
- Phenological information (timing of flowering, seed set, nesting, etc.) improves the timing of restoration implementation.
- Phenology monitoring provides suitable indicators to assess restoration success.

Restoration Ecology

OPINION ARTICLE

Plant phenological research enhances ecological restoration

Elise Buisson[1,2], Swanni T. Alvarado[3,4], Soizig Le Stradic[4,5], Leonor Patricia C. Morellato[5]

4. Practical implications: phenology conservation, restoration, and management

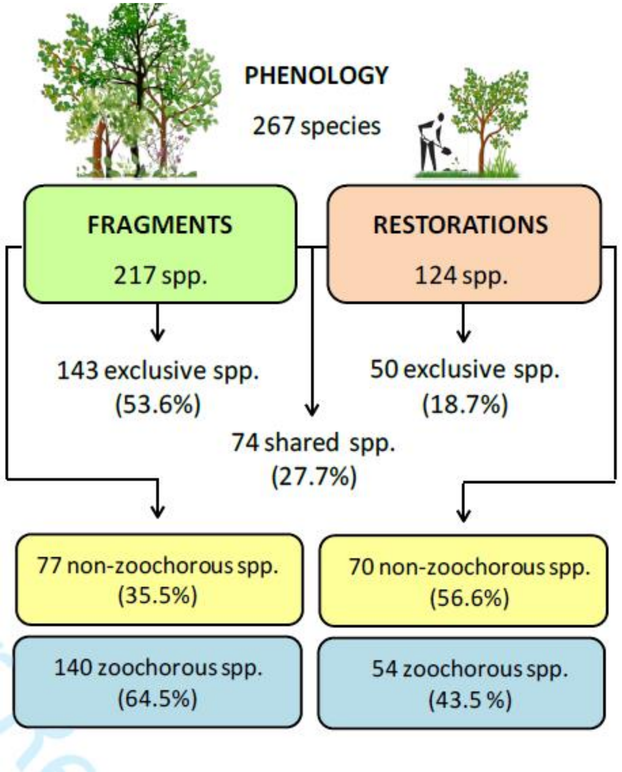
RESTORATION ECOLOGY
The Journal of the Society for Ecological Restoration

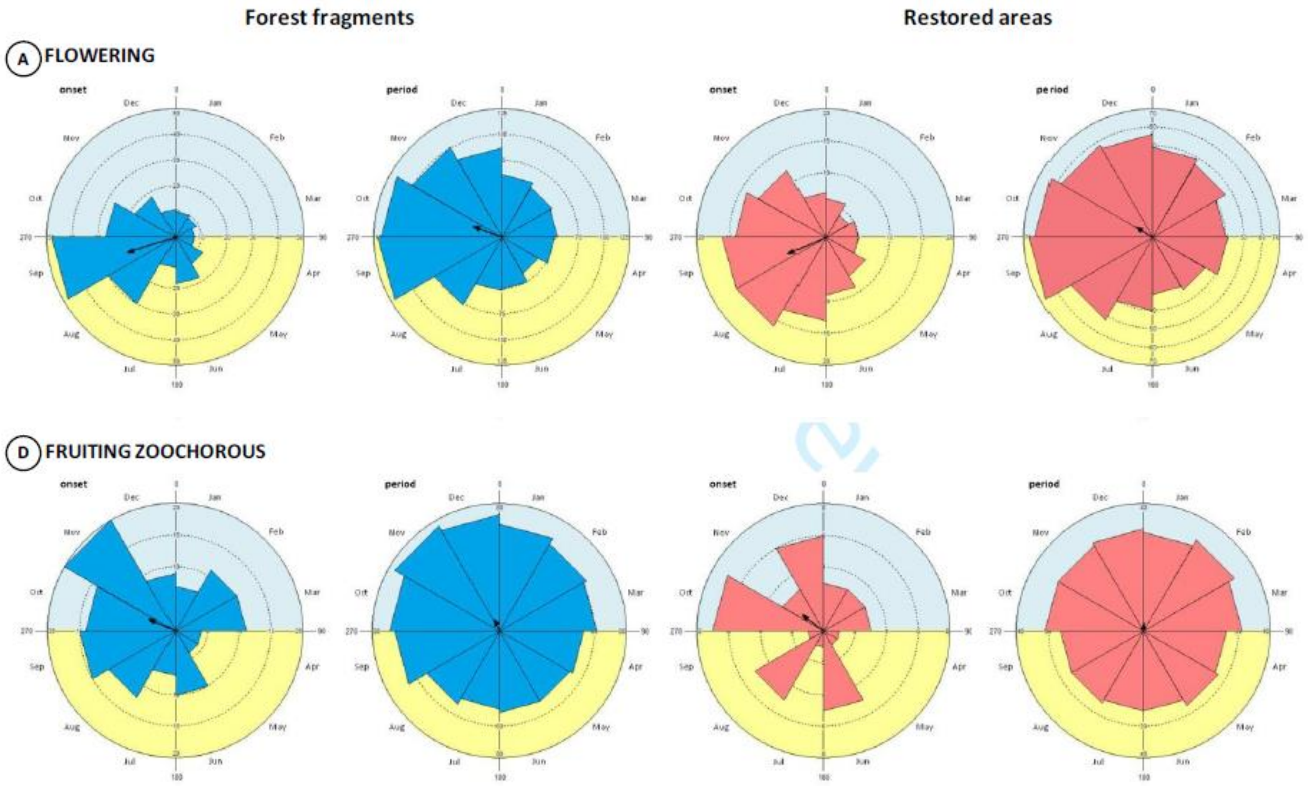
UN DECADE ON ECOSYSTEM RESTORATION

RESEARCH ARTICLE

Comparing the potential reproductive phenology between restored areas and native tropical forest fragments in Southeastern Brazil

Débora C. Rother[1,2,3], Igor L. F. de Sousa[4], Eliana Gressler[4], Ana P. Liboni[2,5], Vinícius C. Souza[2], Ricardo R. Rodrigues[2], L. Patrícia C. Morellato[4]





4. Practical implications: phenology conservation, restoration, and management

Phenology Lab

→ Light Detection And Ranging (LiDAR), radar, etc.

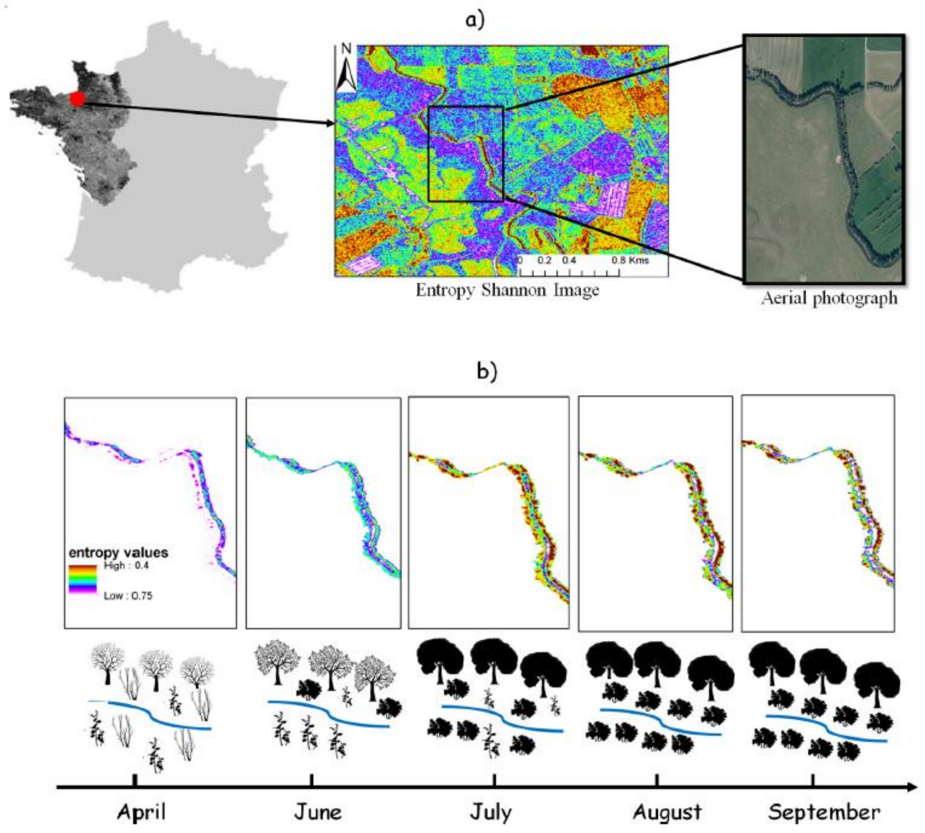


Figure 7
Riparian vegetation monitoring, with the Shannon Entropy parameter derived from TerraSAR-X images (Dual-polarization): a) Riparian vegetation extracted from the image registered in July and b) Evolution of the intra-annual riparian vegetation during the year 2012.

Dufour *et al.* (2013)

Time will tell: resource continuity bolsters ecosystem services

Nancy A Schellhorn[1], Vesna Gagic[1,2], and Riccardo Bommarco[2]

[1] CSIRO, GPO Box 2583, Brisbane, QLD, 4001, Australia
[2] Swedish University of Agricultural Sciences, Department of Ecology, Uppsala 75007, Sweden

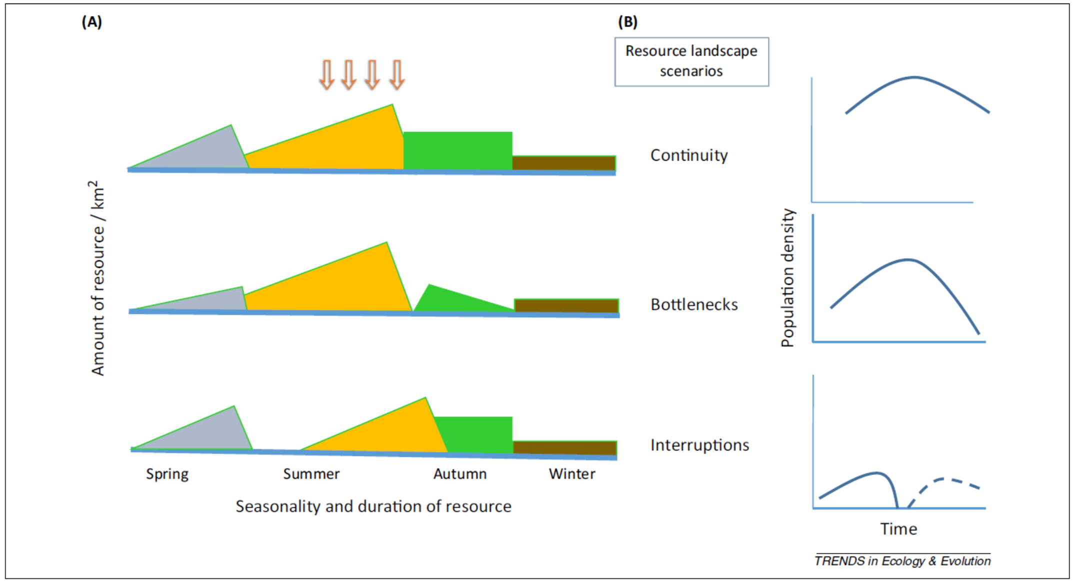


Figure 1. Scenarios of resource availability over time. Hypothetical schematic **(A)** depicting resource amount (per km^2; 'y' axis), against time of year when available, and duration (X axis). Examples show resource continuity (top), discontinuity as bottlenecks (middle), and as interruptions (bottom), as related to the resource needs of a target organism. Panel **(B)** depicts implications for population dynamics for each respective resource situation. Colours represent types of resources. The top left continuity example shows resources to be available throughout the year, although in different amounts, and corresponding population densities (top right) are sustained at high and more constant levels. The bottleneck and interruption scenarios exemplify extreme limitation or absence of resources, respectively; peaks in population densities will be lower and changes in density will occur faster. The four arrows represent the sampling period of data collection of typical snapshot landscape ecology studies.

Phenology, Climate Change and Conservation in highly diverse ecosystems

Phenology Lab

1. Phenology in highly diverse ecosystems
2. Climate change and Phenology
3. Phenological responses to climate change in tropical higly diverse ecosystem
4. Practical implications: phenology conservation, restoration, and management
5. Challenges: detect temporal responses in highly diverse ecosystems

5. Challenges: detect temporal responses in highly diverse ecosystems

I. reviews and synthesis, unlocking literature and old observations;
II. use of herbarium records, to recover long term patterns and responses;
III. applications of evolutionary and modelling tools to search for clade's sensitiveness to changes on their phenological niche;
IV. combine observations and experiments to understand temporal mismatches;
V. networking- develop citizen science initiatives and monitoring networks to collect more comparative data over large special scales;
VI. experiments - impose climate scenarios to tropical plants (e.g. CO_2 enrichment – FACE, drought experiments, transplants);
VII. new technologies which may maximize our understanding at large scales (new remote sensing tools).
VIII. ……….

