Vulnerability to global change of Mediterranean forests: towards an interdisciplinary approach in functional ecology

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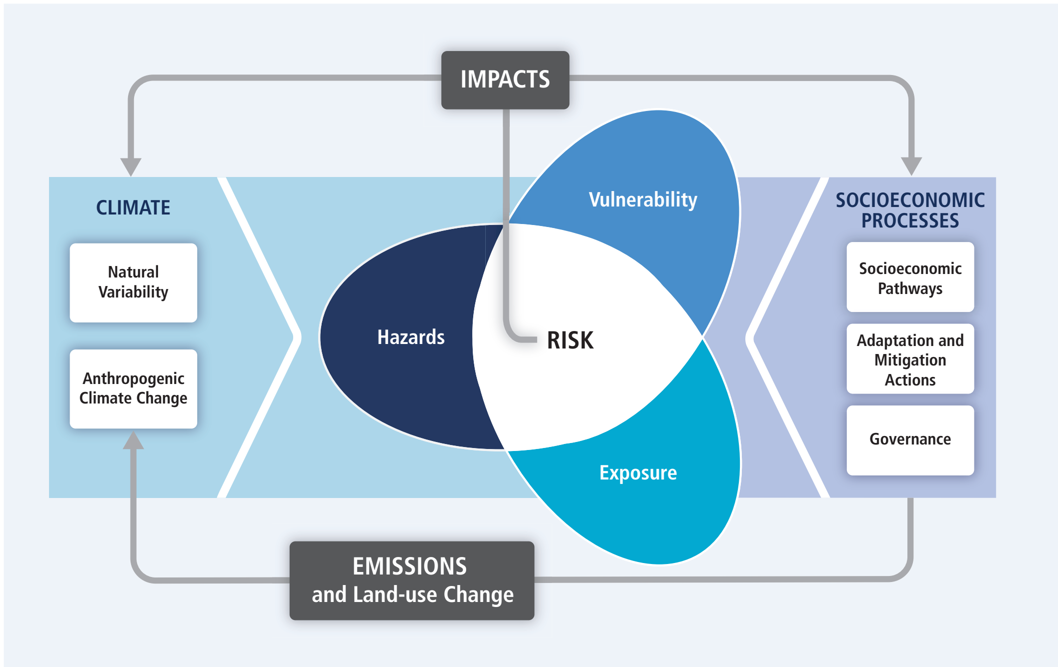
Forest vulnerability to global change in the Mediterranean

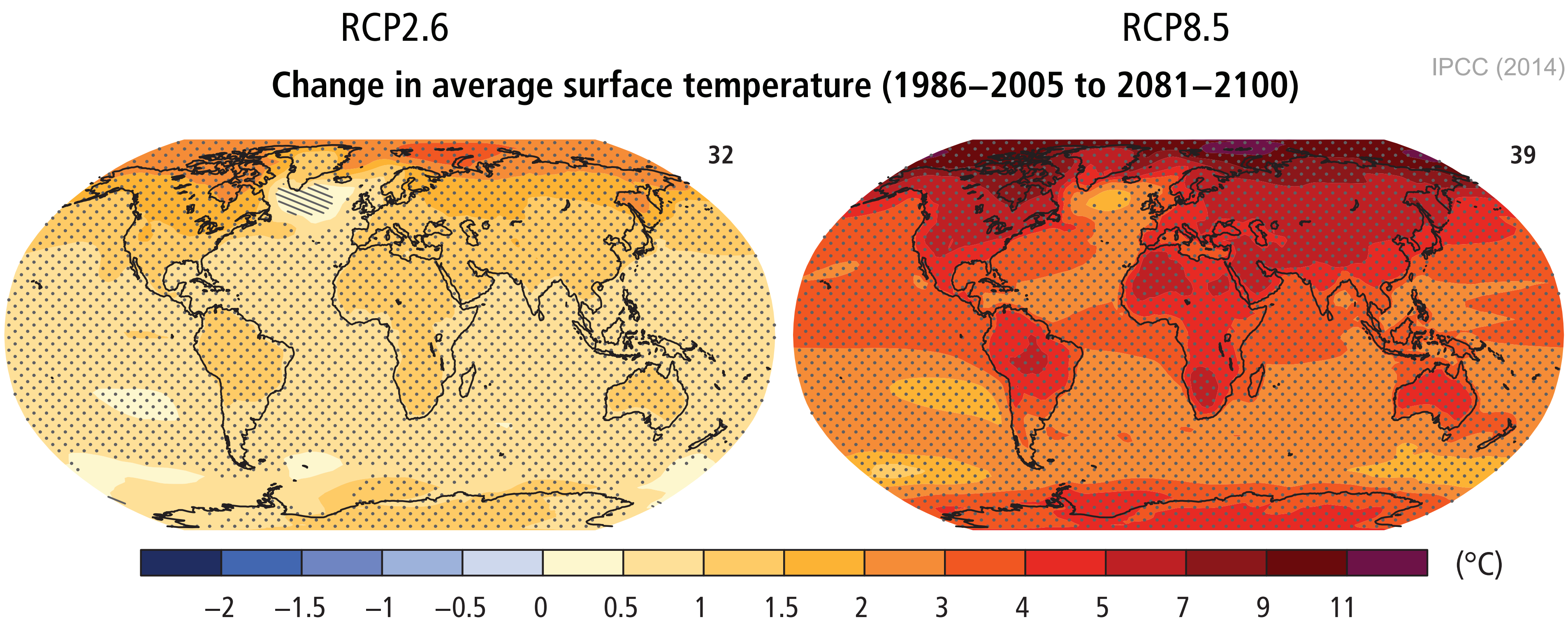
AR5 2014, AR6 Climate Change 2021: Impacts, Adaptation and **Vulnerability.**

Vulnerability: ‘sensitivity, exposition and capacity of adaptation and/or acclimation.’ (IPCC, 2014)

- ✧ Vulnerability to some factor.
- ✧ Non-sustainable species dynamics: non-acclimation, non-adaptation.
- ✧ Negative effect for species at all ontogenic stages and at the population-level.
- ✧ Population changes, biodiversity loss.



IPCC (2014)



Climate change

Warming = increased water stress

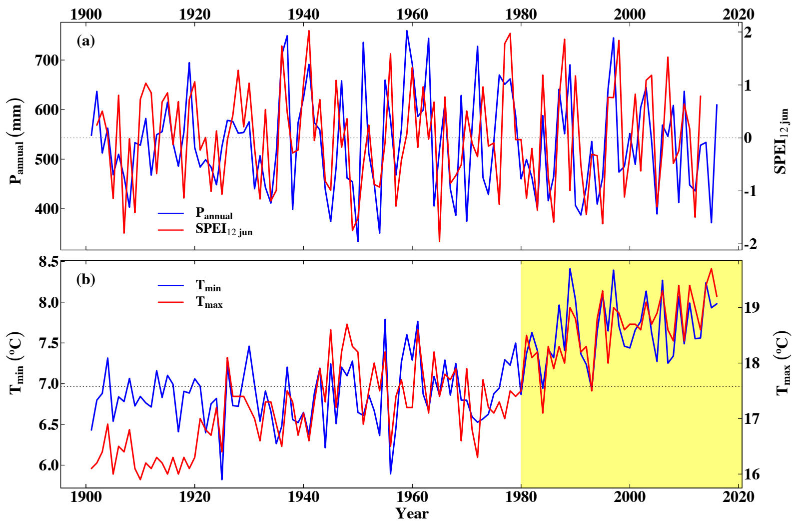
Negative for forest ecosystems

Transformed, overexploited landscapes

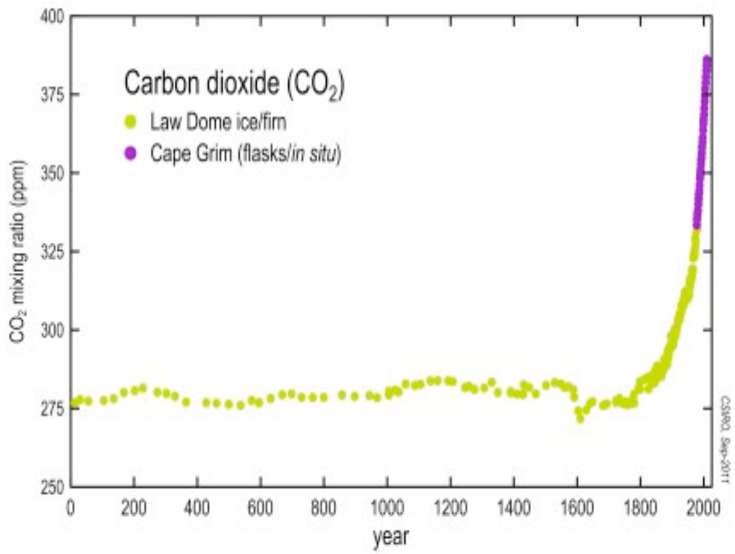
Land-use legacies are often negative

Climate

[CO_2]

