

# Christopher D. Muir

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Born: July 2, 1984 — Reston, Virginia  
Nationality: USA

## Current position

2019 -

*Assistant Professor*

School of Life Sciences

University of Hawai'i at Mānoa

Honolulu, Hawai'i, USA

Graduate Faculty member in Ecology, Evolution, and Conservation Biology program  
Cooperating Graduate Faculty member of Tropical Plant and Soil Sciences

## Areas of specialization

Evolutionary Biology; Plant Ecophysiology; Quantitative Biology

## Past Appointments

2017 - 2018

*Scientist* – Biological Statistics for Global Agronomy

Novozymes Inc.

Durham, North Carolina, USA

Novozymes develops biological solutions to improve yield and make crops more sustainable. I lead data science for the global field trial program to commercialize new agricultural products. I developed computational workflows to process, analyze, and interpret large datasets for stakeholders.

2017 *Computational Biologist*  
Poisson Consulting Ltd.  
Vancouver, Canada

I helped conserve natural resources in Canada through statistical consulting for industrial and government clients. I developed open source software in R to analyze and make sense of large ecological datasets using Bayesian statistical approaches.

2015 - 2017 *Postdoctoral Researcher*  
Departments of Botany and Zoology  
University of British Columbia  
Vancouver, Canada

2013 - 2015 *Biodiversity Postdoctoral Fellow*  
Biodiversity Research Centre  
University of British Columbia  
Vancouver, Canada

As a postdoctoral researcher I studied fundamental problems in the evolution and ecology of biodiversity. My funding provided extraordinary independence to develop and pursue my research interests in evolutionary physiology using theory, computational approaches, phylogenetic comparative methods, and field experiments.

#### Education

2013 PhD in Evolutionary Biology (Geology minor)  
Indiana University  
Bloomington, Indiana, USA

2006 BS in Biology (Economics minor)  
College of William and Mary  
Williamsburg, Virginia, USA

#### Grants, Awards, & Fellowships

##### Major Grants and Fellowships

##### **Awarded**

2022-2025 NSF DEB Bridging Ecology and Evolution

“Collaborative Research: BEE: Integrating evolutionary genetics and population ecology to detect contemporary adaptation to climate change across a species range” with lead PI Seema Sheth, PI **Muir**, PI Lluvia Flores-Renteria, PI Jason Sexton, and PI Jeff Diez. \$1,452,695 (\$220,404 to UHM)

2020–2022 NSF EPSCoR RII Track 4

“Penetrating the inner lives of leaves to breed water-wise crops using math, 3D imaging, and experiments.” PI **Muir**, \$133,971

2013 – 2015 Biodiversity Postdoctoral Fellowship (UBC, \$100,000)

2008 – 2012 NSF Graduate Research Fellowship (\$120,000)

### Awards



2020 Emerging Leader Award (Botanical Society of America)  
Early Career Open Science Award (*Annals of Botany PLANTS*)


### Small Grants and Fellowships



2022 UHM UROP Faculty Mentoring Award (\$9,380)  
2021 SEED Inclusion, Diversity, Equity, Access and Success (\$1,000)  
2020 Test proposal at the Paul Scherrer Institute, Switzerland (\$22,000)  
UHM UROP Faculty Mentoring Award (\$4,452)  
UHM Office of Vice Chancellor of Research Faculty Travel Award (\$1,779)  
2019 UHM Office of Vice Chancellor of Research Faculty Travel Award (\$2,000)  
2012 – 2013 Payne Dissertation Year Fellowship (IU, \$20,000)  
2011 Evo-Devo-Eco Network Research Exchange Experience (\$3000)  
2010 Rosemary Grant Award from the Society for the Study of Evolution (\$2450)  
2008 Charles B. Heiser Graduate Fellowship in Plant Evolution (IU, \$1000)  
2008 Indiana University Fellowship (\$10,000)  
2008 METACYT Fellowship (IU, \$10,000)  
2007 Society for Systematic Biology Graduate Research Award (\$1650)


Publications (34 peer-reviewed publications; 18 as (co-)first or corresponding author; 2 in-review)



### Peer-reviewed Publications

2022 **Muir CD\***, MÀ Conesa, J Galmés, VA Pathare, P Rivera, R López, T Terrazas, D Xiong. Packing limits and developmental integration are not sufficient to explain stomatal anatomical evolution in flowering plants. Accepted at *The American Naturalist*. **Rx** preprint  code  data