5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

I. reviews and synthesis, unlocking literature and old observations

Chapter 2.5

SOUTH AMERICA

L. Patrícia C. Morellato
Departamento de Botânica, Plant Phenology and Seed Dispersal Research Group, Universidade Estadual Paulista, São Paulo, Brasil

Acta bot. bras. 18(1): 99-108. 2004

Métodos de amostragem e avaliação utilizados em estudos fenológicos de florestas tropicais[1]

Fernanda F. d'Eça-Neves[2] e L. Patrícia C. Morellato[3,4]

OPEN ACCESS Freely available online — PLOS ONE

Phenological Changes in the Southern Hemisphere

Lynda E. Chambers[1*], Res Altwegg[2,15], Christophe Barbraud[3], Phoebe Barnard[2,16], Linda J. Beaumont[4], Robert J. M. Crawford[5], Joel M. Durant[6], Lesley Hughes[4], Marie R. Keatley[7], Matt Low[8], Patricia C. Morellato[9], Elvira S. Poloczanska[10], Valeria Ruoppolo[11,12], Ralph E. T. Vanstreels[12], Eric J. Woehler[13], Anton C. Wolfaardt[14]

Chapter 6
A Review of Plant Phenology in South and Central America

L. Patrícia C. Morellato, Maria Gabriela G. Camargo, and Eliana Gressler

Contents lists available at ScienceDirect
Global and Planetary Change
journal homepage: www.elsevier.com/locate/gloplacha

Invited review article
Continental-scale patterns and climatic drivers of fruiting phenology: A quantitative Neotropical review

Irene Mendoza[a,*], Carlos A. Peres[b], Leonor Patrícia C. Morellato[a]
[a] Universidade Estadual Paulista, Departamento de Botânica, Laboratório de Fenologia, Av. 24A, 1515, 13506-900 Rio Claro, SP, Brazil

Restoration Ecology

OPINION ARTICLE
Plant phenological research enhances ecological restoration

Elise Buisson[1,2], Swanni T. Alvarado[3,4], Soizig Le Stradic[4,5], Leonor Patricia C. Morellato[5]

Biological Conservation 195 (2016) 60–72
Contents lists available at ScienceDirect
Biological Conservation
journal homepage: www.elsevier.com/locate/bioc

Perspective
Linking plant phenology to conservation biology

Leonor Patrícia Cerdeira Morellato[a,*], Bruna Alberton[a,b], Swanni T. Alvarado[c], Bruno Borges[a,b], Elise Buisson[d], Maria Gabriela G. Camargo[a], Leonardo F. Cancian[a], Daniel W. Carstensen[a], Diego F.E. Escobar[a,e], Patrícia T.P. Leite[a,e], Irene Mendoza[a], Nathália M.W.B. Rocha[a], Natalia C. Soares[a,e], Thiago Sanna Freire Silva[c], Vanessa G. Staggemeier[a], Annia Susin Streher[b,c], Betânia C. Vargas[a,e], Carlos A. Peres[f]

Contents lists available at ScienceDirect
Ecological Engineering
journal homepage: www.elsevier.com/locate/ecoleng

Modeling plant phenology database: Blending near-surface remote phenology with on-the-ground observations

Greice C. Mariano[a,*], Leonor Patricia C. Morellato[b], Jurandy Almeida[a,c], Bruna Alberton[b], Maria Gabriela G. de Camargo[b], Ricardo da S. Torres[a]

Revista Brasil. Bot., V.25, n.3, p.269-275, set. 2002

Comparação de dois métodos de avaliação da fenologia de plantas, sua interpretação e representação[1]

CINARA S.C. BENCKE[2,3] e L. PATRÍCIA C. MORELLATO[2,4]

5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

II. use of herbarium records, to recover long term patterns and responses;

Trends in Ecology & Evolution

Review

Old Plants, New Tricks: Phenological Research Using Herbarium Specimens

Charles G. Willis,[1,*] Elizabeth R. Ellwood,[2,*] Richard B. Primack,[3] Charles C. Davis,[1] Katelin D. Pearson,[2] Amanda S. Gallinat,[3] Jenn M. Yost,[4] Gil Nelson,[2] Susan J. Mazer,[5] Natalie L. Rossington,[5] Tim H. Sparks,[6,7] and Pamela S. Soltis[8]

Analysis of flowering patterns from herbarium specimens: relationships with the climate and long-term shifts in flowering times

herbarium specimens in a stage of early leaf-out demonstrated that trees now leaf-out earlier than a century ago and leaf-out earlier in warm years [18]. A surprising finding was that annual variation in temperature was far greater in determining leaf-out dates than geographical variation in temperature and that differences among species in leaf-out times were not significant. Further, the geographic variation in leaf-out dates determined using herbarium specimens was significantly correlated with geographic variation in leaf-out dates determined using remote sensing data provided by satellites. This correlation provides independent confirmation that remote sensing, a rapidly growing tool in climate change research, is accurately measuring leaf-out times over large geographic areas. The study also showed that, on average, herbarium specimens show later leaf-out dates than remote sensing dates, perhaps because remote sensing instruments are sensitive to ground cover, the shrub layer, and the very first tree leaves.

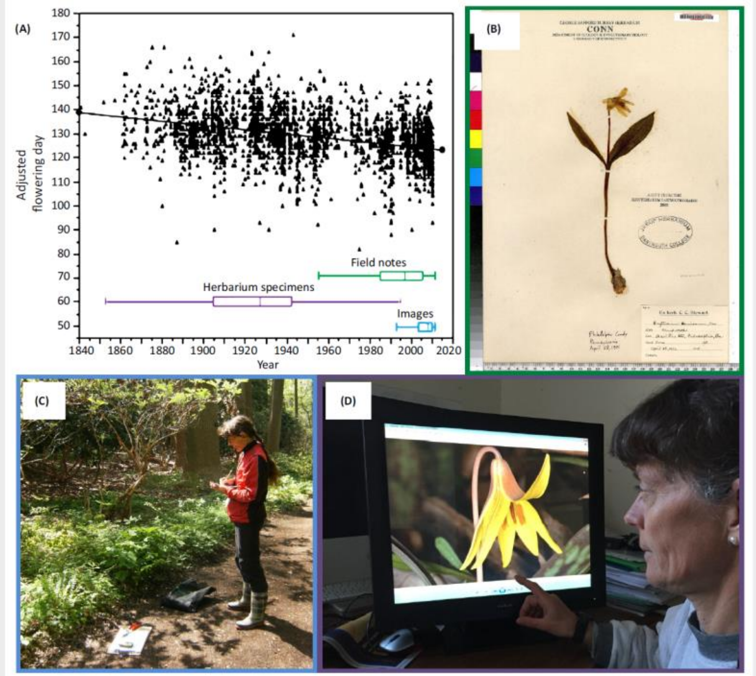


Figure I. Example of Integrated Historical Data Sources. (A) Plot of flowering day over time for 28 species in the Philadelphia area based on a combination of

1 Identify species with conspicuous flowers


(Tabebuia aurea)

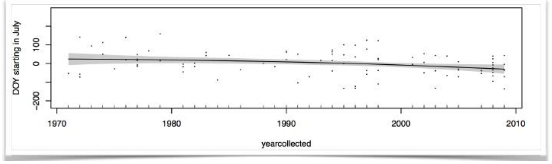

Photography and collector note indicating the presence of flowers

2 Search online databases for herbarium records of target species

GBIF speciesLink

3 Use machine learning to retain reliable records of specimens with flowers

4 Model the derived long term time series to identify changes in flowering times and relationships with the climate for several species



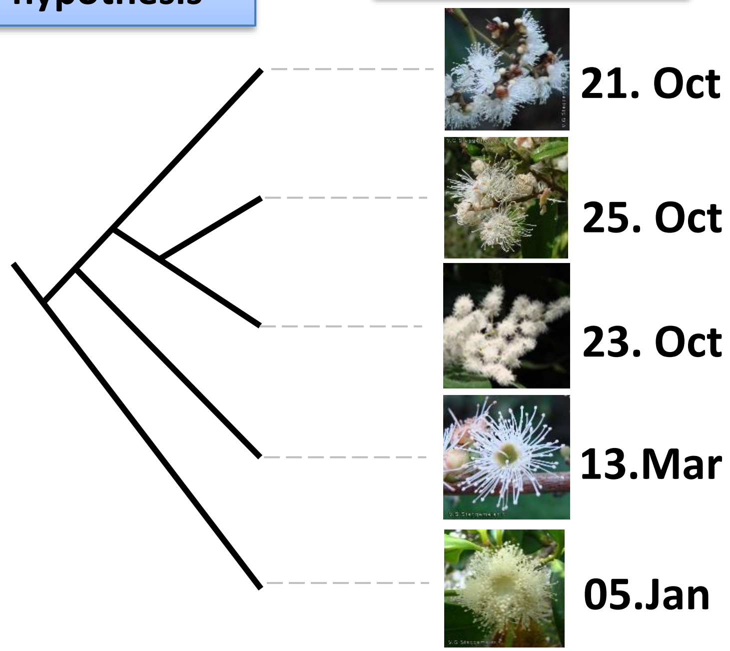
5. Challenges: detect temporal responses in highly diverse ecosystems

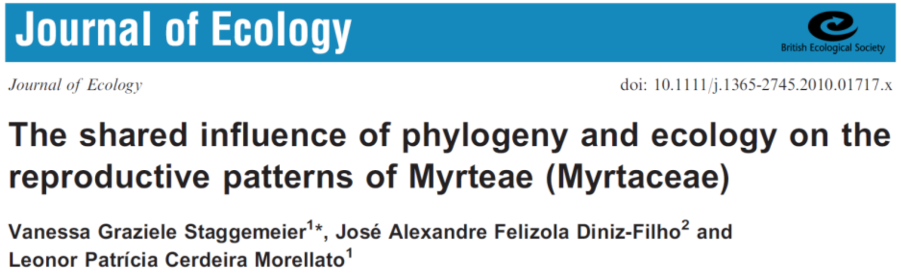
Phenology Lab

III. applications of evolutionary and modelling tools to search for clade's sensitiveness to changes on their phenological niche;

- ✓ Detect trends, sensitivities and shifts to climate change
- ➢ Phylogeny, Modeling and forecasting phenology

Phylogenetic hypothesis ✚ **Phenology**





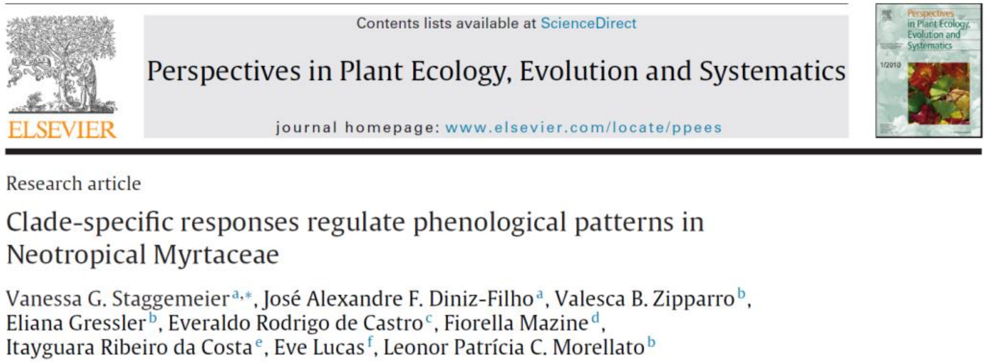
Journal of Ecology

British Ecological Society

Journal of Ecology doi: 10.1111/j.1365-2745.2010.01717.x

The shared influence of phylogeny and ecology on the reproductive patterns of Myrteae (Myrtaceae)

Vanessa Graziele Staggemeier[1]*, José Alexandre Felizola Diniz-Filho[2] and Leonor Patrícia Cerdeira Morellato[1]



Contents lists available at ScienceDirect

Perspectives in Plant Ecology, Evolution and Systematics

journal homepage: www.elsevier.com/locate/ppees

ELSEVIER

Research article

Clade-specific responses regulate phenological patterns in Neotropical Myrtaceae

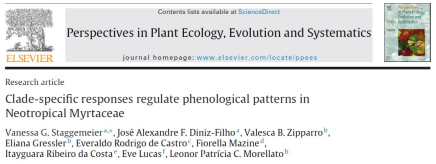
Vanessa G. Staggemeier[a,*], José Alexandre F. Diniz-Filho[a], Valesca B. Zipparro[b], Eliana Gressler[b], Everaldo Rodrigo de Castro[c], Fiorella Mazine[d], Itayguara Ribeiro da Costa[e], Eve Lucas[f], Leonor Patrícia C. Morellato[b]

5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

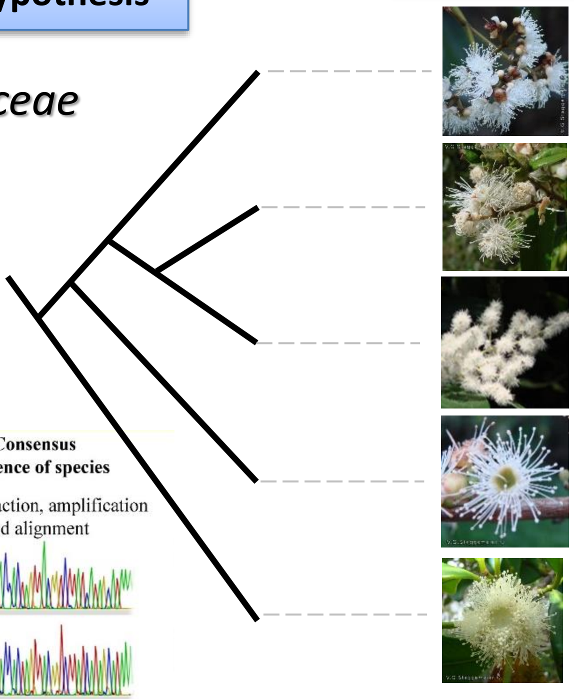
III. applications of evolutionary and modelling tools to search for clade’s sensitiveness to changes on their phenological niche;