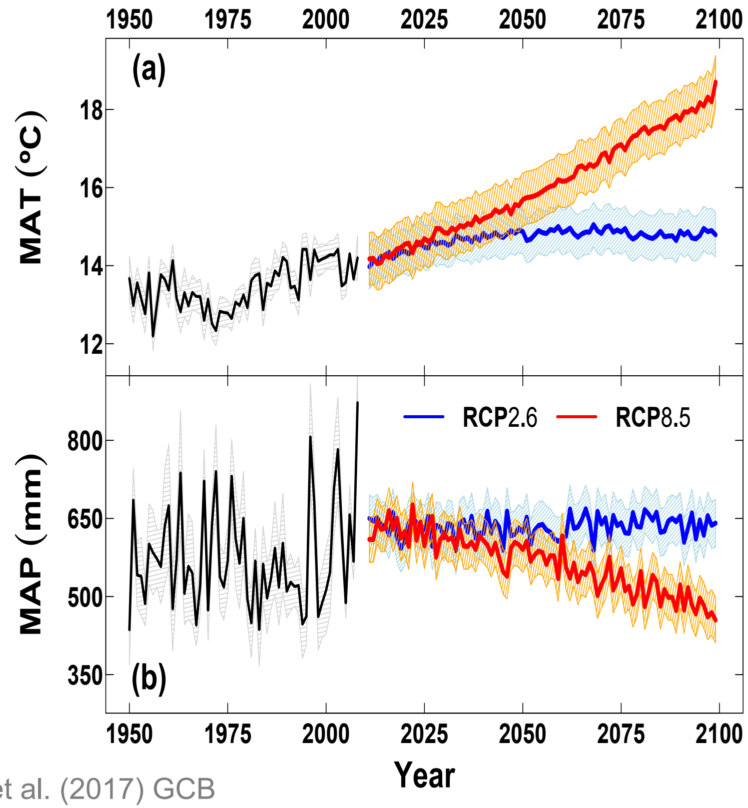


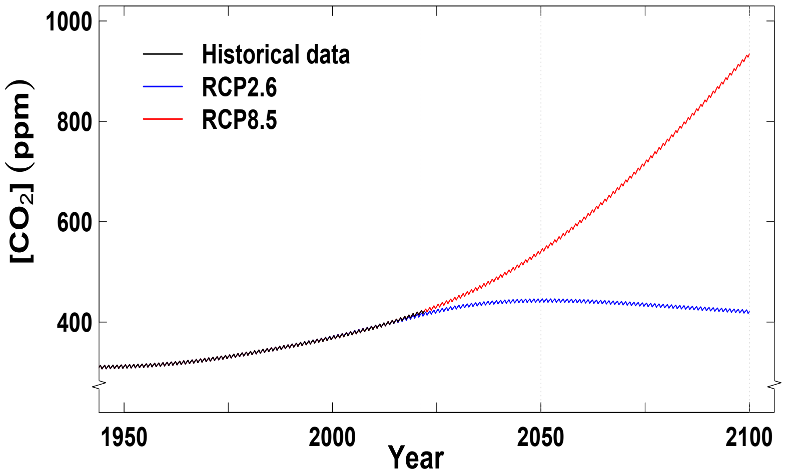
West Mediterranean Region



Past

Future





Gea-Izquierdo et al. (2017) GCB

- **Climate change**
- **Land-use legacies**: fire, management (logging, …), grazing, …

Transformed Landscapes: paleoecology, socioeconomy

Implication for sustainable dynamics of forest species

- Species decline?
- Accelerated mortality? (vs. Base-line “healthy” mortality)
- But [CO_2] fertilization?
- Interactions among biotic and abiotic factors?

When? Why? How?

Uncertainty in interaction between factors and impact on physiological mechanisms

Interdisciplinary: phenotypic plasticity to mitigate negative effects

Threats, Risks

REVIEW

https://doi.org/10.1038/s41586-018-0240-x

Triggers of tree mortality under drought

Brendan Choat[1]*, Timothy J. Brodribb[2], Craig R. Brodersen[3], Remko A. Duursma[1], Rosana López[1,4] & Belinda E. Medlyn[1]

Trends in Ecology & Evolution

CellPress REVIEWS

Opinion

Predicting Chronic Climate-Driven Disturbances and Their Mitigation

Nate G. McDowell,[1,*] Sean T. Michaletz,[2] Katrina E. Bennett,[2] Kurt C. Solander,[2] Chonggang Xu,[2] Reed M. Maxwell,[3] Craig D. Allen,[4] and Richard S. Middleton[2]

Forest Ecology and Management 259 (2010) 660–684

Contents lists available at ScienceDirect

Forest Ecology and Management

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

ELSEVIER

A global overview of drought and heat-induced tree mortality reveals emerging climate change risks for forests

Craig D. Allen[a,*], Alison K. Macalady[b], Haroun Chenchouni[c], Dominique Bachelet[d], Nate McDowell[e], Michel Vennetier[f], Thomas Kitzberger[g], Andreas Rigling[h], David D. Breshears[i], E.H. (Ted) Hogg[j], Patrick Gonzalez[k], Rod Fensham[l], Zhen Zhang[m], Jorge Castro[n], Natalia Demidova[o], Jong-Hwan Lim[p], Gillian Allard[q], Steven W. Running[r], Akkin Semerci[s], Neil Cobb[t]

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nature ecology & evolution
ARTICLES
DOI: 10.1038/s41559-017-0248-x

A multi-species synthesis of physiological mechanisms in drought-induced tree mortality

Henry D. Adams[1]*, Melanie J. B. Zeppel[2,3], William R. L. Anderegg[4], Henrik Hartmann[5], Simon M. Landhäusser[6], David T. Tissue[7], Travis E. Huxman[8], Patrick J. Hudson[9], Trenton E. Franz[10], Craig D. Allen[11], Leander D. L. Anderegg[12], Greg A. Barron-Gafford[13,14], David J. Beerling[15], David D. Breshears[16,17], Timothy J. Brodribb[18], Harald Bugmann[19], Richard C. Cobb[20], Adam D. Collins[21],

esa
ECOSPHERE
SYNTHESIS & INTEGRATION

Ecosystem dynamics and management after forest die-off: a global synthesis with conceptual state-and-transition models

Richard C. Cobb,[1,†] Katinka X. Ruthrof,[2,3] David D. Breshears,[4] Francisco Lloret,[5] Tuomas Aakala,[6] Henry D. Adams,[7] William R. L. Anderegg,[8] Brent E. Ewers,[9] Lucía Galiano,[10] José M. Grünzweig,[11] Henrik Hartmann,[12] Cho-ying Huang,[13] Tamir Klein,[14] Norbert Kunert,[15] Thomas Kitzberger,[16] Simon M. Landhäusser,[17] Shaun Levick,[12,18] Yakir Preisler,[11,19] Maria L. Suarez,[20] Volodymyr Trotsiuk,[21] and Melanie J. B. Zeppel[22]

Review
New Phytologist

Tansley review

Evaluating theories of drought-induced vegetation mortality using a multimodel–experiment framework

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Received: *5 June 2013*

Nate G. McDowell[1], Rosie A. Fisher[2], Chonggang Xu[1], J. C. Domec[3,4], Teemu Hölttä[5], D. Scott Mackay[6], John S. Sperry[7], Amanda Boutz[8], Lee Dickman[1], Nathan Gehres[8], Jean Marc Limousin[8], Alison Macalady[9], Jordi Martínez-Vilalta[10,11], Maurizio Mencuccini[12,13], Jennifer A. Plaut[8],

Review
New Phytologist

Research review

Tree mortality from drought, insects, and their interactions in a changing climate

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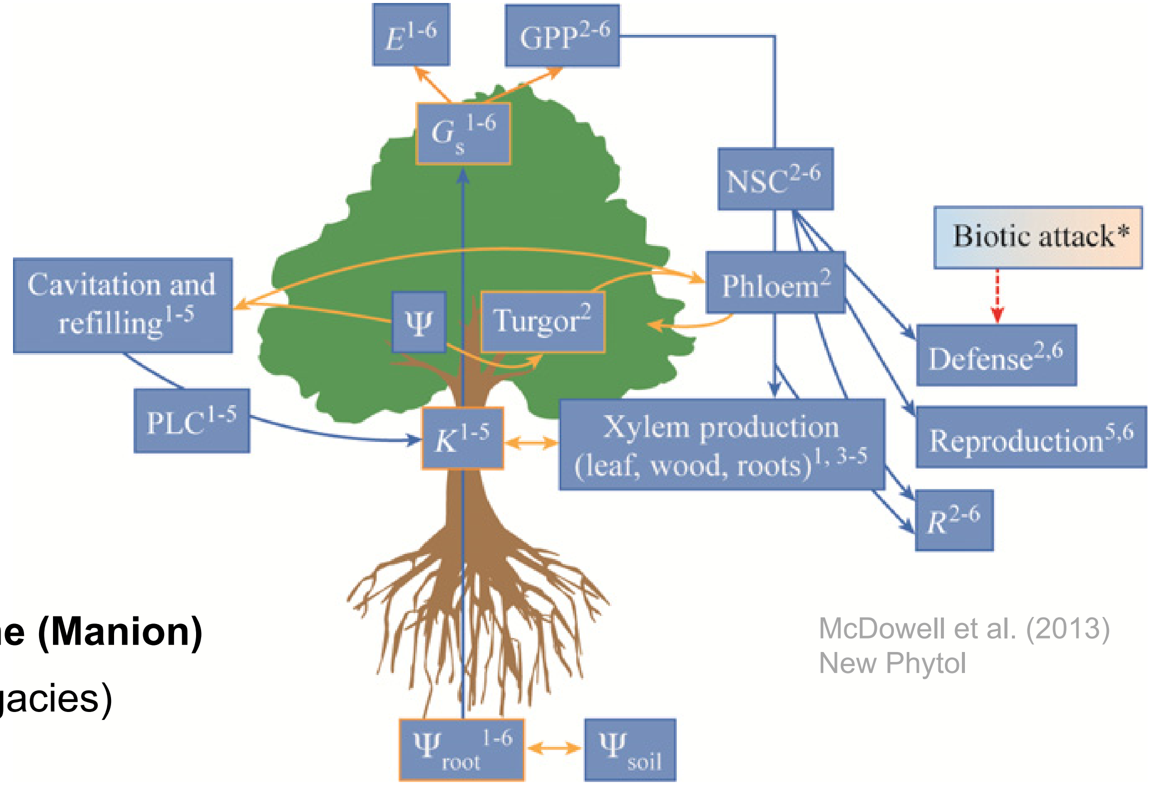
Received: *20 November 2014*
Accepted: *23 April 2015*

William R. L. Anderegg[1], Jeffrey A. Hicke[2], Rosie A. Fisher[3], Craig D. Allen[4], Juliann Aukema[5], Barbara Bentz[6], Sharon Hood[7], Jeremy W. Lichstein[8], Alison K. Macalady[9], Nate McDowell[10], Yude Pan[11], Kenneth Raffa[12], Anna Sala[7], John D. Shaw[13], Nathan L. Stephenson[14], Christina Tague[15] and Melanie Zeppel[16]

[1]Department of Ecology and Evolutionary Biology, Princeton University, Princeton, NJ 08540, USA; [2]Department of Geography,

Mechanisms explaining drought-induced mortality: how are different factors involved? Vulnerability



McDowell et al. (2013) New Phytol

Theories and mechanisms

- Carbon starvation: assimilation constraints
- Hydraulic failure: complete cavitation in adult trees?
- + Biotic factors

Spatio-temporal relationship factors: models of decline (Manion)

- Predisposing: long-term, primary (climate, land-use legacies)
- Inciting: discrete events (drought).
- Contributive: short- or long-term, secondary, final (pathogens).