**Muir CD\***. Technical comment on ‘Negative-assortative mating for color in wolves’. Accepted at *Evolution*. **Rx** preprint  code

**Muir CD\***, CL Van Den Elzen, AL Angert. Selection on early survival does not explain germination rate clines in *Mimulus cardinalis*. Accepted at *The American Journal of Botany*. **Rx** preprint  code  data



Gorné LD, *et al.* (author 6 of 13). The acquisitive-conservative axis of leaf trait variation emerges even in homogeneous environments. *Annals of Botany* 129(6):709-722.  [article](#)




Kajihara KT, CP Egan, SOI Swift, CB Wall, **CD Muir**, NA Hynson. Core arbuscular mycorrhizal fungi are predicted by their high abundance occupancy relationship while host specialists are rare and geographically structured. *New Phytologist* 234(4): 1464-1476.  [article](#)  [code](#)



2021


Stinziano JR, C Roback, D Gamble, BK Murphy, PJ Hudson, **CD Muir\***. Principles of resilient coding for plant ecophysiologicalists. *AoB PLANTS* 13(5):plab059.  [article](#)  [preprint](#)  [cran](#) (\* corresponding author)

Neto-Bradley BM, **CD Muir**, J Whitton, MW Pennell. Phylogenetic history of vascular plant metabolism revealed using a macroevolutionary common garden. *Proc R Soc B* 288: 20210605.  [article](#)  [code](#)  [data](#)




Egan CP, J Koko, **CD Muir**, G Zahn, SOI Swift, AS Amend, NA Hynson. Restoration of the mycobiome of the endangered Hawaiian mint *Phyllostegia kaalaensis* increases its pathogen resistance. *Fungal Ecology* 52: 101070.  [article](#)  [code](#)

Bontrager M, T Usui, JA Lee-Yaw, DN Anstett, HA Branch, AL Hargreaves, **CD Muir**, AL Angert. Adaptation across geographic ranges is consistent with strong selection in marginal climates and legacies of range expansion. *Evolution* 75: 1316-1333.  [article](#)  [preprint](#)  [data](#)

Nelson TC\*, **CD Muir\***, A Stathos\*, DD Vanderpool, K Anderson, AL Angert, L Fishman. Quantitative trait locus mapping reveals an independent genetic basis for joint divergence in leaf function, life-history, and floral traits between scarlet monkeyflower (*Mimulus cardinalis*) populations. *American Journal of Botany* 108: 844-856.  [article](#)  [preprint](#) (\* equal contribution)


Richardson AD, DM Aubrecht, D Basler, K Hufkens, **CD Muir**, L Hanssen. Developmental changes in the reflectance spectra of temperate deciduous tree leaves, and implications for thermal emissivity and leaf temperature. *New Phytologist* 229: 791-804.  [article](#)

2020


**Muir CD**. A stomatal model of anatomical tradeoffs between gas exchange and pathogen colonization. *Frontiers in Plant Science* 11: 518991.  [article](#)  [preprint](#)  [code](#)

Conesa MÀ, **CD Muir**, A Molins, J Galmés. Stomatal anatomy coordinates leaf size with Rubisco kinetics in the Balearic *Limonium*). *AoB PLANTS*. 12: plz050.

 [article](#)  [code](#)




Kattge J *et al.* (author 447 of 724). TRY plant trait database - enhanced coverage and open access. *Global Change Biology* 26: 119-188.  [article](#)





2019 **Muir CD.** tealeaves: an R package for modelling leaf temperature using energy budgets. *AoB PLANTS*. 11: plz054.  [article](#)  [preprint](#)  [code](#)  [cran](#)





Lowry DB *et al.* (author 23 of 37). The case for the continued use of the genus name *Mimulus* for all monkeyflowers. *Taxon* 68: 617-623.  [article](#)


**Muir CD.** Is amphistomy an adaptation to high light? Optimality models of stomatal traits along light gradients. *Integrative & Comparative Biology* 59: 571-584.