- ✓ Detect trends, sensitivities and shifts to climate change


Contents lists available at ScienceDirect
Perspectives in Plant Ecology, Evolution and Systematics
journal homepage: www.elsevier.com/locate/ppees
Research article
Clade-specific responses regulate phenological patterns in Neotropical Myrtaceae
Vanessa G. Staggemeier, José Alexandre F. Diniz-Filho, Valesca B. Zipparro, Eliana Gressler, Everaldo Rodrigo de Castro, Fiorella Mazine, Itayguara Ribeiro da Costa, Eve Lucas, Leonor Patrícia C. Morellato

Phylogenetic hypothesis ✚ **Phenology**

Myrtaceae



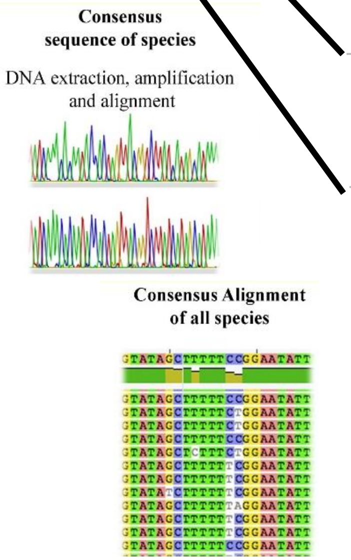
21. Oct

25. Oct

23. Oct

13.Mar

05.Jan



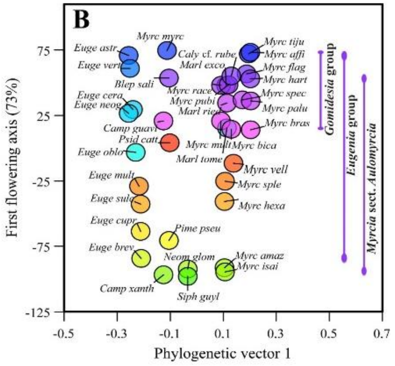
Monthly systematic collection in the field

Prediction

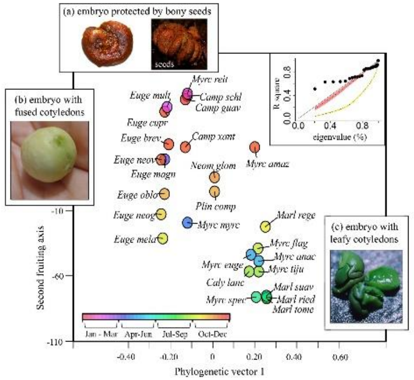
Closely related species would exhibit similar phenological patterns because of their common ancestry

Useful for:

- Identify groups with conservative phenology (potentially less resilient face to global warming)



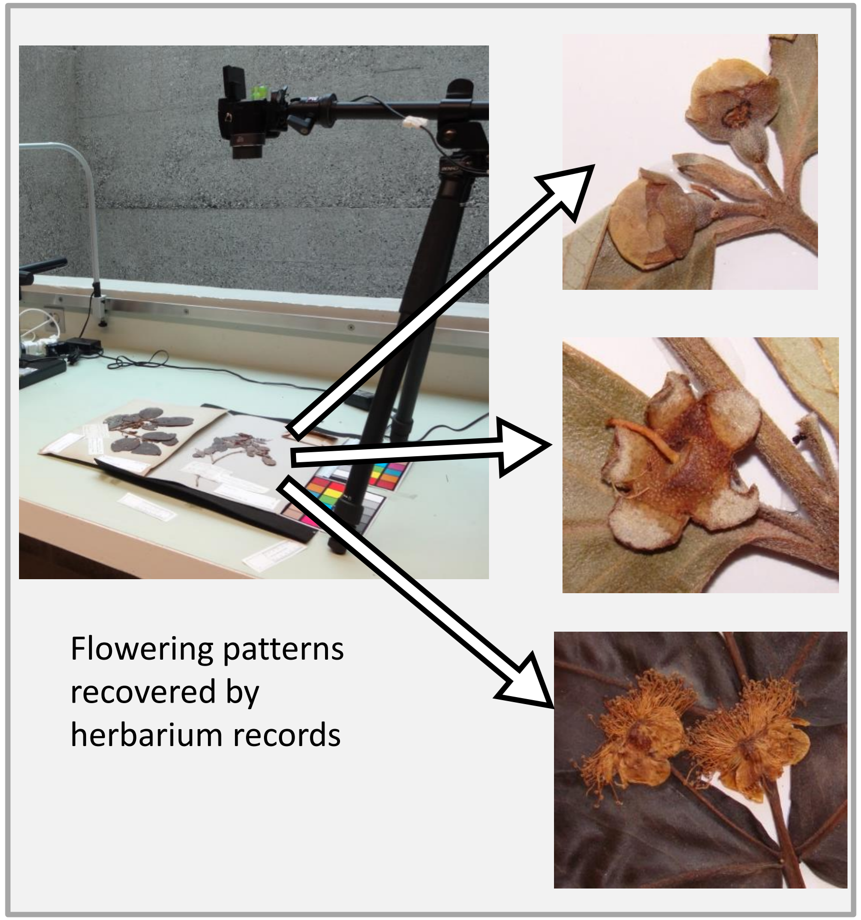
- Understand the evolution of phenological strategies on plants



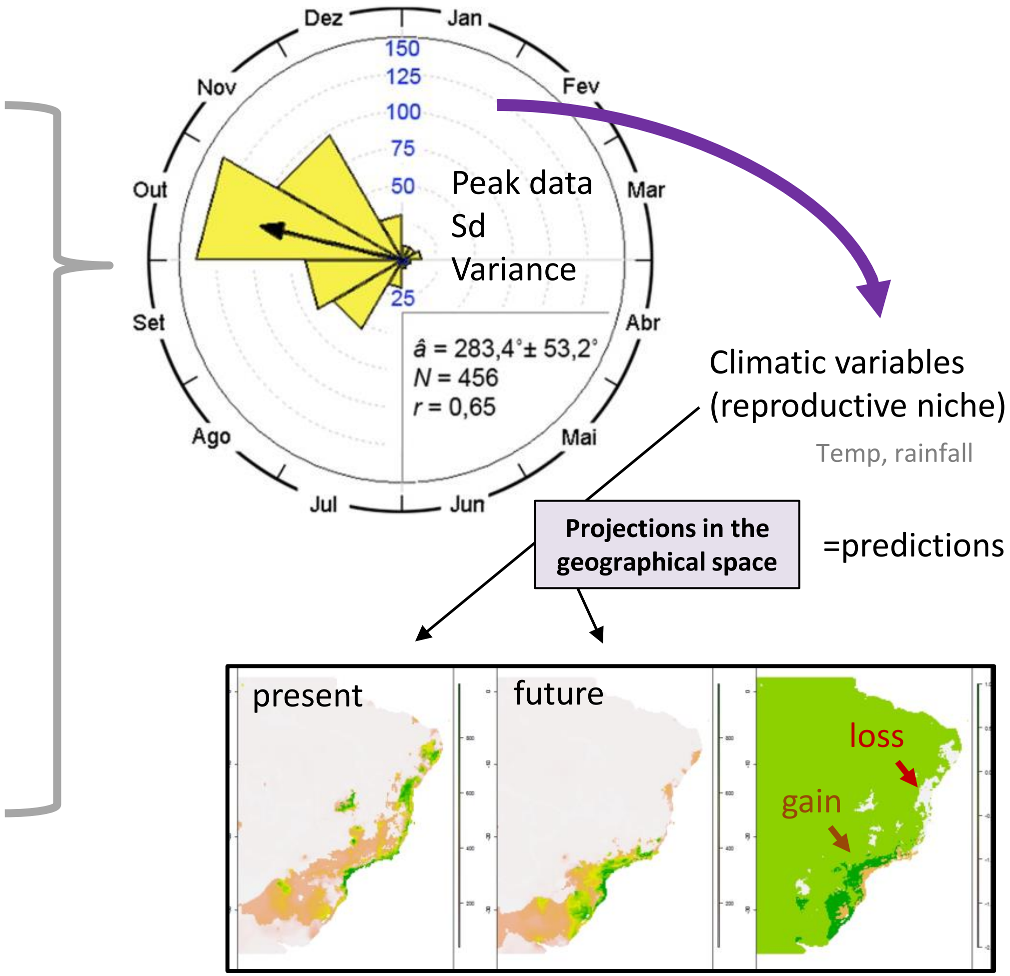
5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

II. use of herbarium records, to recover long term patterns and responses;
III. applications of evolutionary and modelling tools to search for clade's sensitiveness to changes on their phenological niche;



Phenograms: best time for flowering



Received: 2 September 2018 | Accepted: 22 July 2019
DOI: 10.1111/1365-2745.13266

MINI-REVIEW

Journal of Ecology

The circular nature of recurrent life cycle events: a test comparing tropical and temperate phenology

Vanessa Graziele Staggemeier[1] | Maria Gabriela Gutierrez Camargo[1] | José Alexandre Felizola Diniz-Filho[2] | Robert Freckleton[3] | Lucas Jardim[2] | Leonor Patrícia Cerdeira Morellato[1]

- Phylogeny, Modeling and forecasting phenology

5. Challenges: detect temporal responses in highly diverse ecosystems

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IV. combine observations and experiments to understand temporal mismatches;

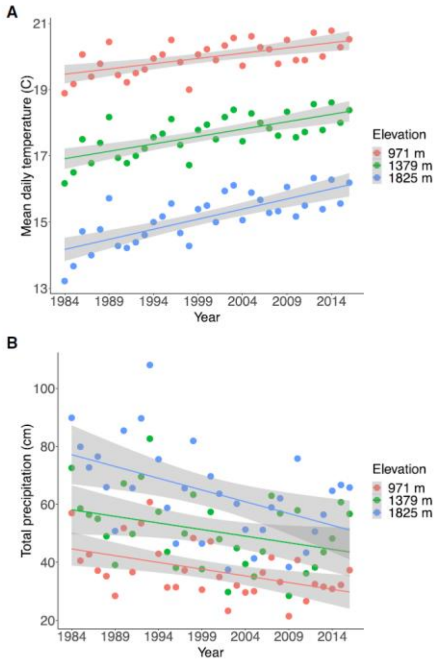


Figure 3. Change in Temperature and Precipitation

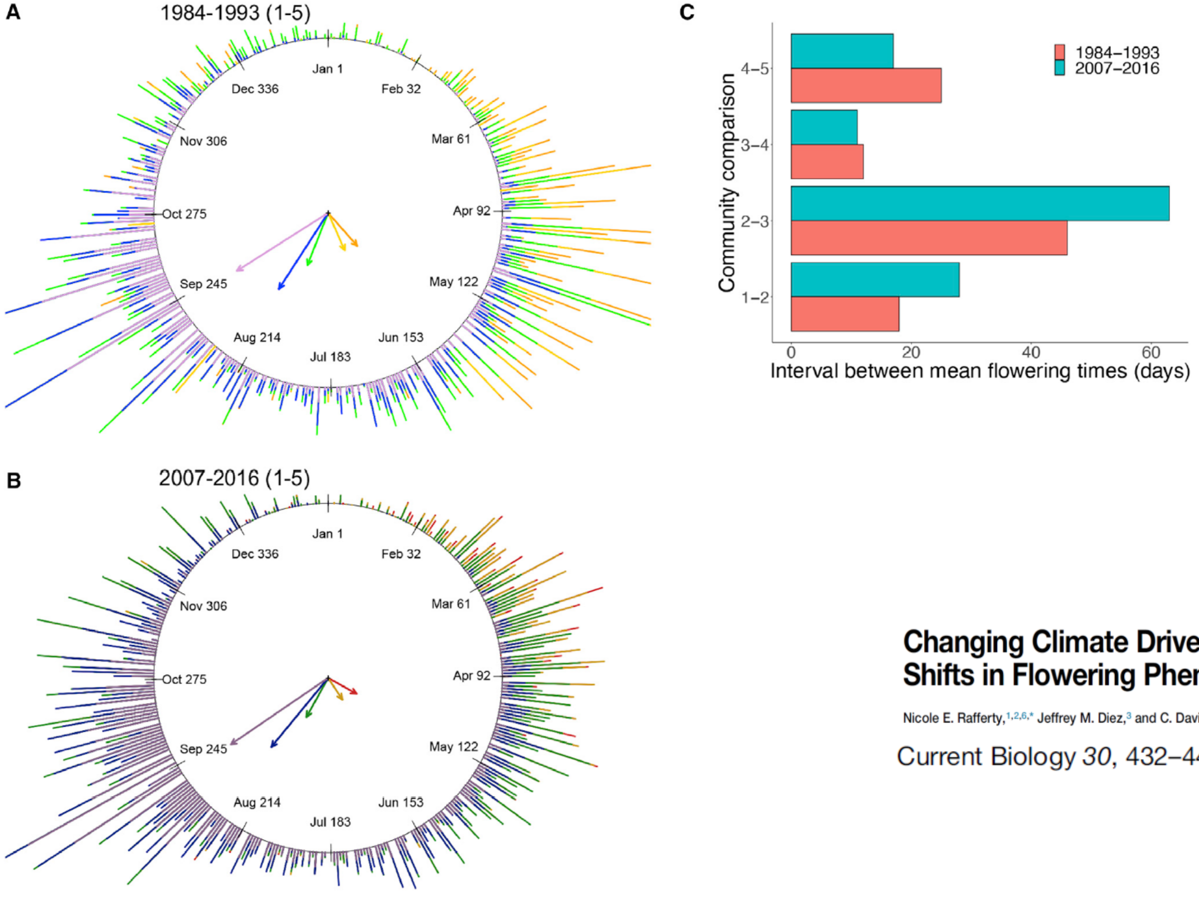
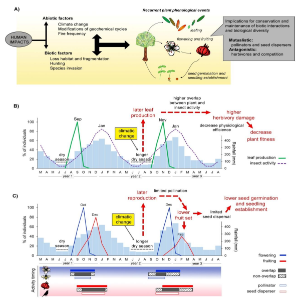