Interdiscplinary approach: experimentation+modelling

- Characterization plasticity anatomical-physiological: multidisciplinary

Forest Ecology and Management 432 (2019) 884–894

Contents lists available at ScienceDirect

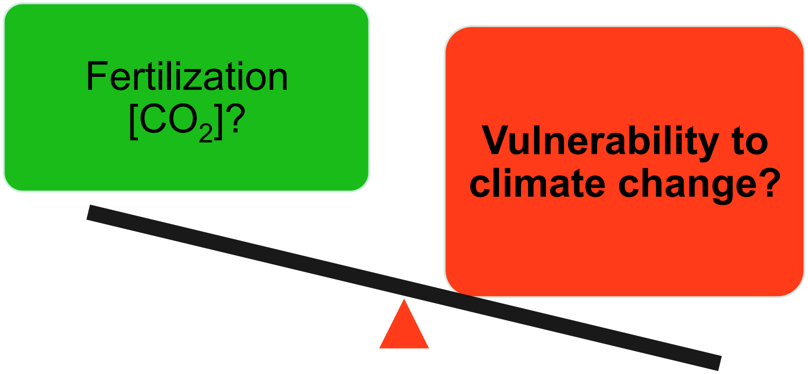
Forest Ecology and Management

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

Negative synergistic effects of land-use legacies and climate drive widespread oak decline in evergreen Mediterranean open woodlands

Daniel Moreno-Fernández[a,b,*], Alicia Ledo[c], Darío Martín-Benito[a], Isabel Cañellas[a], Guillermo Gea-Izquierdo[a]

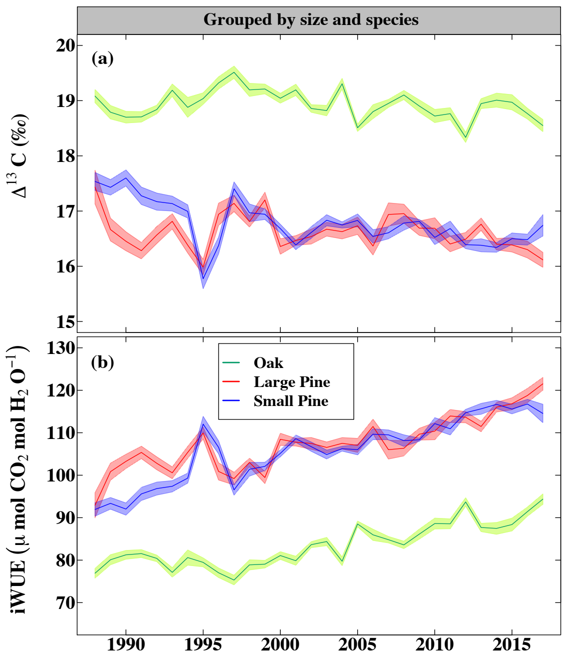
Understanding C and Water long-term dynamics



NPP dynamics
(≈ growth)

iWUE dynamics
(≅A/g_s)

Need to advance towards analyses of full functional processes (e.g. ecosystem WUE)



Gea-Izquierdo et al. (In prep)

Forests have increased their iWUE but no overall growth increase in response to warming and $[CO_2]$

e.g. Peñuelas et al. (2011) GEB; Keenan et al. (2013) Nature; Reichstein et al. (2013) Nature; van der Sleen et al. (2014) Nat Geos; Kim et al. (2016) New Phytol

Global Ecology and Biogeography, (Global Ecol. Biogeogr.) (2011) **20**, 597–608

RESEARCH PAPER

Increased water-use efficiency during the 20th century did not translate into enhanced tree growth

Josep Peñuelas[1]*, Josep G Canadell[2] and Romà Ogaya[1]

nature climate change — LETTERS

PUBLISHED ONLINE: 11 MAY 2015 | DOI: 10.1038/NCLIMATE2614

Water-use efficiency and transpiration across European forests during the Anthropocene

D. C. Frank[1,2]*, B. Poulter[3,4]*, M. Saurer[5], J. Esper[6], C. Huntingford[7], G. Helle[8], K. Treydte[1], N. E. Zimmermann[1], G. H. Schleser[8,9], A. Ahlström[10,11], P. Ciais[4], P. Friedlingstein[12], S. Levis[13], M. Lomas[14], S. Sitch[12], N. Viovy[4], L. Andreu-Hayles[15], Z. Bednarz[16], F. Berninger[17], T. Boettger[18]

Global Change Biology — celebrating 20 years

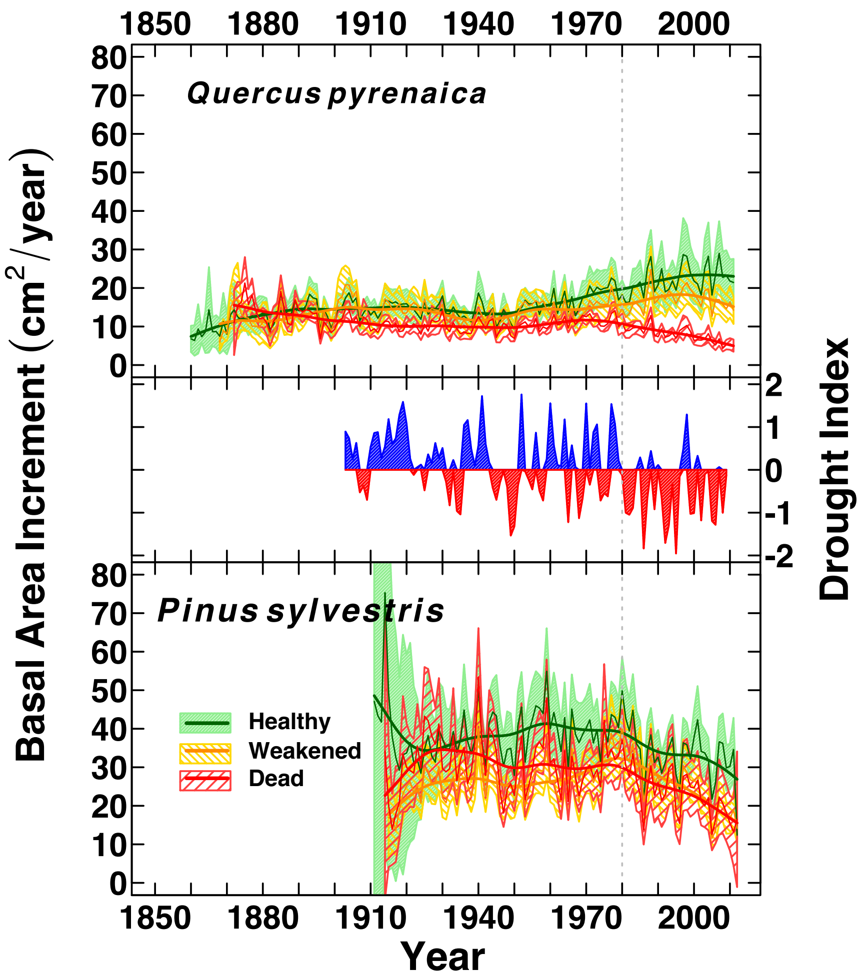
Global Change Biology (2014) **20**, 3700–3712, doi: 10.1111/gcb.12717

Spatial variability and temporal trends in water-use efficiency of European forests

MATTHIAS SAURER[1], RENATO SPAHNI[2,4], DAVID C. FRANK[3,4], FORTUNAT JOOS[2,4], MARKUS LEUENBERGER[2], NEIL J. LOADER[5], DANNY MCCARROLL[5], MARY GAGEN[5], BEN POULTER[6], ROLF T.W. SIEGWOLF[1], LAIA ANDREU-HAYLES[7], TATIANA

Analysis of mortality and decline using dendroecological data: negative growth trends often precede mortality … but not always

→ **Mechanisms**



Forest Ecology and Management 320 (2014) 70–82

Contents lists available at ScienceDirect

Forest Ecology and Management

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

Drought induced decline could portend widespread pine mortality at the xeric ecotone in managed mediterranean pine-oak woodlands

Guillermo Gea-Izquierdo [a,b,*], Bárbara Viguera [a], Miguel Cabrera [c], Isabel Cañellas [a]