 [article](#)  [preprint](#)  [code](#)



Bontrager M, **CD Muir**, AL Angert. Geographic and climatic drivers of reproductive assurance in *Clarkia pulchella*. *Oecologia* 190: 59-67.  [article](#)  [preprint](#)  [code](#)

2018 **Muir CD.** Light and growth form interact to shape stomatal ratio among British angiosperms. *New Phytologist* 218: 242-52.  [article](#)  [preprint](#)  [code](#)  [data](#)

2017 **Muir CD & AL Angert.** Grow with the flow: a latitudinal cline in physiology is associated with more variable precipitation in *Erythranthe cardinalis*. *Journal of Evolutionary Biology* 30: 2189-203.  [article](#)  [preprint](#)  [code](#)  [data](#)












Conesa MÀ, **CD Muir**, EJ Roldán, A Molins, JA Perdomo, J Galmés. Growth capacity in wild tomatoes and relatives correlates with original climate in arid and semi-arid species. *Environmental and Experimental Botany* 141: 181-90.  [article](#)

Guerrero RF, **CD Muir**, S Josway, LC Moyle. Pervasive antagonistic interactions among hybrid incompatibility loci. *PLoS Genetics* 13: e1006817.  [article](#)  [preprint](#)


**Muir CD**, MÀ Conesa, EJ Roldán, A Molins, J Galmés. Weak coordination between leaf structure and function among closely related tomato species. *New Phytologist* 213: 1642-53.  [article](#)  [preprint](#)  [data](#)


2015 **Muir CD & M Thomas-Huebner** (undergraduate coauthor). Constraint around quarter-power allometric scaling in wild tomatoes (*Solanum* sect. *Lycopersicon*; Solanaceae). *The American Naturalist* 186: 421-33.  [article](#)  [data](#)

**Muir CD.** Making pore choices: repeated regime shifts in stomatal ratio. *Proc R Soc B* 282: 20151498.  [article](#)  [preprint](#)  [data](#)

- 2014 **Muir CD** & MW Hahn. The limited contribution of reciprocal gene loss to increased speciation rates following whole genome duplication. *The American Naturalist* 185: 70-86.  [article](#)  [data](#)
- Muir CD**, JB Pease, LC Moyle. Quantitative genetic analysis indicates natural selection on leaf phenotypes across wild tomato species (*Solanum* sect. *Lycopersicon*; Solanaceae). *Genetics* 198: 1629-43.  [article](#)  [data](#)
- Muir CD**, RP Hangarter, LC Moyle, PA Davis. Morphological and anatomical determinants of mesophyll conductance in wild relatives of tomato (*Solanum* sect. *Lycopersicon* and sect. *Lycopersicoides*). *Plant, Cell & Environment* 37: 1415-26.  [article](#)
- 2013 **Muir CD**. How did the Swiss cheese plant get its holes? *The American Naturalist* 181: 273-81.  [article](#)
- 2012 Hahn MW, BJ White, **CD Muir**, NJ Besansky. No evidence for biased co- transmission of speciation islands in *Anopheles gambiae*. *Phil. Trans. R. Soc. B* 367: 374-84.  [article](#)
- 2010 Moyle LC & **CD Muir**. Reciprocal insights into adaptation from agricultural and evolutionary studies in tomato. *Evolutionary Applications* 3: 409-21.  [article](#)
- Moyle LC, **CD Muir**, MV Han, MW Hahn. The contribution of gene movement to the 'Two Rules of Speciation'. *Evolution* 64: 1541-57.  [article](#)
- 2009 **Muir CD** & LC Moyle. Antagonistic epistasis for ecophysiological trait differences between *Solanum* species. *New Phytologist* 183: 789-802.  [article](#)
- Wilczek AM *et al.* (author 7 of 18). Effects of genetic perturbation on seasonal life history plasticity. *Science* 323: 930-4.  [article](#)

## Preprints

Liu C\*, **CD Muir\***, Y Li, J Zhang, G Yu, L Xu, M Li, Z Zhang, HJ de Boer, L Sack, X Han, N He. Scaling between stomatal size and density in forest plants. In revision.  [preprint](#) (\* equal contribution)

Bontrager M, **CD Muir**, C Mahony, DE Gamble, RM Germain, AL Hargreaves, EJ Kleynhans, KA Thompson, AL Angert. Climate warming weakens local adaptation. In revision.  [preprint](#)

## Open-source Software

**tealeaves:** Solve for Leaf Temperature Using Energy Balance

 [github](#)  [cran](#)