Figure 2. Change in Flowering Phenology of All Communities Comprising the Larger Metacommunity



Changing Climate Drives Divergent and Nonlinear Shifts in Flowering Phenology across Elevations

Nicole E. Rafferty,[1,2,6,*] Jeffrey M. Diez,[3] and C. David Bertelsen[4,5]

Current Biology *30*, 432–441, February 3, 2020

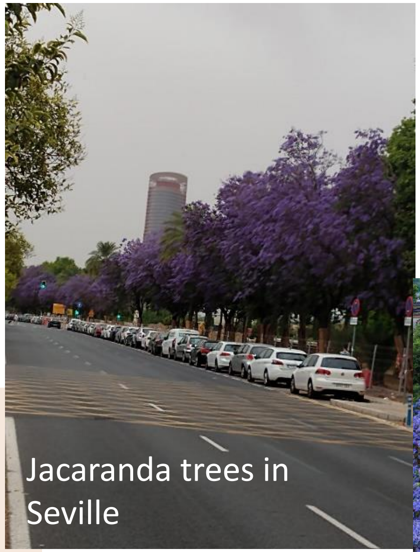
5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

V. networking- develop citizen science initiatives and monitoring networks to collect more comparative data over large special scales;

Citizen Science – Citizen Phenology

Phenological monitoring and citizen science

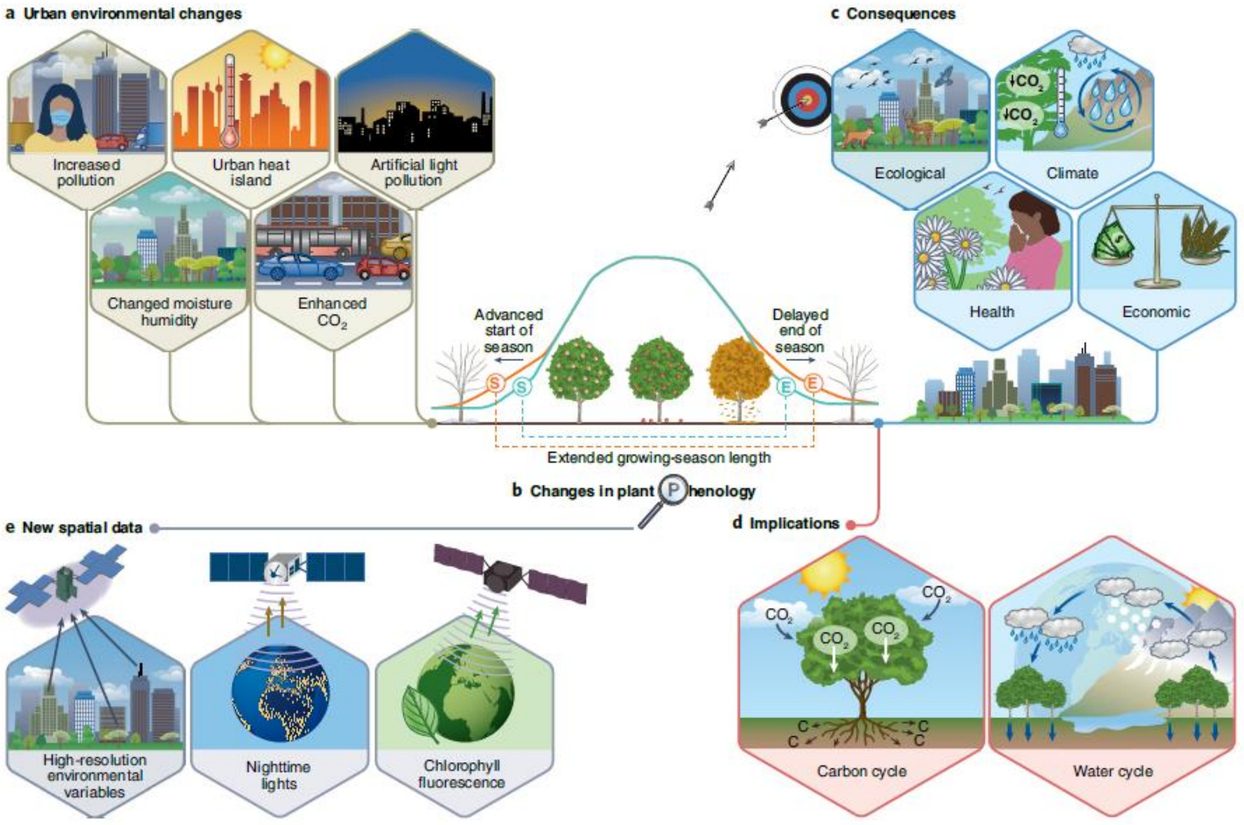


5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

V. networking- develop citizen science initiatives and monitoring networks to collect more comparative data over large special scales;

Understanding urban plant phenology for sustainable cities and planet



Yuyu Zhou
Department of Geological and Atmospheric Sciences, Iowa State University, Ames, IA, USA.
e-mail: yuyuzhou@iastate.edu

Published online: 6 April 2022
https://doi.org/10.1038/s41558-022-01331-7

5. Challenges: detect temporal responses in highly diverse ecosystems

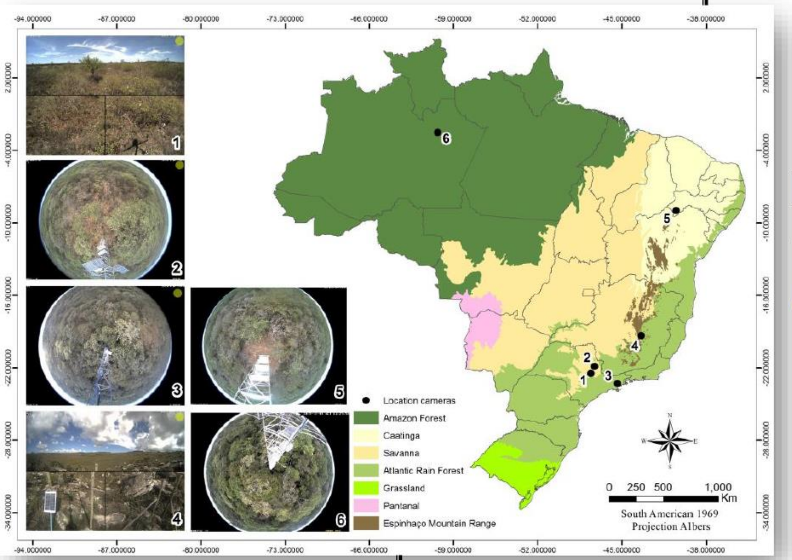
Phenology Lab

V. networking- develop citizen science initiatives and monitoring networks to collect more comparative data over large special scales;

The *e-phenology* network

(examples of applications)

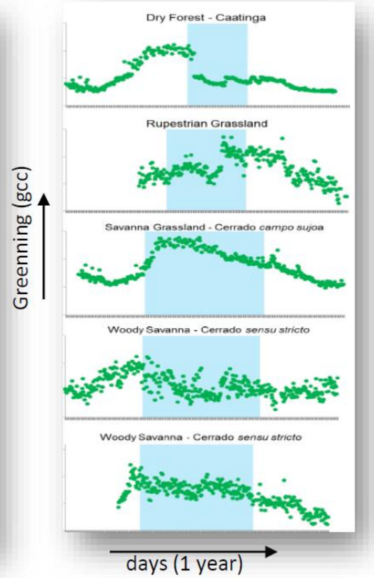
PHENOCAMS NETWORK IN THE TROPICS (BRAZIL)



e-Phenology Network main goals:

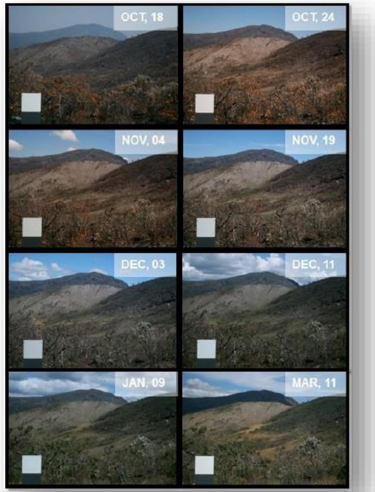
- Increase knowledge about phenological patterns for the tropics, principally for seasonal tropical vegetation
- Investigate drivers triggering leaf phenophases at multi sites
- Contribute for management and conservation of threatened ecosystems and biodiversity.

Multi sites monitoring

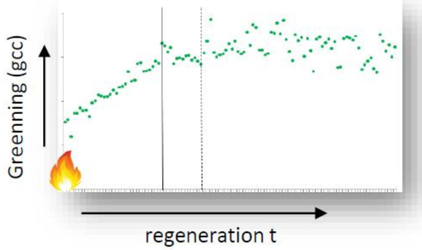


Monitoring sites along a gradient of seasonality

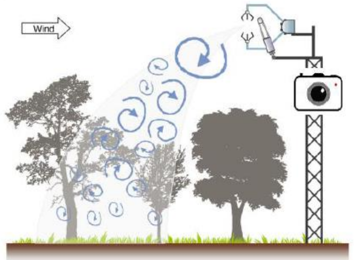
Post-fire Vegetation recovery



Monitoring sites of fire prone vegetations at Serra do Cipó National Park, Minas Gerais, Brazil.



Leaf phenology X ecosystem-scale photosynthesis



carbon fluxes

↑

photosynthesis

↑

leaf phenophases

5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

VI. experiments - impose climate scenarios to tropical plants (e.g. CO2 enrichment – FACE, drought experiments, transplants);

FACE experiments aim to investigate how terrestrial ecosystems respond to elevated atmospheric CO2 concentration

AMAZONFACE

Assessing the effects of increased atmospheric CO_2 on the ecology and resilience of the Amazon forest.

NEWS IN FOCUS

Experiment aims to steep rainforest in carbon dioxide

Sensor-studded plots in the Amazon forest will r

NATURE | VOL 496 | 25 APRIL 2013

PERSPECTIVE — nature climate change

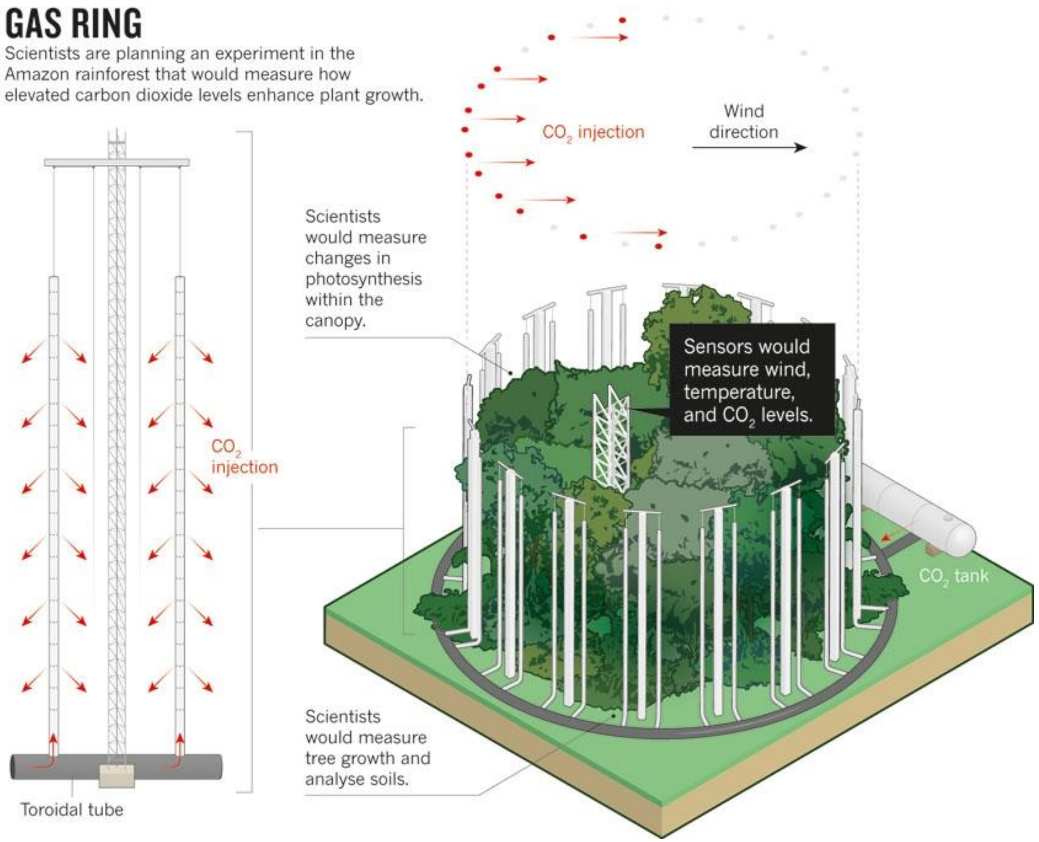
PUBLISHED ONLINE: 21 MAY 2015 | DOI: 10.1038/NCLIMATE2621