Empirical models to disengangle factors causing mortality and decline

Species	Model
Q. pyrenaica	$\text{logit}(P_{kq}) = a_{kq} + b_{1q} \cdot NGC + b_{2q} \cdot s_{1970} + b_{3q} \cdot ms + b_{4q} \cdot Density$
P. sylvestris	$\text{logit}(P_{kp}) = a_{kp} + b_{1p} \cdot NGC + b_{2p} \cdot PGC + b_{3p} \cdot BA + b_{4p\text{-high/med}} \cdot G_{40}$

frontiers in Plant Science

ORIGINAL RESEARCH
published: 08 January 2019
doi: 10.3389/fpls.2018.01964

Early-Warning Signals of Individual Tree Mortality Based on Annual Radial Growth

OPEN ACCESS

Maxime Cailleret[1,2*], Vasilis Dakos[3], Steven Jansen[4], Elisabeth M. R. Robert[5,6,7], Tuomas Aakala[8], Mariano M. Amoroso[9,10], Joe A. Antos[11], Christof Bigler[1], Harald Bugmann[1], Marco Caccianaga[12], Jesus-Julio Camarero[13], Paolo Cherubini[2], Marie R. Coyea[14], Katarina Čufar[15], Adrian J. Das[16], Hendrik Davi[17], Guillermo Gea-Izquierdo[18], Sten Gillner[19], Laurel J. Haavik[20,21], Henrik Hartmann[22],

Science of the Total Environment 685 (2019) 963–975

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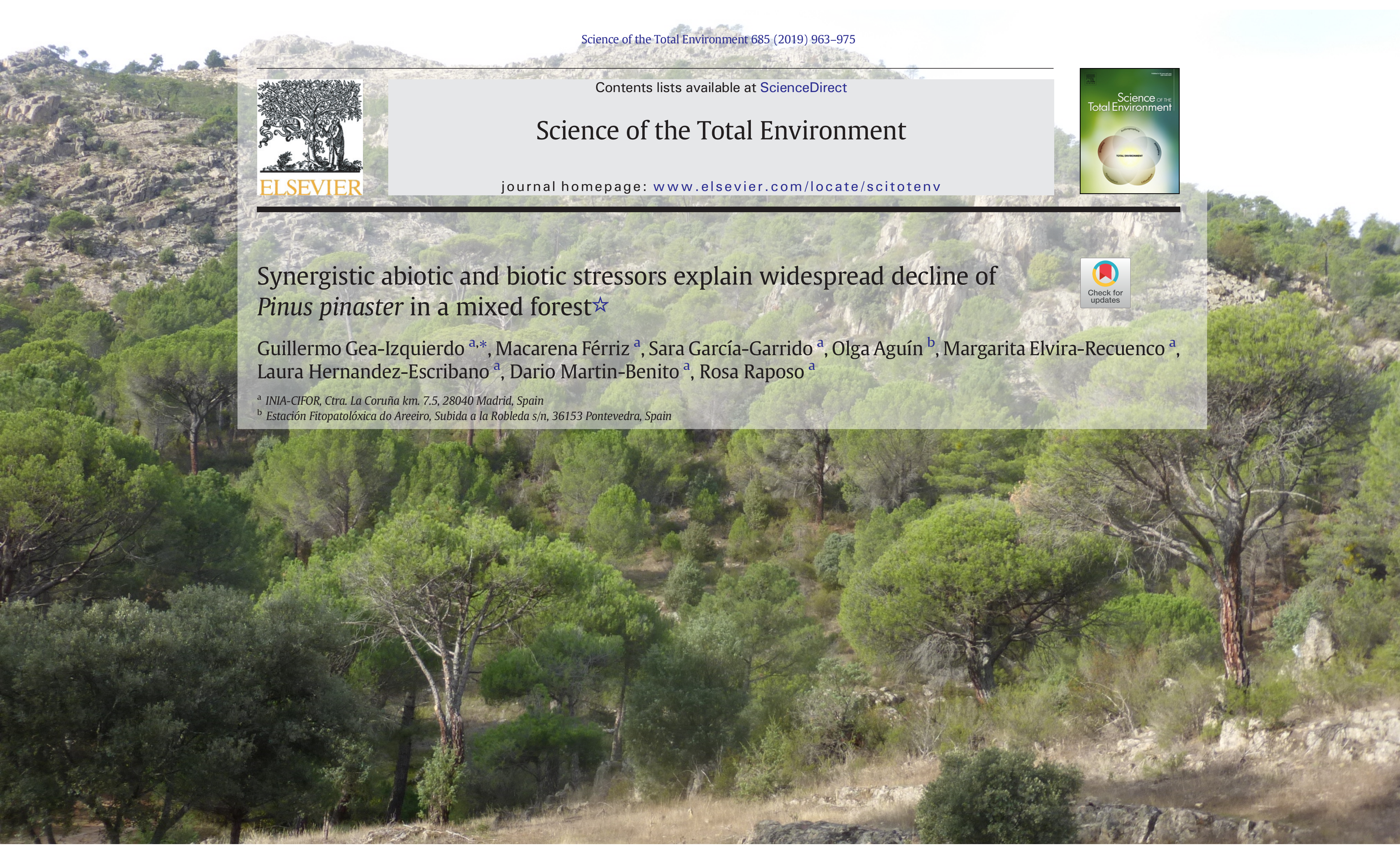
Science of the Total Environment

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



Synergistic abiotic and biotic stressors explain widespread decline of *Pinus pinaster* in a mixed forest☆

Guillermo Gea-Izquierdo [a,*], Macarena Férriz [a], Sara García-Garrido [a], Olga Aguín [b], Margarita Elvira-Recuenco [a], Laura Hernandez-Escribano [a], Dario Martin-Benito [a], Rosa Raposo [a]

[a] INIA-CIFOR, Ctra. La Coruña km. 7.5, 28040 Madrid, Spain
[b] Estación Fitopatolóxica do Areeiro, Subida a la Robleda s/n, 36153 Pontevedra, Spain

Example of negative dynamics in response to global change in Mediterranean mixed forests at the xeric limit for species



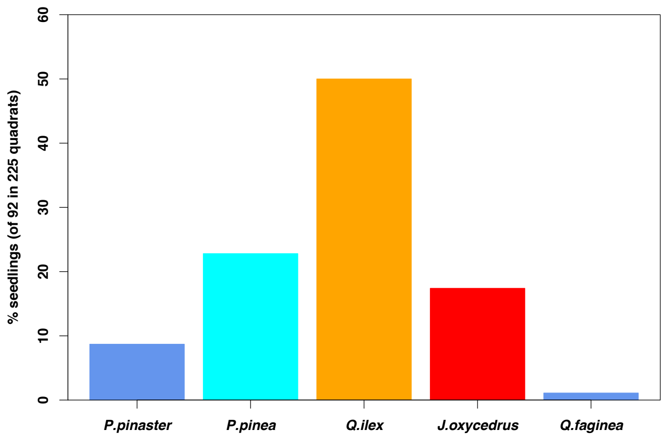
Pinillos (2014) Foresta

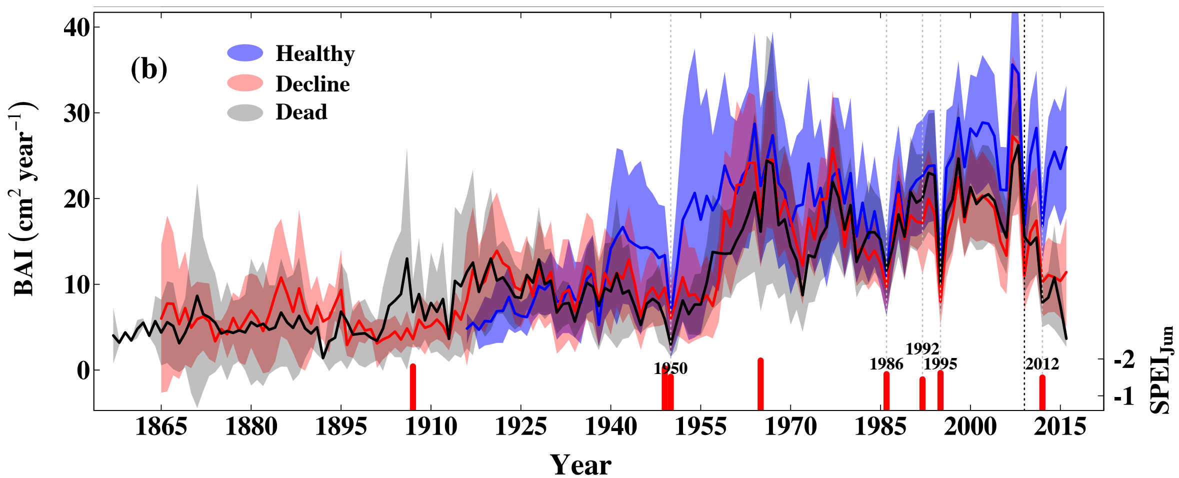
Old fire scar in studied plot

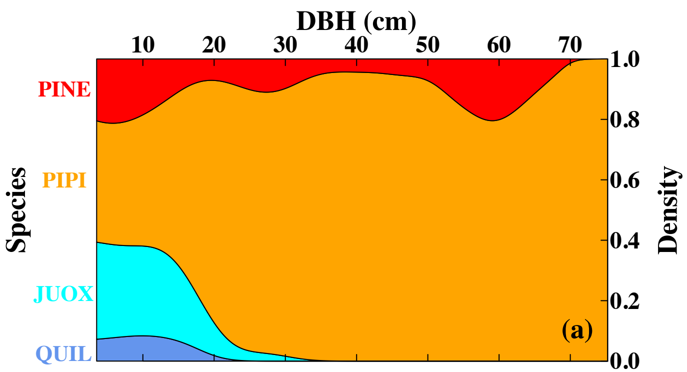
Pinus pinaster vulnerability in mixed forests (low elevation limit for the species)

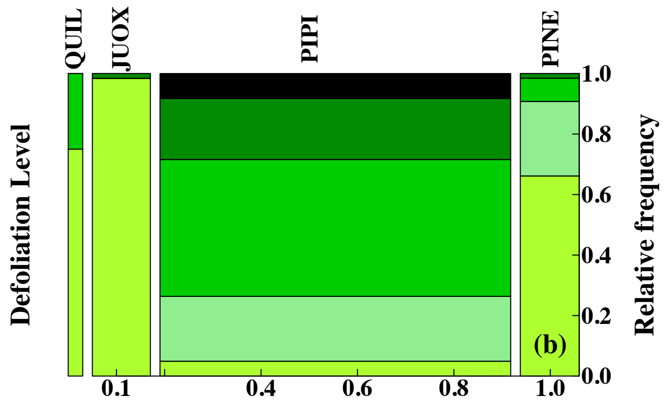
- Mortality all age-classes: less drought-tolerant species
- Climate predisposing.
- Land-use legacies predisposing: fire, drought-induced mortality, …?
- Fungal pathogens(*Armillaria* sp.) contributing but not systematic.