**photosynthesis:** Model C<sub>3</sub> Photosynthesis

 [github](#)  [cran](#)

**gunit:** Converts Conductance Units

 [github](#)  [cran](#)

**smbr:** R package to facilitate analyses using STAN

 [github](#)

## Talks

Invited Seminars (28 since 2012)

2021

University of Richmond, Department of Biology, *Global syntheses of stomatal evolution and local adaptation.*

University of California, Davis, Department of Plant Biology, *Global syntheses of stomatal evolution and local adaptation.*

University of Mississippi, *Global syntheses of stomatal evolution and local adaptation.*

Carleton University, *Global syntheses of stomatal evolution and local adaptation.*

University of Hawai'i at Mānoa, Department of Natural Resources and Environmental Management, *Global patterns of stomatal evolution and local adaptation.*

2020

University of California, Berkeley, Botany Lunch Seminar, *Global patterns of stomatal evolution and local adaptation*

2019

University of Hawai'i at Mānoa, Ecology, Evolution and Conservation Biology Evoluncheon Series, *Climate anomalies are altering local adaptation.*

University of Hawai'i at Mānoa, Department of Tropical Plant and Soil Sciences, *Global patterns of stomatal evolution and local adaptation.*

University of Hawai'i at Mānoa, Department of Tropical Plant and Soil Sciences, *Synthesizing evolution and ecophysiology using leaves, trees, and math.*

- 2018 University of Hawai'i at Mānoa, Department of Botany, *Synthesizing evolution and ecophysiology using leaves, trees, and math.*
- Michigan State University, *Evolving resilience: Lessons from the ecophysiology of crop cousins and other wild plants.*
- 2017 University of Virginia, *How and Why? Synthesizing Evolution and Physiology.*  
 Rice University, *How and Why? Synthesizing Evolution and Physiology.*  
 Purdue University, *How and Why? Synthesizing Evolution and Physiology.*
- 2016 University of Arizona, *How and Why? Synthesizing Evolution and Physiology.*  
 University of Arkansas, *How and Why? Synthesizing Evolution and Physiology.*  
 University of Wyoming, *How and Why? Synthesizing Evolution and Physiology.*  
 University of Pittsburgh, *How and Why? Synthesizing Evolution and Physiology.*
- 2015 Virginia Tech, *How and Why? Synthesizing Evolution and Physiology.*  
 University of Texas, Arlington, *How and Why? Synthesizing Evolution and Physiology.*  
 University California, Davis, *How and Why? Synthesizing Evolution and Physiology.*  
 Purdue University, *Is it time for an evolutionary physiological synthesis, yet?.*
- 2014 ETH Zürich, *The physiology and genetics of adaptation.*  
 Simon Fraser University, *Phenotypic variation and constraint.*  
 Harvard University Herbarium, *Why do some plants have stomata on both leaf surfaces?.*  
 University of British Columbia, *Is it time for an evolutionary physiological synthesis, yet?.*  
 Michigan State University, *Is it time for an evolutionary physiological synthesis, yet?.*
- 2012 University of Virginia EEBio Seminar, *Through thick and thin: the adaptive significance of leaf trait variation in wild tomatoes.*
- Invited Conference Presentations
- 2021 **Muir CD.** *Emerging Leader Lecture: Eons of pore decisions: how selection shapes the stomatal morphospace. Botany.* Virtual!
- 2019 **Muir CD.** *Synthesizing evolution and ecophysiology using leaves, trees, and math.* Society for Integrative and Comparative Biology, Tampa, Florida, USA.
- 2016 **Muir CD.** *What is evolutionary physiology?.* Evolution, Austin, Texas, USA.
- 2012 **Muir CD.** *Functional and genetic analysis of leaf traits associated with drought in wild tomatoes* (Poster). Ecological Genomics Symposium, Kansas City, Missouri, USA.