Using ecosystem experiments to improve vegetation models

Belinda E. Medlyn[1,2*], Sönke Zaehle[3], Martin G. De Kauwe[1], Anthony P. Walker[4], Michael C. Dietze[5], Paul J. Hanson[4], Thomas Hickler[6], Atul K. Jain[7], Yiqi Luo[8], William Parton[9], I. Colin Prentice[1,10], Peter E. Thornton[4], Shusen Wang[11], Ying-Ping Wang[12], Ensheng Weng[13], Colleen M. Iversen[4], Heather R. McCarthy[8], Jeffrey M. Warren[4], Ram Oren[14,15] and Richard J. Norby[4]

Info: http://amazonface.inpa.org.br/

Dr David Lapola – UNICAMP Brazil

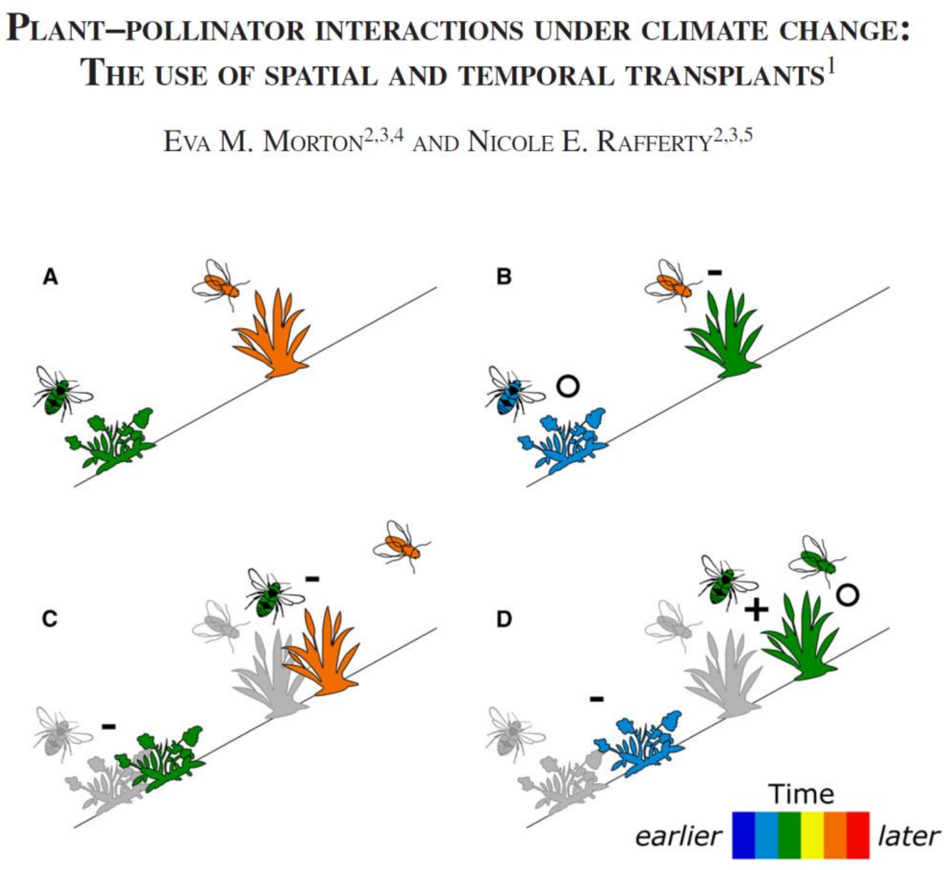


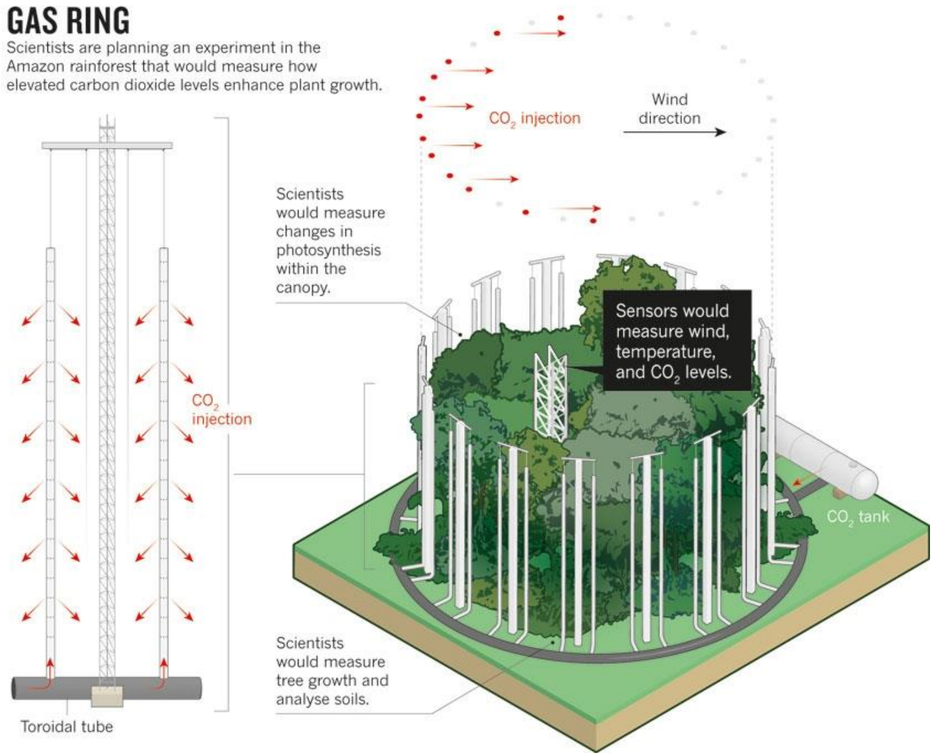
5. Challenges: detect temporal responses in highly diverse ecosystems

VI. experiments - impose climate scenarios to tropical plants (e.g. CO_2 enrichment – FACE, drought experiments, transplants);

AMAZONFACE

Assessing the effects of increased atmospheric CO_2 on the ecology and resilience of the Amazon forest.





5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

scientific reports

VII. new technologies which may maximize our understanding at large scales

Check for updates

OPEN **The flowering of Atlantic Forest *Pleroma* trees**

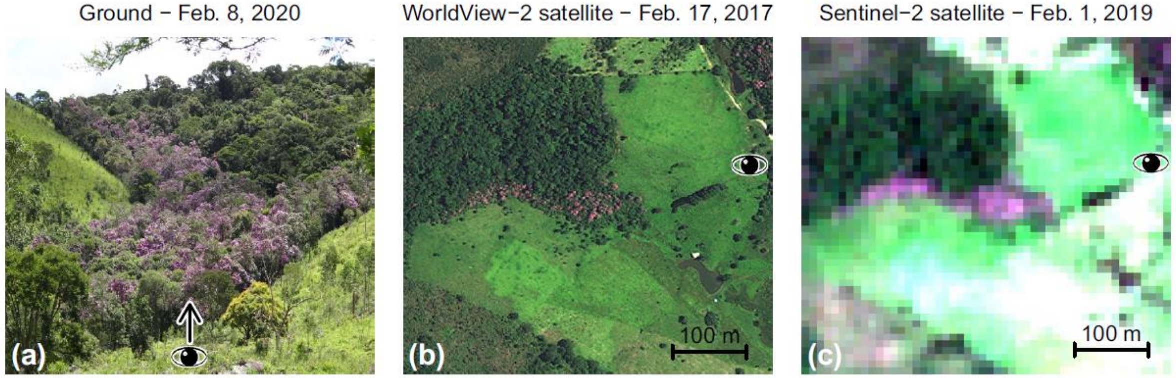


Figure 1. Same scene of a blooming *Pleroma pulchra*-dominated forest taken from different points of view: from the ground (**a**), from the satellite WorldView-2 at a very high spatial resolution of 50 cm (**b**) and from the satellite Sentinel-2 at a sp
and longitude – 45.18446
other parts of the forest w
images and a history of th
DigitalGlobeFoundation.

High resolution images are allowing to map individuals or groups of the same tree species, at special and temporal scales.

Recent work uses **high-resolution images with 10 m** of spatial resolution to map the ***Pleroma*** trees (**Sentinel-2 satellites - Copernicus Sentinel-2)**. The **frequency** of revisit is of **five days** at the Equator and enables to **monitor Earth's surface changes.** The blooming of *Pleroma* forest patches are visible, their colours rendering them detectable and separable from the forest and other landcover (Fig. 1c)**, showing local landscape changes and plant phenology shifts**.

Further studies and land validations may allow detect forest regeneration patterns amd climate-related changes on phenology

5. Challenges: detect temporal responses in highly diverse ecosystems

Phenology Lab

VII. new technologies which may maximize our understanding at large scales

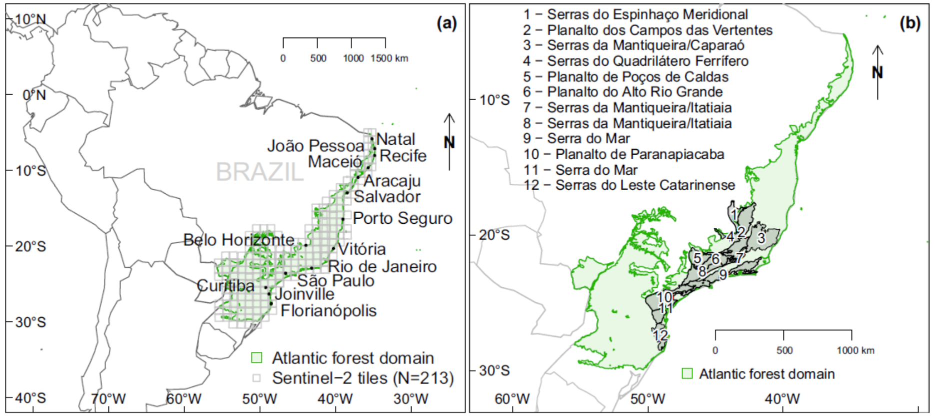


Figure 2. Geographical location of the Atlantic Forest domain in green, extents of the 213 Sentinel-2 tiles in light grey and main cities within the domain (a). Geographical locations and local names of principal mountain chains and high plateaus of the Atlantic Forest domain, geomorphological units respectively named *Serras* and *Planalto* in Portuguese[33] (b).

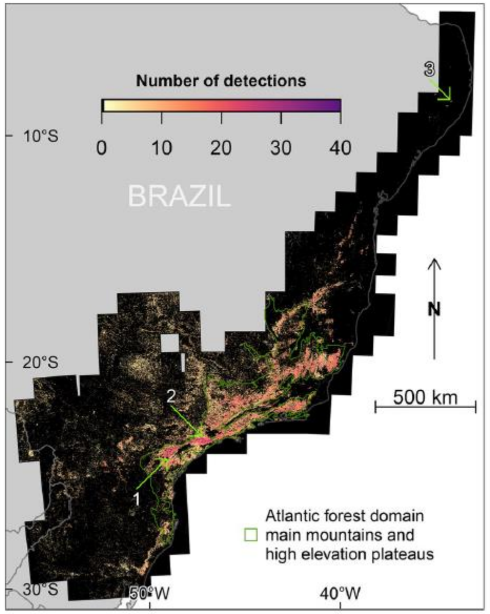


Figure 3. Pink and magenta blossoms detections in the Atlantic Forest

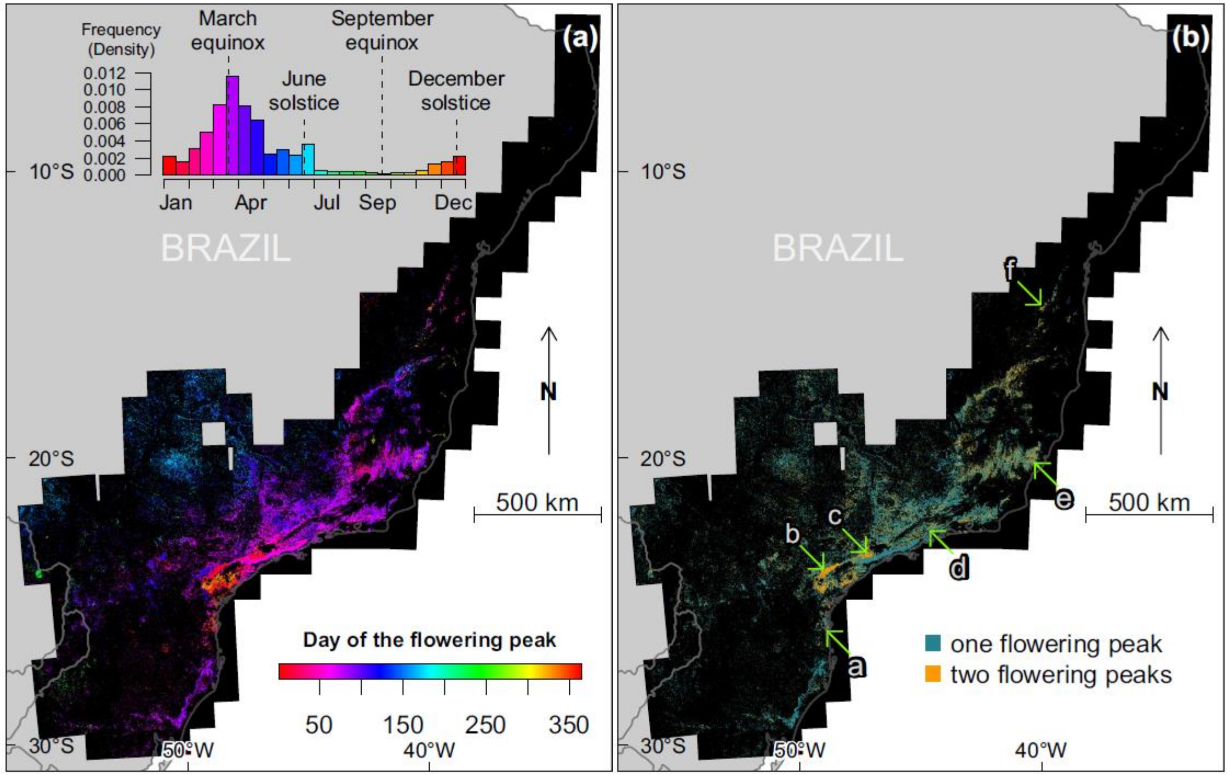


Figure 7. Day of the flowering peak (**a**) estimated from the mean monthly detection time series and Fourier transform signal decomposition (see Methods). For the pixel showing two flowering peaks in per year in (**a**), only the highest peak is represented. Number of flowering peaks per year (**b**). Subset images of locations indicated by arrows are given in Fig. 8. The flowering peaks on the map are mainly from trees of the genus *Pleroma* and in a lesser proportion from large trees of the genus *Handroanthus* that can be also detected.