- **Population decline**: adults and lack regeneration.

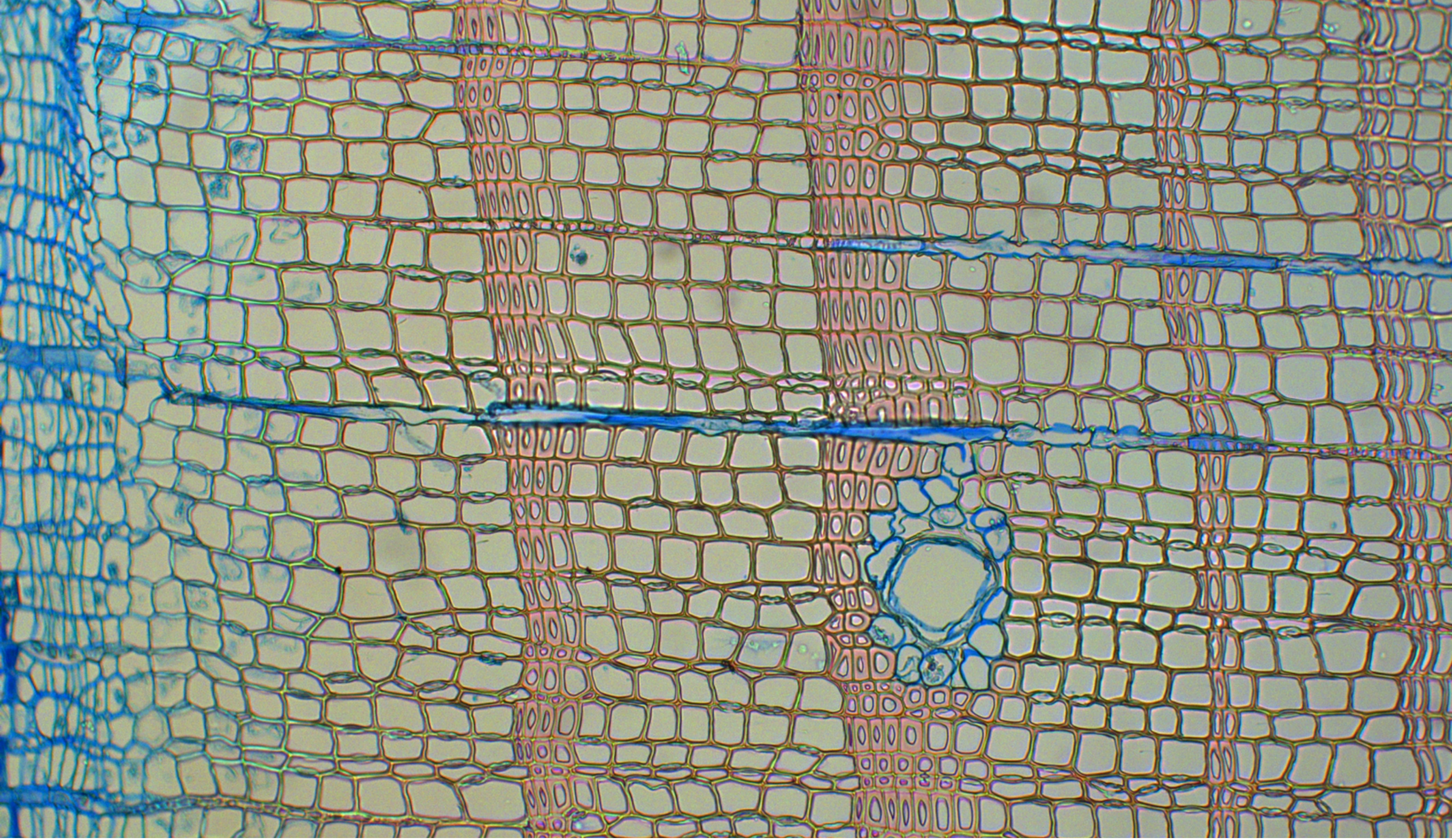








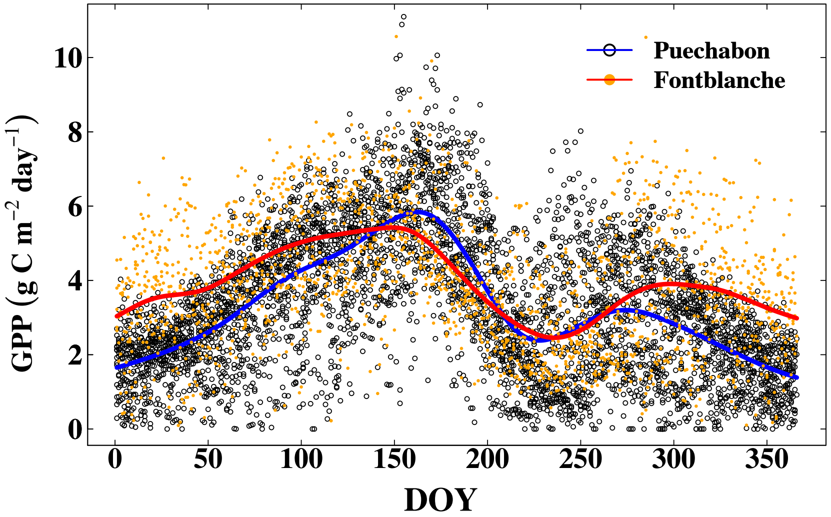
y-axis label from (b) to (f): Level 0 Level 1 Level 2 Level 3 Level 4



Need to understand variability in functional traits and processes: process-based models as tools in science and management

Need to model intranual processes to understand long-term dynamics

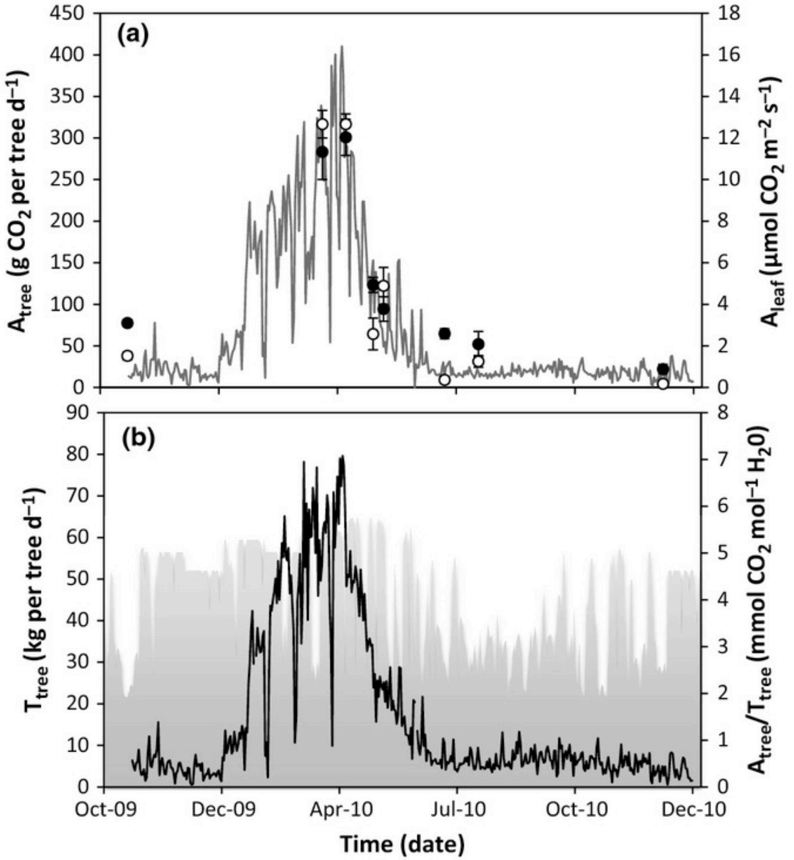
GPP, NPP, transpiration and carbon allocation in evergreen Mediterranean forests: double stress and bimodality (occasional)