## Contributed Conference Presentations

- 2022 Bonn-Savage, MA, **CD Muir**, KE Barton. Genetic variation in ontogenetic patterns in leaf anatomical traits in a long-term field experiment. *Botany*. Anchorage, Alaska.
- Muir CD**, A Bonnin, TN Buckley, MÀ Conesa, J Galmés, S McKlin, DA Rippner, M Schmeltz, G Thérout-Rancourt. Finding genes responsible for evolution of complex 3D leaf anatomy using tomographic microscopy. *Botany*. Anchorage, Alaska.
- 2021 **Muir CD**, SN Sheth, AL Angert. How will climate change affect the variance in fitness? An empirical test in the perennial herb *Mimulus cardinalis*. *Society for Integrative and Comparative Biology*. Virtual!
- 2020 **Muir CD**. Independent evolution of ab- and adaxial stomatal density enables adaptation. *Botany*. Virtual!
- Bontrager M, **CD Muir**, C Mahony, DE Gamble, RM Germain, AL Hargreaves, EJ Kleinhans, KA Thompson, AL Angert. Climate anomalies are altering local adaptation. *Society for Integrative and Comparative Biology*. Austin, Texas.
- 2019 **Muir CD**. Open source computational tools for plant ecophysiology. *SACNAS*. Honolulu, Hawai'i.
- This presentation is part of the symposium *Abupua'a: From the mountains to the ocean. Desde la montaña hasta el océano* co-organized by Rosana Zenil-Ferguson, Emily Sessa, and myself.
- Muir CD**. Poster: Assimilation *in silico* and in practice: Open source computational tools for simulating CO<sub>2</sub> assimilation and fitting models to data. *Gordon Research Conference: CO<sub>2</sub> Assimilation in Plants from Genome to Biome*. Newry, Maine.
- 2017 Conesa MÀ, **CD Muir**, EJ Roldán, JJ Piguero-Pina, A Molins, J Galmés. Poster: Adaptive strategies in tomato wild relatives: sources to adapt tomato crop to more water-restrictive cultivation conditions. *XIV Solanaceae and 3rd Cucurbitaceae Joint Conference*. Barcelona, Spain.
- 2015 **Muir CD** & M Thomas-Huebner. Constraint around quarter-power allometric scaling in wild tomatoes. *Botany*, Edmonton, Alberta, Canada
- 2014 **Muir CD**, JB Pease, LC Moyle. Connecting macroevolution to the genetics of adaptation: a case study using stomatal ratio. *Evolution*, Raleigh, North Carolina, USA
- Muir CD**. Pore choices: the adaptive significance of stomatal ratio. *American Society of Naturalists*, Asilomar, California, USA

- 2013 **Muir CD.** Pore choices: the adaptive significance of stomatal ratio. *Evolution*, Snowbird, Utah, USA
- Muir CD.** Poster: Functional and genetic analysis of leaf traits associated with drought in wild tomatoes. *Society of Integrative and Comparative Biology*, San Francisco, California, USA
- 2012 **Muir CD.** Through thick and thin: the adaptive significance of leaf trait variation in wild tomatoes. *Evolution*, Ottawa, Ontario, Canada
- 2010 **Muir CD.** Genetics of drought adaptation in wild tomatoes. *Evolution*, Portland, Oregon, USA
- 2008 Evolution, Minneapolis, Minnesota, USA
- 2006 Evolution, Stony Brook, New York, USA

#### Professional Activities, Affiliations & Outreach

##### Editor

- 2016 - 2017 Axios Review

##### External Grant Reviews

- 2022 NSF BIO Integrative Organismal Systems  
NSF BIO Integrative Organismal Systems: Integrative Ecological Physiology Program
- 2017 Austrian Science Fund (FWF)
- 2016 NSF BIO Division of Environmental Biology

##### Manuscript Reviews

*American Journal of Botany; American Naturalist; Annals of Botany; AoB PLANTS; Applications in Plant Sciences; Botany; Current Biology; Ecology; Evolution; Global Ecology and Biogeography; International Journal of Plant Sciences; Journal of Evolutionary Biology; Methods in Ecology and Evolution; Molecular Biology and Evolution; Molecular Ecology; Nature Climate Change; Nature Ecology and Evolution; New Phytologist; Photosynthesis Research; Physiologia Plantarum; Plant, Cell & Environment; Plant Physiology; PLOS Biology; PLOS ONE; Proceedings B; Scientific Reports; Theoretical Population Biology*

##### University Service

- 2022 Life Sciences Assessment Committee Member  
Life Sciences Funding and Fellowship Committee Member  
EECB Fellowship Reviewer
- 2021 Life Sciences Assessment Committee Member  
Life Sciences Funding and Fellowship Committee Member