Ongoing research collaboration

Evaluation of plant biodiversity in Andalousia, from genes to ecosystems (BIOVEGAN*)

1. Floristic diversity: environmental correlates
2. Floristic diversity: historical (phylogenetic) correlates
3. Conservation biology: natural/national parks as biodiversity museums. Spatial phylogenetics in high priority reserves
4. Conservation biology: incorporating phylogenies to rarity measurements in threatened floras
5. The community dimension. Mutualistic and antagonistic biological interactions as biodiversity builders: pollination and galls
6. The population dimension: DNA barcoding of key threatened species

* Funded by Andalousian PAIDI2020 programme, with participation of Brazilian researchers

Phenology Lab

6. Final remarks

Evolutionary convergence between Mediterranean and Campo Rupestre type ecosystems in the context of OCBIL theory*

Ongoing research collaboration

1. Seasonal climates
2. Poor soils
3. Fire frequency and intensity
4. Isolated floristic pools
5. Megadiverse regions

→

1. Similar biodiversity spatial patterns
2. Similar ecophysiological and demographic patterns
3. Different modes of reproduction
4. Similar patterns of differentiation/diversification?

FAPESP

L. Gustavo Dias

J.L. García Meléndez, Junta de Andalucía

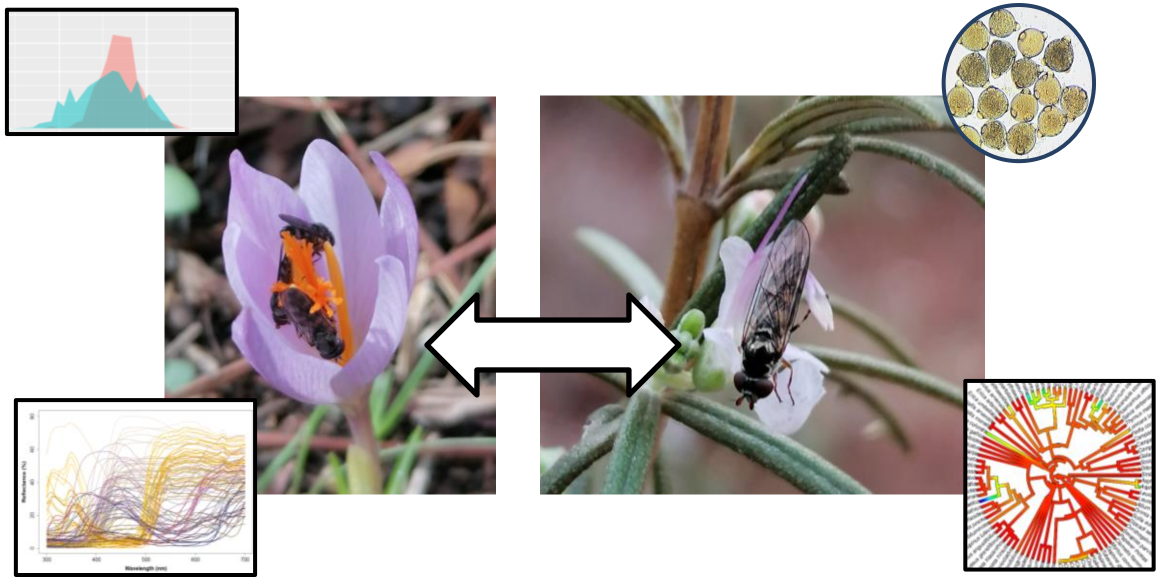
T. Freibott, Wikipedia, Creative Commons

*OCBIL: Old, Climatically-Buffered, Infertile Landscapes

6. Final remarks

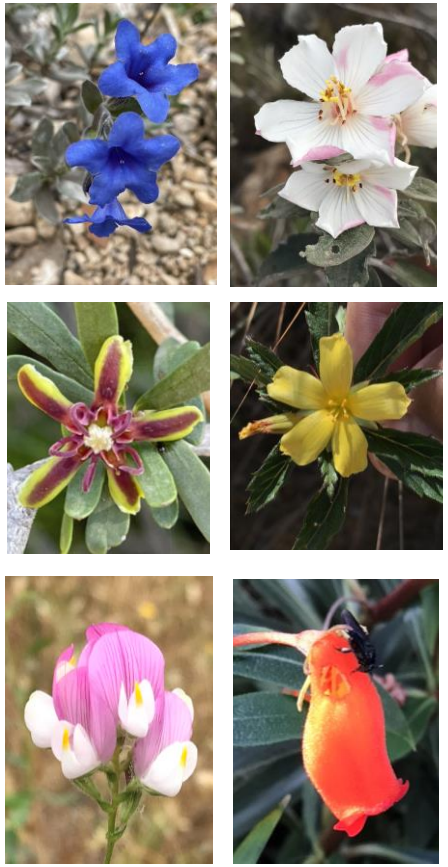
Changes in plant-pollinator assembly as a result of climate change

- ✓ *Flowering and pollinator phenology: in high diverse communities (1986-2021)*
- ✓ *Plant synchrony: inter- and intraspecific patterns*
- ✓ *Floral and pollinator traits influencing plant-pollinator interactions*
- ✓ *Phylogenetic constraints in plant and pollinator phenology*



* Funded by University of Seville, PPITUS programme, US-UNESP

Reconciling patterns and processes in flower color evolution (RECOLOR)



Shared biotic/abiotic factors

- High plant-animal biodiversity
- High plant-animal interactions
- High solar radiation and seasonal drought stress

Non shared factors

- Historical events
- Plant Species composition
- Pollinator Fauna

PATTERNS

Global

Local

Biotic &

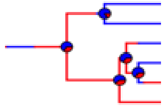
Diversity of pollinators
Plant richness
Background

Abiotic

Solar radiation
Drought
Temperature

PROCESSES

Interspecific



Intraspecific

Biotic

Competence
Facilitation
Mimicry

Abiotic

Pollen protection

* Ministry of Science and Technology, Spain Government, participation of researchers from UNESP


GRACIAS!!

The e-phenology network

Thank you

unesp

FAPESP

Phenology Lab

Universidad de Sevilla

FAPESP
MUDANÇAS CLIMATICAS

UNICAMP

RECOD
reasoning for complex data

PELD - CRSC

UFMG

University of Stirling

unesp PrInt Project

SECO: Resolving the current and future carbon dynamics of the dry tropics

The University of Edinburgh

Global Alliance Biodiversity and Climate Change
BioGATe - A multidisciplinary approach on tropical biodiversity

Caatinga-FLUX

IAG USP

CAPES

Microsoft Research

USP
Universidade de São Paulo

RIBEIRÃO PRETO

The University of Edinburgh

University of Exeter

CNPq
Conselho Nacional de Desenvolvimento Científico e Tecnológico

AMAZONFACE
Assessing the effects of increased atmospheric CO_2 on the ecology and resilience of the Amazon forest.

UNIFESP
Universidade Federal de São Paulo
1933

The NORDESTE Project

NERC Science of the Environment

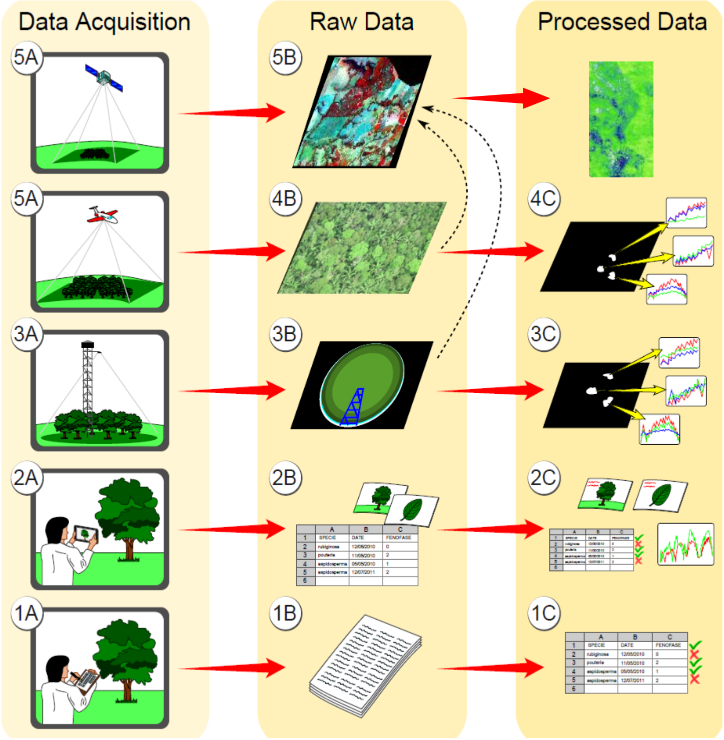
University of Leeds

The University Of Sheffield.

UKRI Natural Environment Research Council

5. Challenges: detect temporal responses in highly diverse ecosystems

VII. new technologies which may maximize our understanding at large scales (new remote sensing tools).



nature ecology & evolution
PERSPECTIVE
https://doi.org/10.1038/s41559-018-0667-3
OPEN

Towards global data products of Essential Biodiversity Variables on species traits

W. Daniel Kissling[1*], Ramona Walls[2], Anne Bowser[3], Matthew O. Jones[4], Jens Kattge[5,6], Donat Agosti[7], Josep Amengual[8], Alberto Basset[9], Peter M. van Bodegom[10], Johannes H. C. Cornelissen[11], Ellen G. Denny[12], Salud Deudero[13], Willi Egloff[7], Sarah C. Elmendorf[14,15], Enrique Alonso García[16], Katherine D. Jones[14], Owen R. Jones[17], Sandra Lavorel[18], Dan Lear[19], Laetitia M. Navarro[6,20], Samraat Pawar[21], Rebecca Pirzl[22], Nadja Rüger[6,23], Sofia Sal[21], Roberto Salguero-Gómez[24,25,26,27], Dmitry Schigel[28], Katja-Sabine Schulz[29], Andrew Skidmore[30,31] and Robert P. Guralnick[32]

Box 3 | Example of a workflow integrating plant phenology data

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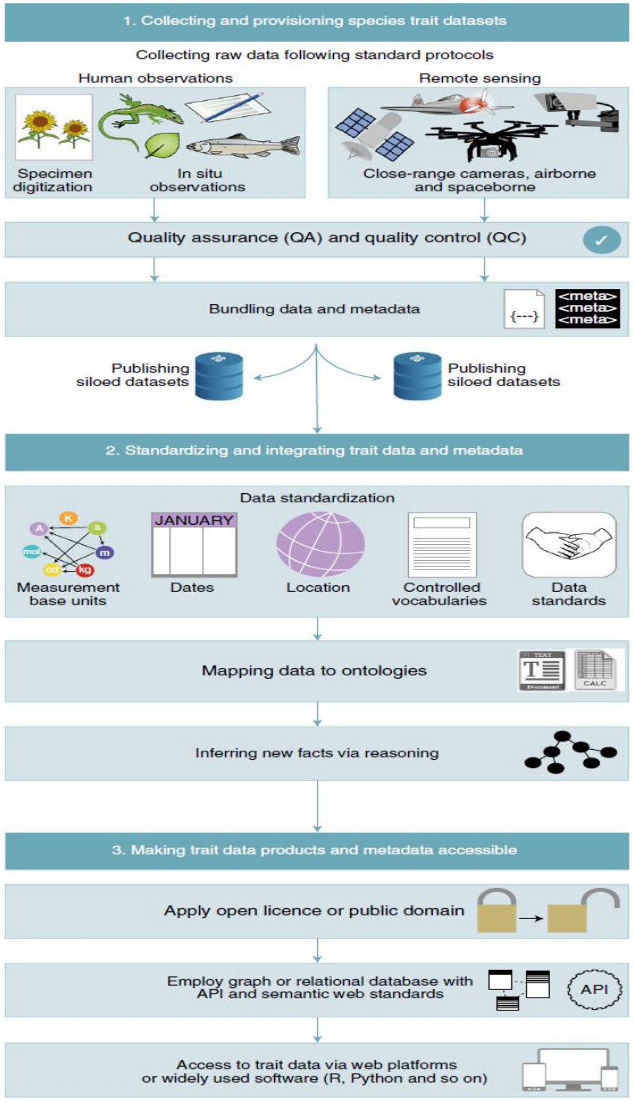