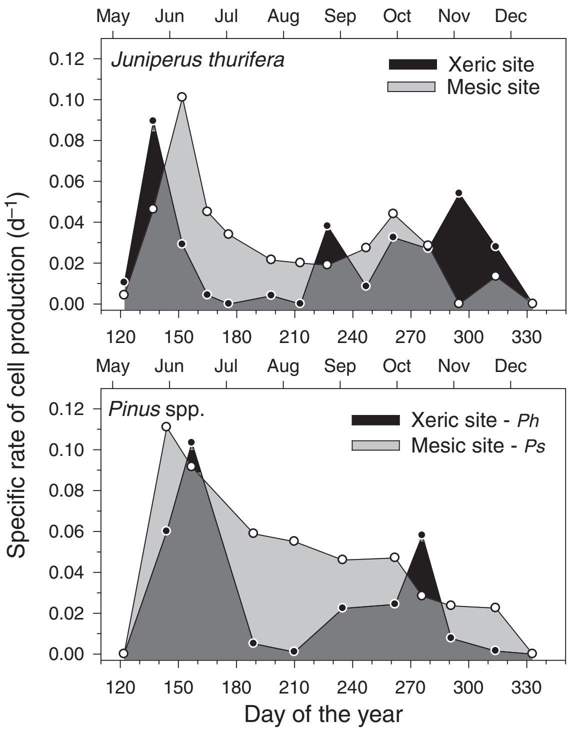


H_2O and CO_2 fluxes

Gea-Izquierdo et al. (2015) Biogeosciences

Klein et al. (2016) New Phytol

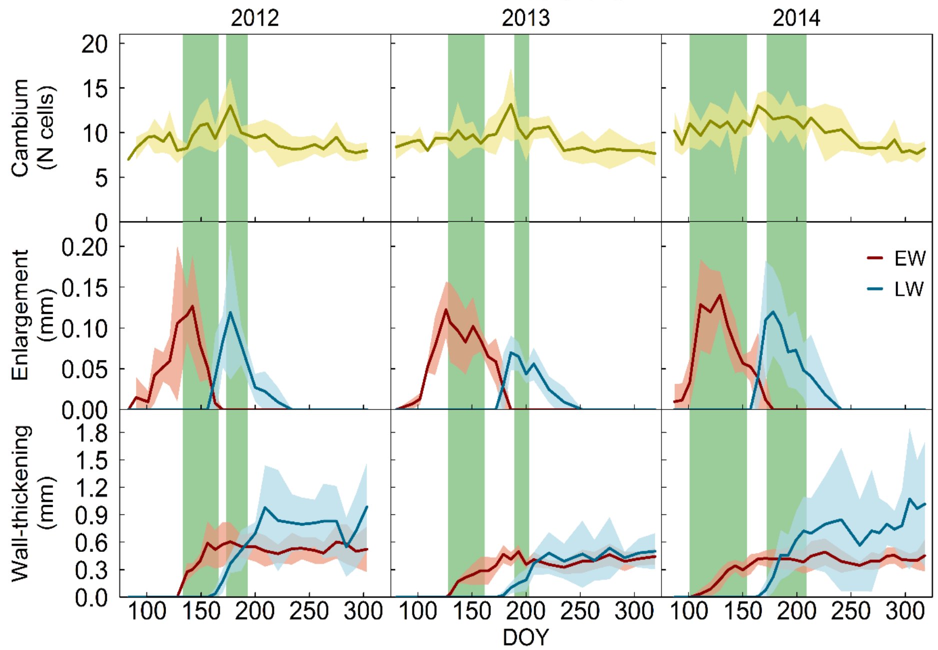




Xylogenesis (cambial phenology)

Fernández-de-Uña et al. (2018) Tree Physiol

Camarero et al. (2010) New Phytol



Need to model plant processes and mechanisms

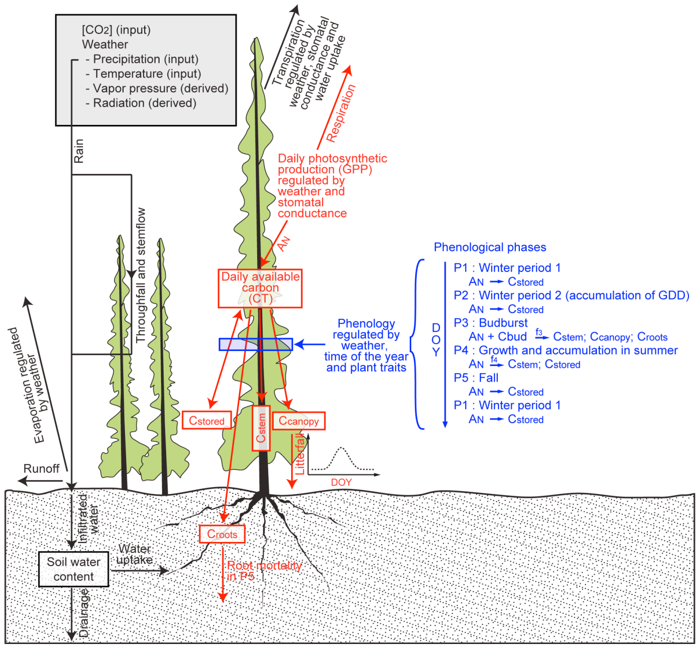
From Gennaretti et al. (2017) Biogeosciences

- ✧ Process-based vegetation models.
  e.g. Le Roux et al. (2001) AFS; Kramer et al. 2002 GCB; Morales et al. 2002 GCB; Guiot et al. 2014,

At least include:

  - ✧ Photsynthesis and transpiration: leaf and canopy.
  - ✧ Autotrophic respiration.
  - ✧ **Carbon allocation** ⟵ **Growth data (dendroecology)**
  - ✧ Reserves (NSC)
  - ✧ …
  - ✧ Hydraulics.

- ✧ Complex processes: dynamics C y H_20, N/P economy, …
- ✧ Complex parametrization of models: need multiproxy



Global Change Biology (1999) 5, 755–770

Toward an allocation scheme for global terrestrial carbon models

P. FRIEDLINGSTEIN,*† G. JOEL,‡ C. B. FIELD‡ and I. Y. FUNG§
*Columbia University/Goddard Institute for Space Studies, 2880 Broadway, New York, NY 10025, USA, †Laboratoire des Sciences du Climat et de L'environnement, CE Saclay, Orme des Merisiers, 91191 Gif sur Yvette, France, ‡Carnegie Institution of Washington, 260 Panama st., Stanford, CA 94305, USA, §School of Earth and Ocean Sciences, University of Victoria, Victoria, B.C., Canada V8W 2Y2

Tree Physiology 32, 648–666
doi:10.1093/treephys/tpr138

Invited review: Part of an invited issue on carbon allocation

Modeling carbon allocation in trees: a search for principles

Oskar Franklin[1,7], Jacob Johansson[1,2], Roderick C. Dewar[3], Ulf Dieckmann[1], Ross E. McMurtrie[4], Åke Brännström[1,6] and Ray Dybzinski[5]

Forest process-based model

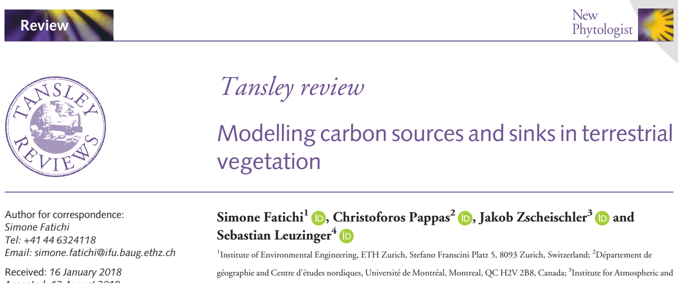
Processes:

- $f_{1growth}$(meteo, soil)
- $f_{2GPP}(f_1, CO_2)$

C-source limitation (photosynthesis)

C-sink limitation (growth)

(e.g. Körner et al. 1996; Sala et al. 2012 Tree Physiol, Fatichi et al. 2019 New Phytol)