EECB Fellowship Reviewer

2020 Life Sciences Diversity, Equity, and Inclusion Committee Member  
Life Sciences Workload Committee Member  
Global Change Botanist Faculty Search Committee  
Botany Graduate Admissions Committee  
Life Sciences Building Space Governance Committee

2019 School of Life Sciences Instructional Workload Survey Committee  
Botany department scholarship reviewer

2014 - 2015 Organized UBC Biodiversity Lunchtime Internal Seminar Series (BLISS)

#### Professional Service

2022 Workshop on "Common methods in leaf gas-exchange research: an introduction to measurements, theory, and data analysis" at Botany 2022  
SICB Division of Botany Best Poster competition judge

2021 SICB Division of Botany Best Poster competition judge  
Botanical Society of America PLANTS Mentor

2019 - 2021 Secretary, Division of Botany, Society for Integrative and Comparative Biology (SICB)

2020 SICB Rising Star in Organismal Botany competition judge

2013 - 2015 Co-organizer SFU/UBC/UVic Ecology and Evolution Retreat

#### Professional Society Memberships

- Society for the Study of Evolution
- The American Society of Naturalists
- Botanical Society of America
- Society for Integrative and Comparative Biology

#### Mentorship & Teaching

##### Certificate in Effective Instruction

2022 Association of College and University Educators

This certificate signifies my completion of a 25-module course in effective teaching practices requiring the implementation of evidence-based instructional approaches. The credential is co-issued by the American Council on Education and distinguishes faculty for their commitment to educational excellence and student success.

##### Graduate Student Committees

Dachuan (Frank) Wang (chair)  
G Young Kim (interim member) Nathan Fumia (UH TPSS, member)  
Devon DeBevoise (member)  
Ana Flores (member)

Caitlyn Genovese (member)  
 Lauren Nerfa (interim member)  
 Ikenna Nometa (UH Mathematics, member)  
 Francisca Rodriguez (member)  
 Joani Viliunas (interim member)

#### Undergraduate Thesis Committees



Genevieve Triplett (chair)  
 Amanda Wong (member)

#### Undergraduate mentorship

2022	Justin Alter (UH Mānoa) Jenna Matsuyama (UH Mānoa) Kai Yasuda (UH Mānoa)
2021	McKenna Bonn-Savage (UH Mānoa) Ezikio Quintana (UH Mānoa) Michelle Leano (UH Mānoa)
2020	Jennifer Guo (UH Mānoa) Skylar Hara (UH Mānoa) Daniel Trupp (UH Mānoa) Genevieve Triplett (UH Mānoa) Awarded UHM UROP project funds (\$4,989)
2017	Selina Dhanani, Alyson Eng, Geety Hafizi, Curtis Logan, Emily Okun (UBC)
2016	Vicki Thill and Austin Koontz (Univ Nevada-Reno undergraduates)
2015	Courtney Van Den Elzen (UBC)
2014	Lisa Lin and Erin Warkman (UBC Work-learn students)
2012	Meret Thomas-Huebner (Indiana University NSF REU)

#### Teaching experience

##### **Instructor of Record (University of Hawai'i)**

2022-fall	BOT 100: Freshman Seminar BIOL 172L: Introduction to Biology II Lab
2022-spring	BIOL / BOT 220: Biostatistics and  lab BIOL 470: Evolution
2021-fall	BOT 100: Freshman Seminar
2021-spring	BIOL / BOT 220: Biostatistics and  lab
2020-fall	BIOL 470: Evolution
2020-spring	BIOL 470: Evolution BIOL / BOT 297: Biostatistics
2019-fall	BIOL / BOT 455: Analysis of Biological Data

Open-source teaching resources

[Shiny apps for Evolutionary Biology](#)

Interviews and Press Coverage

*Botany One*: [AoBP ECOS 2020 Awardee Chris Muir](#)

*Plantae*: [Faculty Job: Myths & Realities - an interview with Christopher Muir](#)

*Botany One*: [tealeaves: an R package for modelling leaf temperature using energy budgets](#)

*Discover*: [“Why Do Houseplants Have Holey Leaves?”](#)  
<https://discovermagazine.com/2014/april/2-o-holey-leaf>

*New Phytologist*: [“Plant evolutionary ecology: molecular genetics, global warming and invasions, and the novel approaches we are using to study adaptations”](#) <https://dx.doi.org/10.1111/nph.12028>