Fig. 3 | A generalized workflow for integrating species trait measurements into harmonized, open, accessible and reusable data products for EBVs. Initial species trait measurements are collected through human

5. What would be the main challenges and new avenues for tropical phenology research in the 21st century?

Phenology Lab

✓ Detect trends and shifts to climate change

Dendrochronology: reconstructing Cerrado long-term phenology

Patricia Leite

Nara Vogado

Tree Rings of Brazilian Cerrado

Dendroclimatology

Chronology

↕

Historical Climate Data

Local → Precipitation and Temperature

Global → *El Niño* (regions 1+2; 3; 3.4; 4)

Dendroecology

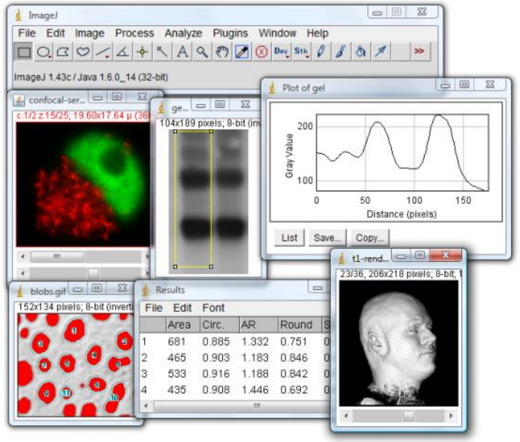
Growth rings

Management "GOL"

Dendrometer

Wood Anatomy

Phenology



5. What would be the main challenges and new avenues for tropical phenology research in the 21st century?

Phenology Lab

✓ Integrate time and space: scaling up phenology

➢ Computer e-science – big-data ecology

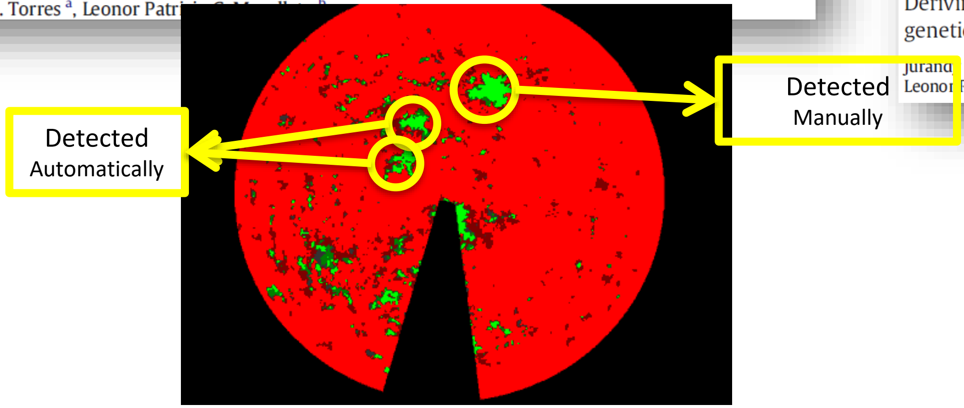

Contents lists available at ScienceDirect

Ecological Informatics

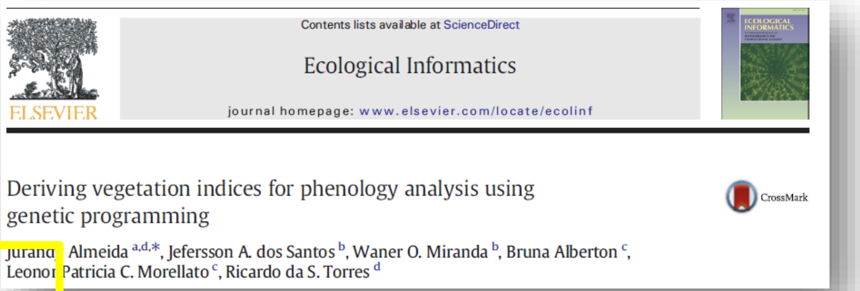
journal homepage: www.elsevier.com/locate/ecolinf

Applying machine learning based on multiscale classifiers to detect remote phenology patterns in Cerrado savanna trees

Jurandy Almeida [a,*], Jefersson A. dos Santos [a], Bruna Alberton [b], Ricardo da S. Torres [a], Leonor Patri...



e-phenology

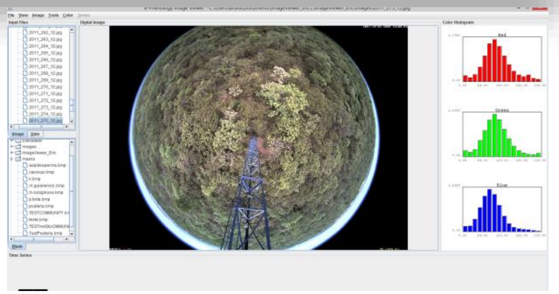

Contents lists available at ScienceDirect

Ecological Informatics

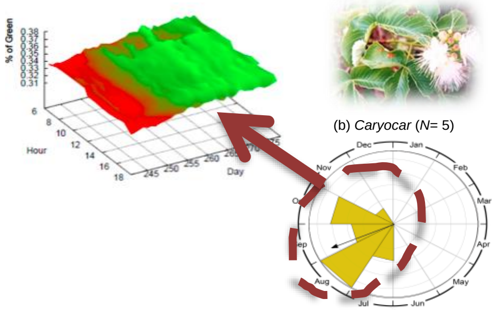
journal homepage: www.elsevier.com/locate/ecolinf

Deriving vegetation indices for phenology analysis using genetic programming

Jurandy Almeida [a,d,*], Jefersson A. dos Santos [b], Waner O. Miranda [b], Bruna Alberton [c], Leonor Patricia C. Morellato [c], Ricardo da S. Torres [d]



PhenoViewer Software



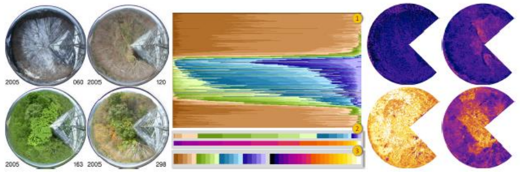
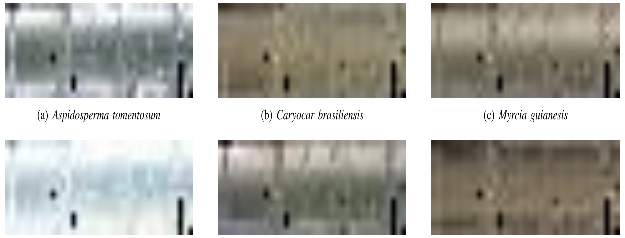


Fig. 1. The 365 images collected for the year 2005 are illustrated on the left by sample images captured at days 60, 120, 163, and 295. These images are used to construct a Chronological Percentage Map. First, a mask is used to remove the support for the camera. Next, for each processed image of one given day, a percentage distribution is built from the green chromatic coefficient (g_{cc}) computed for every pixel. The g_{cc} is one among other image attributes used by phenologists to evaluate chromatic variations within an image, with emphasis on the green channel. The percentage distribution for each image is used to scale a predefined color-scale (3), resulting in a percentage map (2) for each image. The chronological stack of percentage maps defines the CPM (1). The leafing period in this dataset is clearly identified as the colored region in the middle of (1). On the right, we show the results of mapping the color map to the original sample images shown on the left, which allows: (a) to inspect the variation of g_{cc} in different parts of the image, an important step towards the identification of different plant species; and (b) to perform a comparative analysis of images captured at different time periods of leafing.



(a) *Aspidosperma tomentosum* (b) *Caryocar brasiliensis* (c) *Myrcia guianensis*

(d) *Miconia rubiginosa* (e) *Pouteria ramiflora* (f) *Pouteria torta*

5. What would be the main challenges and new avenues for tropical phenology research in the 21st century?

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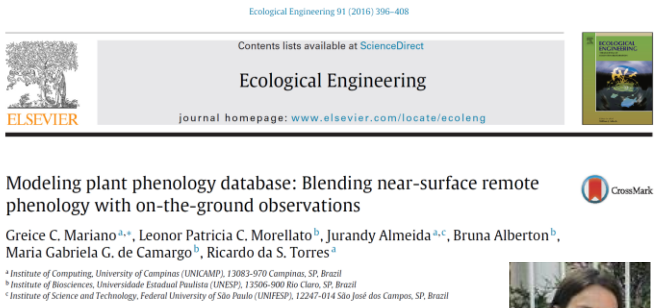
G.C. Mariano et al. / Ecological Engineering 91 (2016) 396–408

Phenology Databases


Ecological Engineering 91 (2016) 396–408

Contents lists available at ScienceDirect

Ecological Engineering

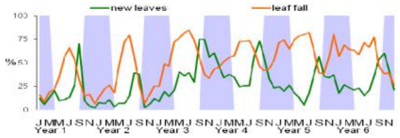
journal homepage: www.elsevier.com/locate/ecoleng

ELSEVIER

Modeling plant phenology database: Blending near-surface remote phenology with on-the-ground observations

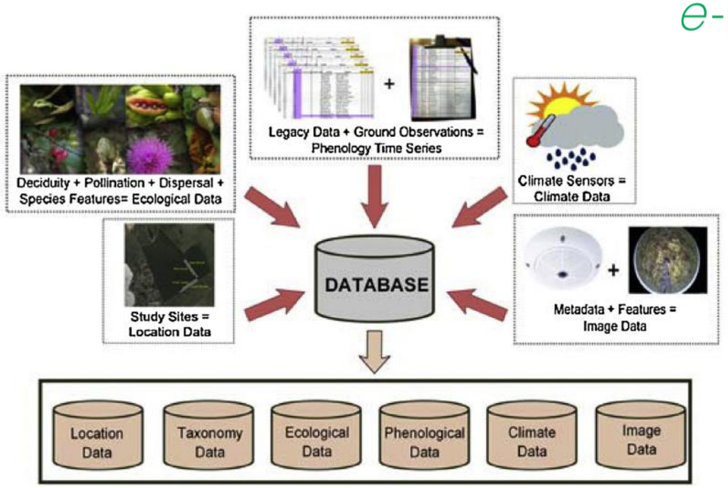
Greice C. Mariano[a,*], Leonor Patricia C. Morellato[b], Jurandy Almeida[a,c], Bruna Alberton[b], Maria Gabriela G. de Camargo[b], Ricardo da S. Torres[a]

[a] Institute of Computing, University of Campinas (UNICAMP), 13083-970 Campinas, SP, Brazil
[b] Institute of Biosciences, Universidade Estadual Paulista (UNESP), 13506-900 Rio Claro, SP, Brazil
[c] Institute of Science and Technology, Federal University of São Paulo (UNIFESP), 12247-014 São José dos Campos, SP, Brazil

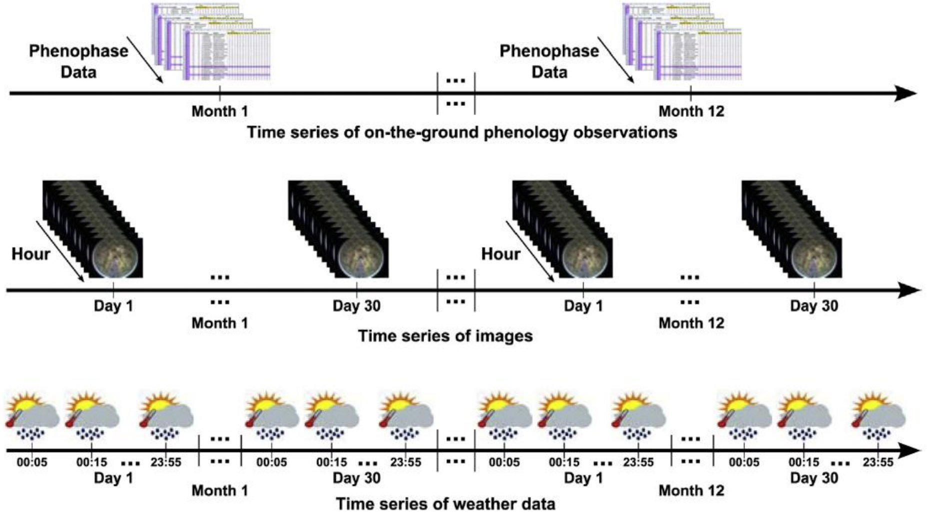


Cerrado savanna (Morellato, LPC)