Review

New Phytologist

Tansley review

Modelling carbon sources and sinks in terrestrial vegetation

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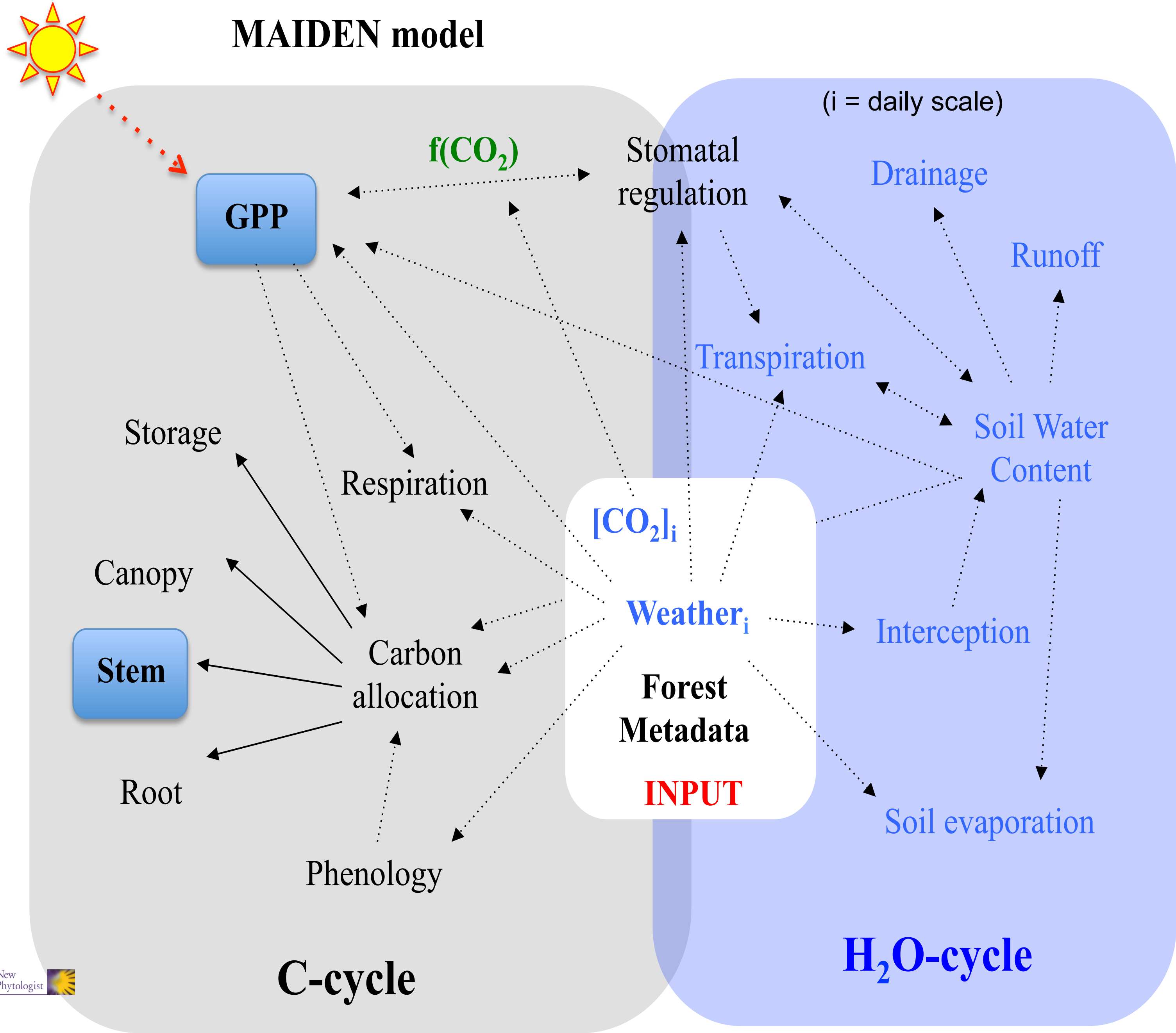
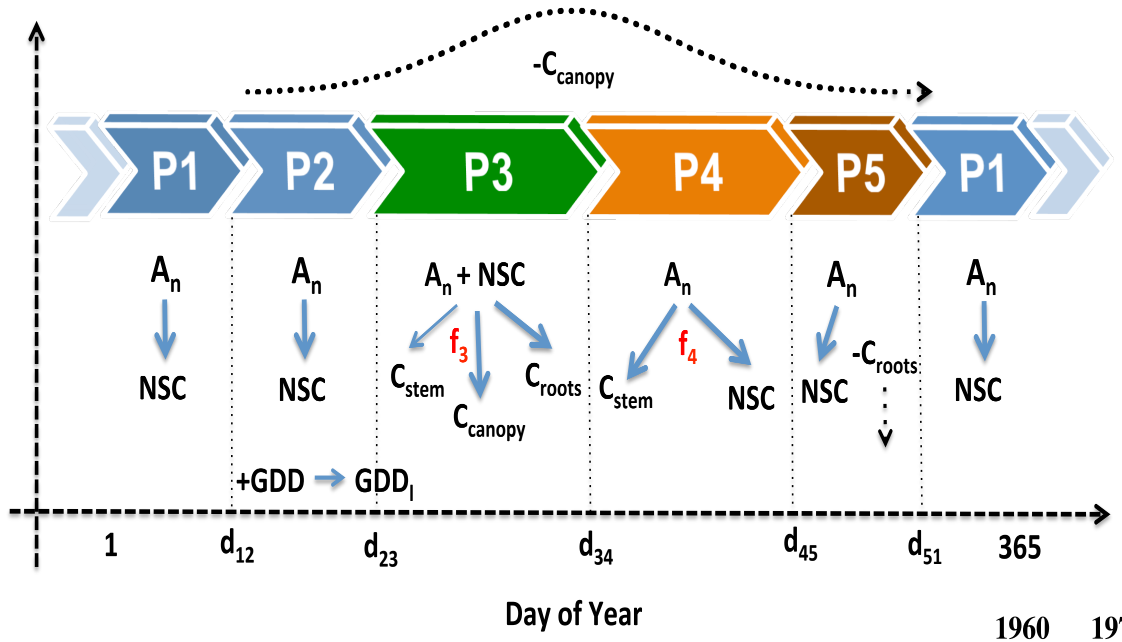
Received: *16 January 2018*

Simone Fatichi[1], Christoforos Pappas[2], Jakob Zscheischler[3] and Sebastian Leuzinger[4]

[1]Institute of Environmental Engineering, ETH Zurich, Stefano Franscini Platz 5, 8093 Zurich, Switzerland; [2]Département de géographie and Centre d'études nordiques, Université de Montréal, Montreal, QC H2V 2B8, Canada; [3]Institute for Atmospheric and

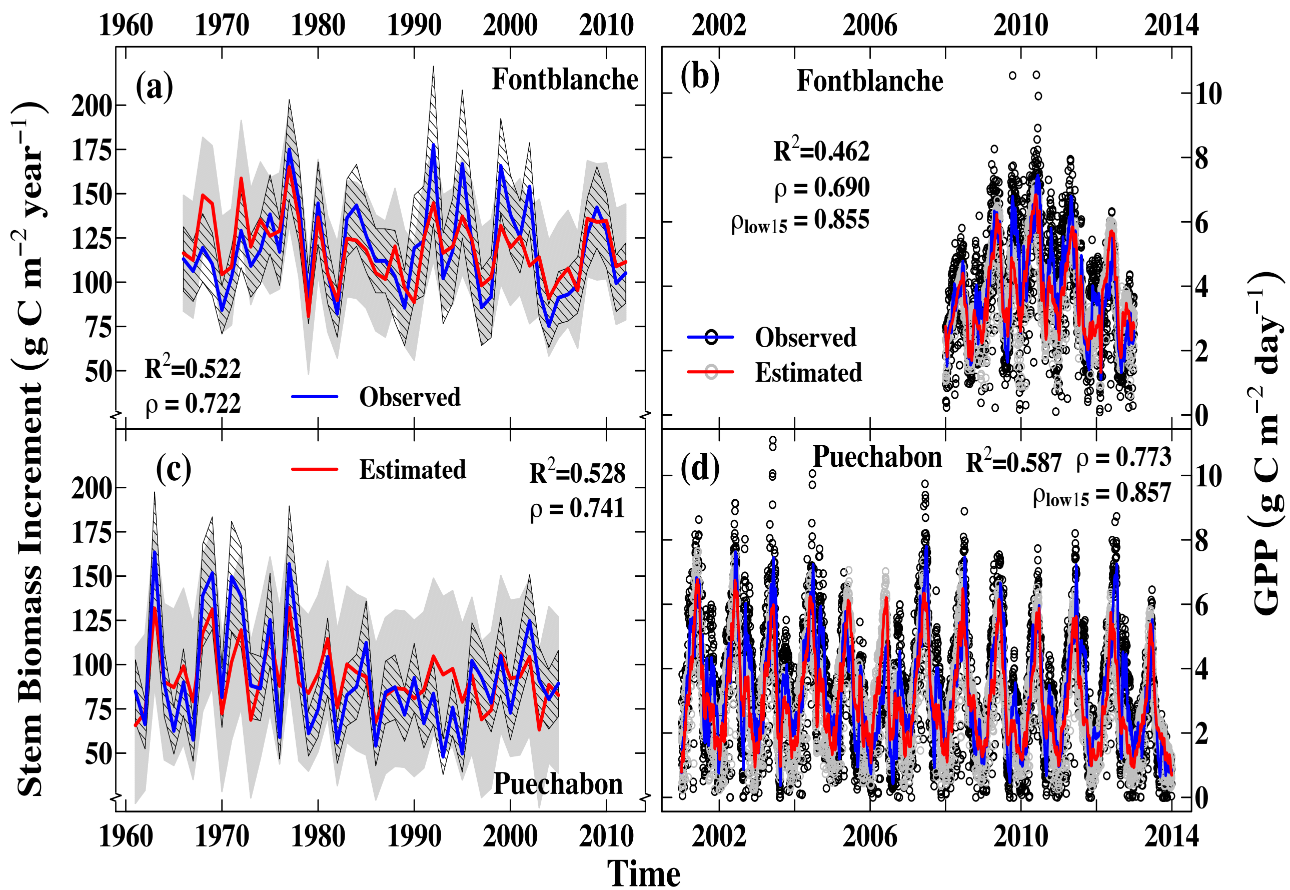


Gea-Izquierdo et al. (2015) Biogeosciences



Modifications in phenology and carbon allocation strategies in response to climate change

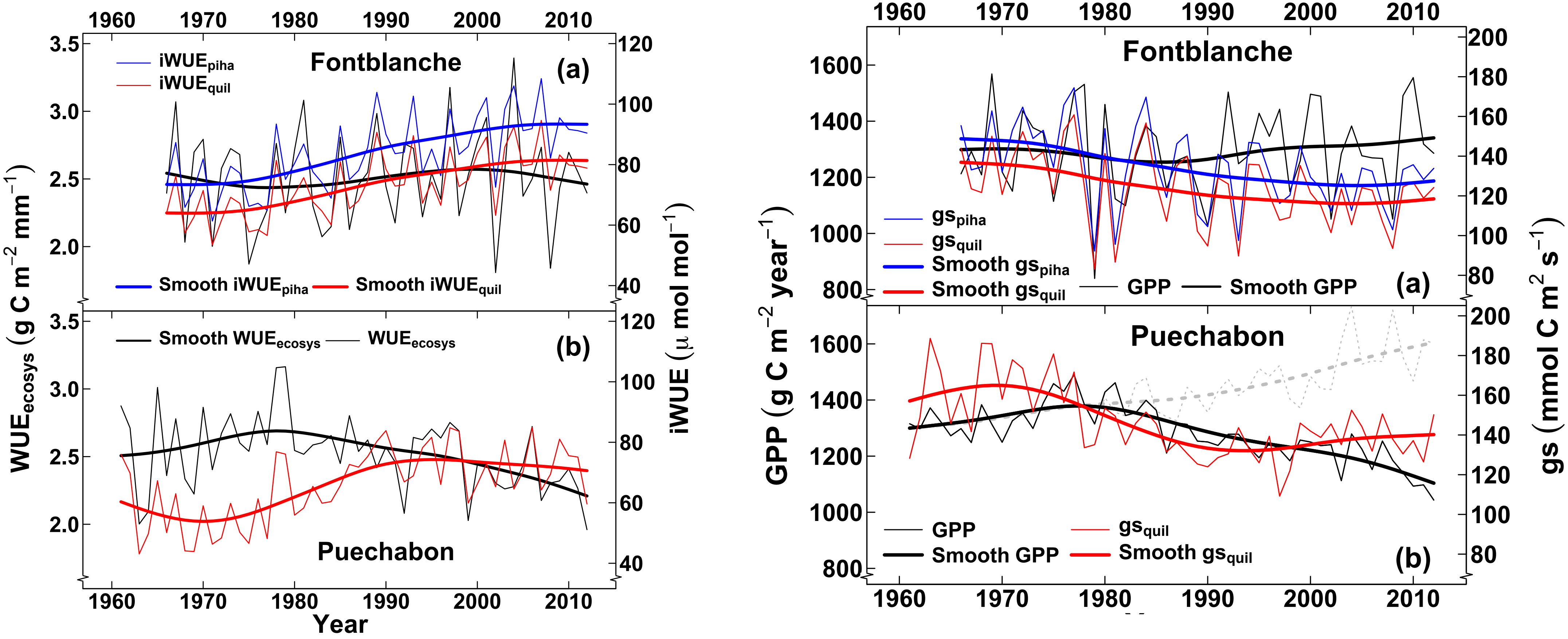
Gea-Izquierdo et al. (2015) Biogeosciences