e-phenology



(a) *Overview of the proposed database*



(b) *Types of temporal data considered in e-phenology Project*

5. What would be the main challenges and new avenues for tropical phenology research in the 21st century?

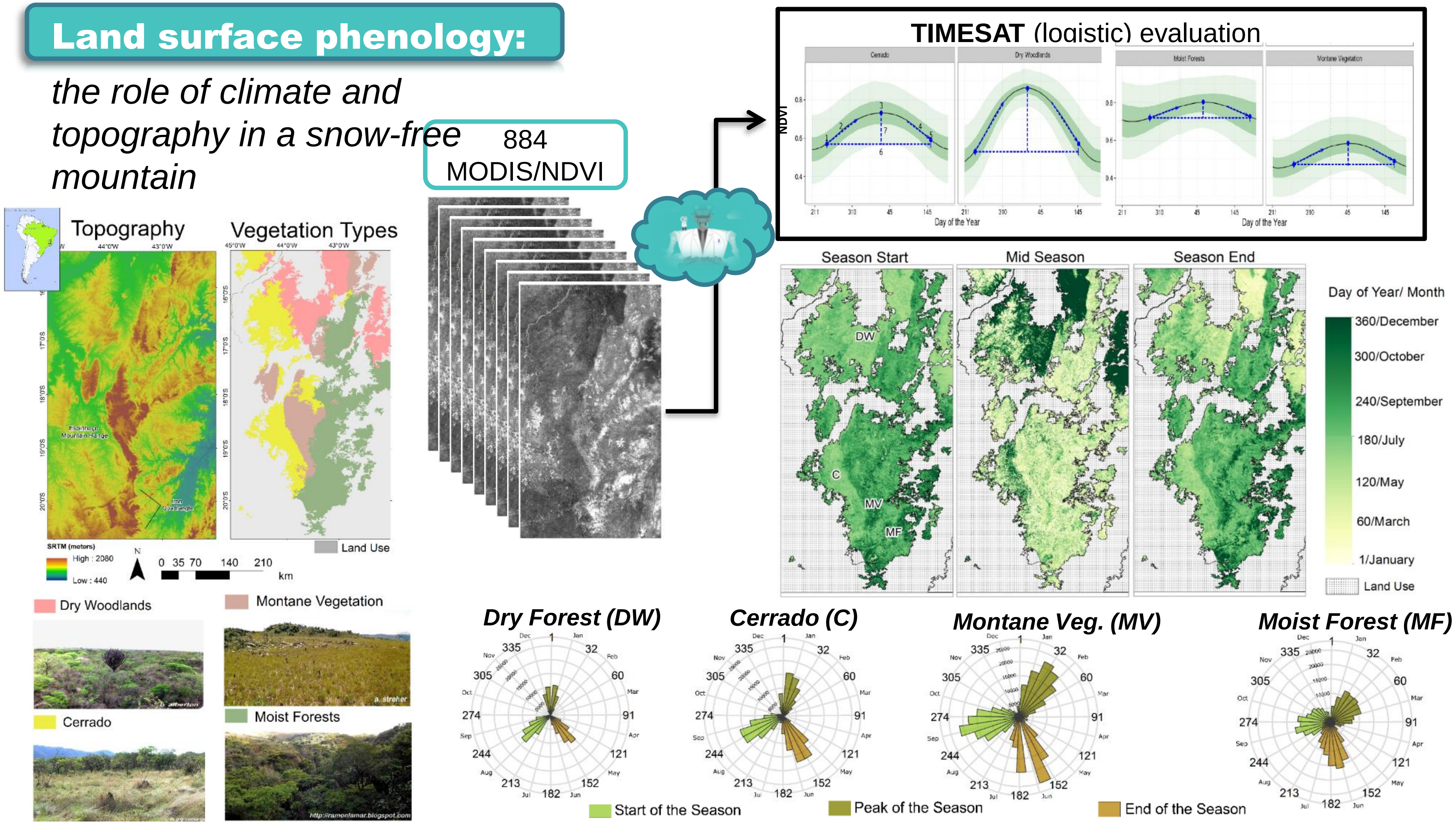
Phenology Lab

✓ Integrate time and space: scaling up phenology

e-phenology

Land surface phenology:

the role of climate and topography in a snow-free mountain



Streher et al. 2017 Ecosytems on line

Phenology Lab

- **Citizen science and Education**
- ✓ The Globe
- ✓ Local initiatives

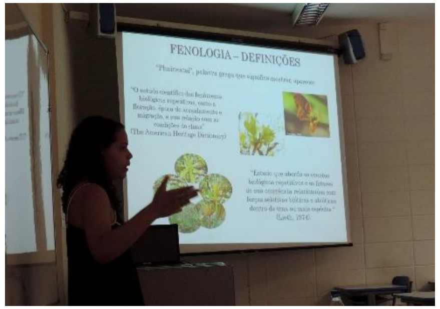
Contents lists available at ScienceDirect

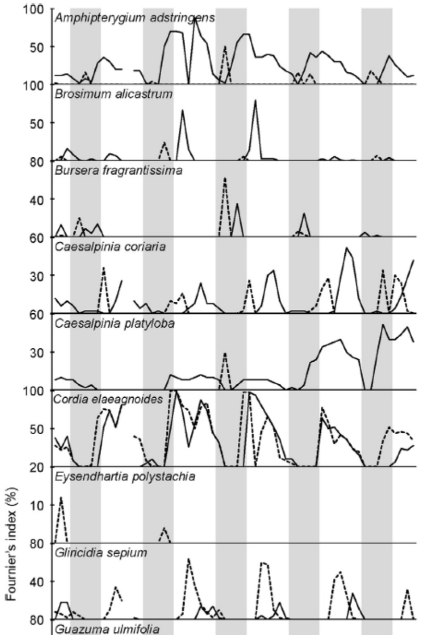
Forest Ecology and Management

journal homepage: www.elsevier.com/locate/foreco

Reproductive phenology of useful Seasonally Dry Tropical Forest trees: Guiding patterns for seed collection and plant propagation in nurseries

Adriana L. Luna-Nieves[a], Jorge A. Meave[b], Leonor Patrícia Cerdeira Morellato[c], Guillermo Ibarra-Manríquez[a,*]





Citizen Science – *Citizen Phenology*

RBCC
Rede Brasileira de Ciência Cidadã
2021

SiBBr SISTEMA DE INFORMAÇÃO SOBRE A BIODIVERSIDADE BRASILEIRA

Citizen science projects take place in several areas, including pollination by bees.

- ✓ We start a pilot project on *Citizen Phenology* at the campus of UNESP Rio Claro, inviting people to observe plants
- ✓ The initiative will expand the Campus Phenology project stated in 2002 but focused mainly on undergrad students

Contact Amanda: amandaeburneom@gmail.com


VAMOS FAZER CIÊNCIA E OBSERVAR A NATUREZA JUNTOS?
PROJETO DE EXTENSÃO
"FENOLOGIA CIDADÃ" ANUNCIA:
QUER APRENDER E COLABORAR NO DESENVOLVIMENTO DE UM PROJETO
VOCÊ GOSTA DE ESTAR EM CONTATO COM A NATUREZA, DE OBSERVAR AS PLANTAS,


NATUREZA JUNTOS?
PROJETO DE EXTENSÃO
"FENOLOGIA CIDADÃ" ANUNCIA:
QUER APRENDER E COLABORAR NO DESENVOLVIMENTO DE UM PROJETO CIENTÍFICO?
VOCÊ GOSTA DE ESTAR EM CONTATO COM A NATUREZA, DE OBSERVAR AS PLANTAS, SUAS FLORES E SEUS FRUTOS?
SERÁ IMPLEMENTADO UM PROJETO DE CIÊNCIA CIDADÃ, A "FENOLOGIA CIDADÃ", PARA MONITORAR ÁRVORES PRESENTES NO CAMPUS DA UNESP DE RIO CLARO. PARA ISSO, PRECISAMOS DA SUA AJUDA!
QUEM PODE PARTICIPAR?
TEMOS 25 VAGAS PARA MORADORES DE RIO CLARO MAIORES DE 18 ANOS. HORÁRIO FLEXÍVEL DE ACORDO COM A DISPONIBILIDADE DE CADA UM!
INSCRIÇÕES PELO GOOGLE FORMS NA DESCRIÇÃO DA NOSSA CONTA DO INSTAGRAM.
REALIZAÇÃO:
unesp
APOIO:
CNPq
PROEX
@FENOLOGIA.CIDADA_RC
FENOLOGIACIDADA.RC@GMAIL.COM

4 QUALITY EDUCATION

13 CLIMATE ACTION

15 LIFE ON LAND

nature ecology & evolution

PERSPECTIVE

https://doi.org/10.1038/s41559-018-0667-3

OPEN

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W. Daniel Kissling[1]*, Ramona Walls[2], Anne Bowser[3], Matthew O. Jones[4], Jens Kattge[5,6], Donat Agosti[7], Josep Amengual[8], Alberto Basset[9], Peter M. van Bodegom[10], Johannes H. C. Cornelissen[11], Ellen G. Denny[12], Salud Deudero[13], Willi Egloff[7], Sarah C. Elmendorf[14,15], Enrique Alonso García[16], Katherine D. Jones[14], Owen R. Jones[17], Sandra Lavorel[18], Dan Lear[19], Laetitia M. Navarro[6,20], Samraat Pawar[21], Rebecca Pirzl[22], Nadja Rüger[6,23], Sofia Sal[21], Roberto Salguero-Gómez[24,25,26,27], Dmitry Schigel[28], Katja-Sabine Schulz[29], Andrew Skidmore[30,31] and Robert P. Guralnick[32]

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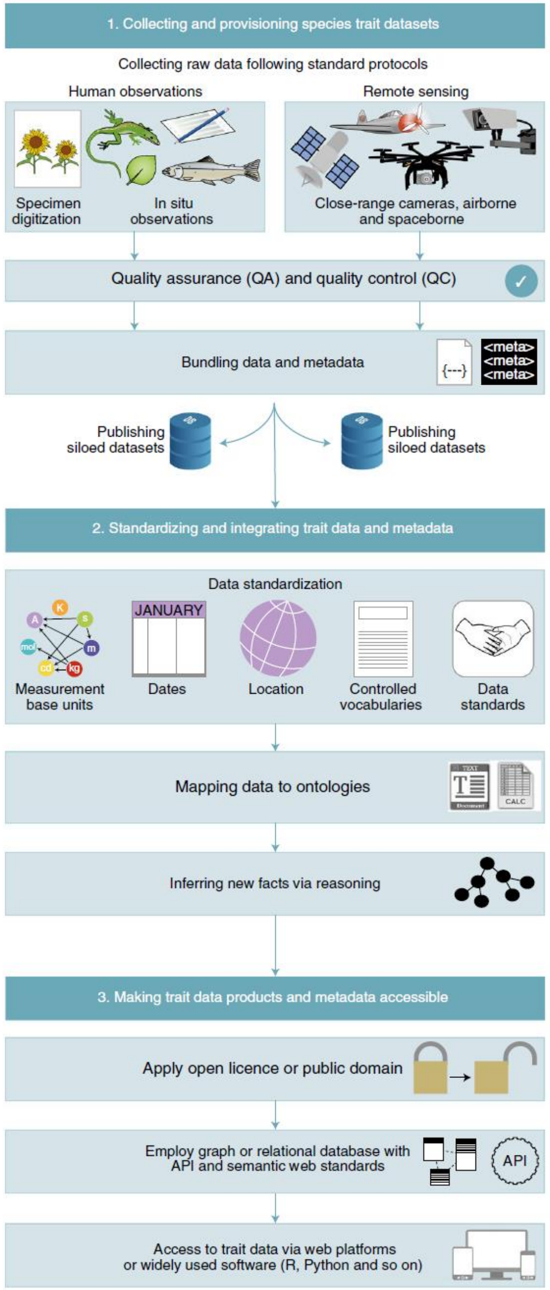

Fig. 3 | A generalized workflow for integrating species trait measurements into harmonized, open, accessible and reusable data products for EBVs. Initial species trait measurements are collected through human

Phenology Lab

3. Tropical/South Hemisphere phenology trends and shifts

✓ What is the status of contemporany tropical phenological research

Timeline of the development of tropical and temperate phenology research over the past 200 years

TEMPERATE PHENOLOGY

- Pre 1700: Some private family phenology and weather records
- 1800: Government weather records begin. Naturalist societies form. Scientific records for spring onset phenology
- 1900: Long term records begin to show change in spring onset in northern hemisphere. Global climate changes start to be investigated
- 1950: First research results links warming temperatures and shifts in spring phenology. Research is led by plant and environmental sciences.
- 1975: Research attributes early spring phenology to climate change. General efforts to compile long-term phenological data sets and weather across Europe Citizen science networks are created.
- 2000: Phenology is recognized as a key discipline for detection and monitoring effects of climate change (IPCC 2007) Remote sensing techniques become widespread as a proxy for leaf phenology across biomes and show feedbacks to local weather patterns. Near-remote phenology with digital cameras starts and networks are created Citizen science creates huge databanks on temperate ecosystems.
- 2010: Phenology is identified as an Essential Biodiversity Variable. Recovered Herbarium records show long-term changes and shifts in North America.
- 2020: Remote sensing enables tropical and temperate phenology research to be compared at large scales; Heavy emphasis on global trends in leafing Citizen science data largely collected and analysed focusing on global change research.

Pre 1700 — 1800 — 1900 — 1950 — 1975 — 2000 — 2010 — 2020

- Pre 1700: No systematic records for phenology or weather
- 1800: No systematic records for phenology or weather
- 1900: Some herbarium records recovered, few weather records. Observations and records from early naturalists
- 1950: Botanists begin first systematic plant phenology studies. Animal biologists begin studies of flower and fruit resources
- 1975: Phenology of tropical trees shown to be responding to climate variables at sites in South and Central America. Reviews addressing tropical phenology
- 2000: Long-term data sets in, Africa and Asia investigated for climate responses Serious gaps in weather data are identified for Africa. Long-term phenology research: new sites and networks
- 2010: Digital cameras, satellite data, climate models and new analytical tools become available for tropical phenology. Collection of empirical data increases Phenology is linked to biodiversity conservation and ecological restoration Reviews and synthesis of tropical phenology and climate change
- 2020: **The future:** Citizen science and phenology networks (ephenology) Long term funding programs Improved weather data Field experiments (Amazon Face) Cross-continental comparisons, New methods and protocols

TROPICAL PHENOLOGY

Albernethy et al. (2018) Current Issues in Tropical Phenology: a synthesis. Biotropica