Realistic trends in model simulations:

GPP, NPP, WUE (A/T, A/ET) y WUEi (A/gs) Beer et al. (2009) GBC

Example: mediterranean forests *Pinus halepensis* and *Q. ilex*

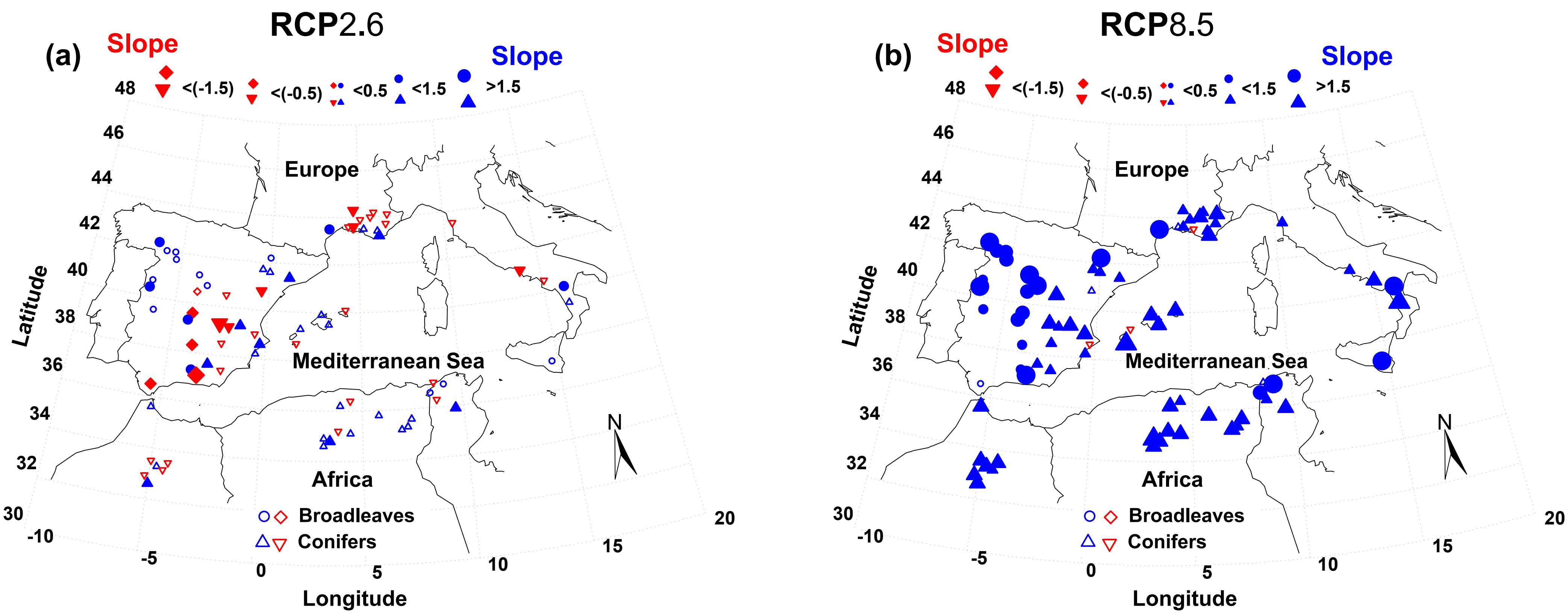


Gea-Izquierdo et al. (2015) Biogeosciences

Where and how are vulnerability expressed?, Thresholds? Ranges?, Traits?

Future forest dynamics (2010-2100) GPP and growth

Fertilization scenario [CO_2]↑



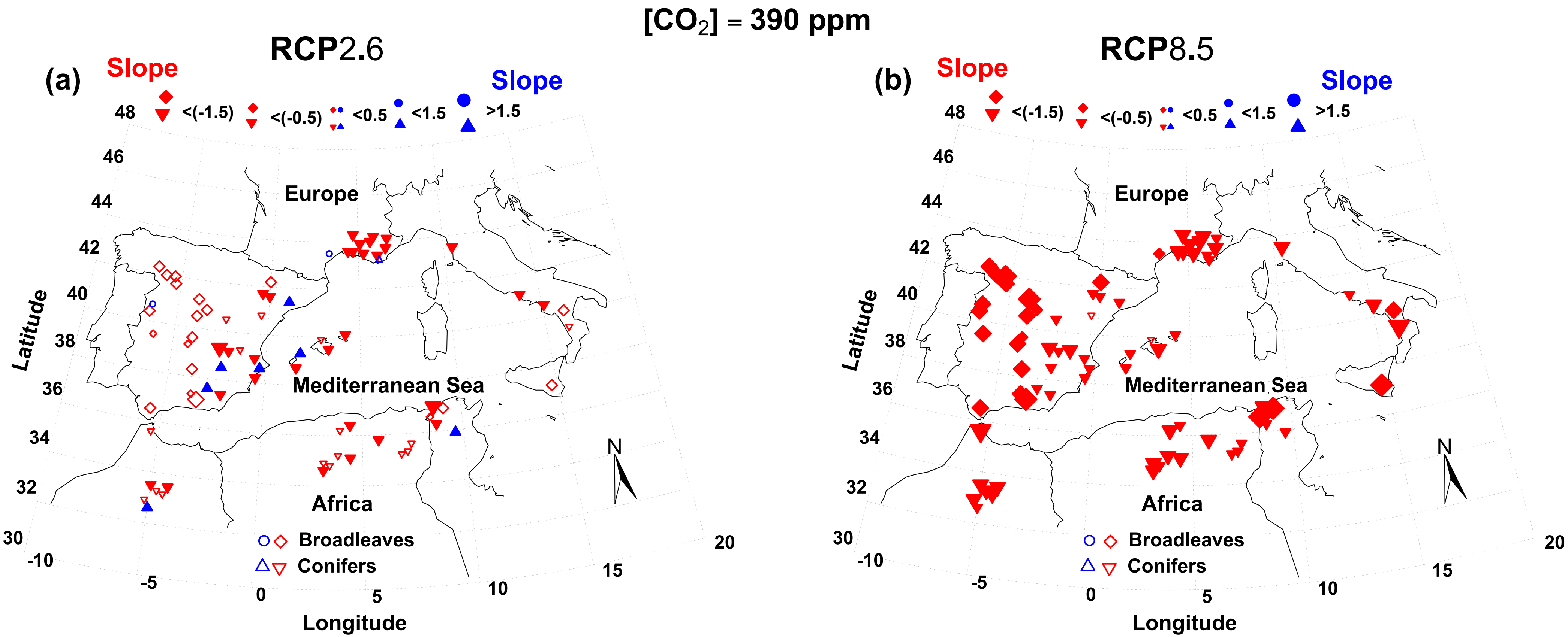
- Most species OK < +2ºC
- Vulnerability under RCP8.5: >+2ºC, 2050, +5ºC, 2100.
- Fertilización effect under RCP8.5 looks unrealistic

Gea-Izquierdo et al. (2017) GCB

Körner (2006) New Phytol; Norby et al. (2010) New Phytol; Fatichi et al. (2014); New Phytol; Fernández et al. (2014) Nat Clim Ch; Friend et al. (2014) Nat Clim Ch; Baig et al. (2015) GCB

Future forest dynamics (2010-2100) GPP and growth

Non-fertilization scenario: $[CO_2]$=390 ppm



- ✧ Most species OK < +2ºC
- ✧ **Vulnerability under RCP8.5: >+2ºC, 2050, +5ºC, 2100.**
- ✧ Fertilización effect under RCP8.5 looks unrealistic

Gea-Izquierdo et al. (2017) GCB

Körner (2006) New Phytol; Norby et al. (2010) New Phytol; Fatichi et al. (2014); New Phytol; Fernández et al. (2014) Nat Clim Ch; Friend et al. (2014) Nat Clim Ch; Baig et al. (2015) GCB

Forests in the Mediterranean under Global Change

- **Climate change**: increased water stress is negative for forest performance.
- **Land-use legacies**: often negative (soils, disruption dynamics,…).
- Threats and risks for forest dynamics, biodiversity and ecosystem services.
- Need to understand mechanisms and traits involved in species vulnerability.
- Need to characterize where, how and why species will be vulnerable: mitigation.
- Need tools (models) addressing physiological mechanisms to be used in sustainable management.
- **Much to learn yet to achieve sustainable management under a changing climate**.