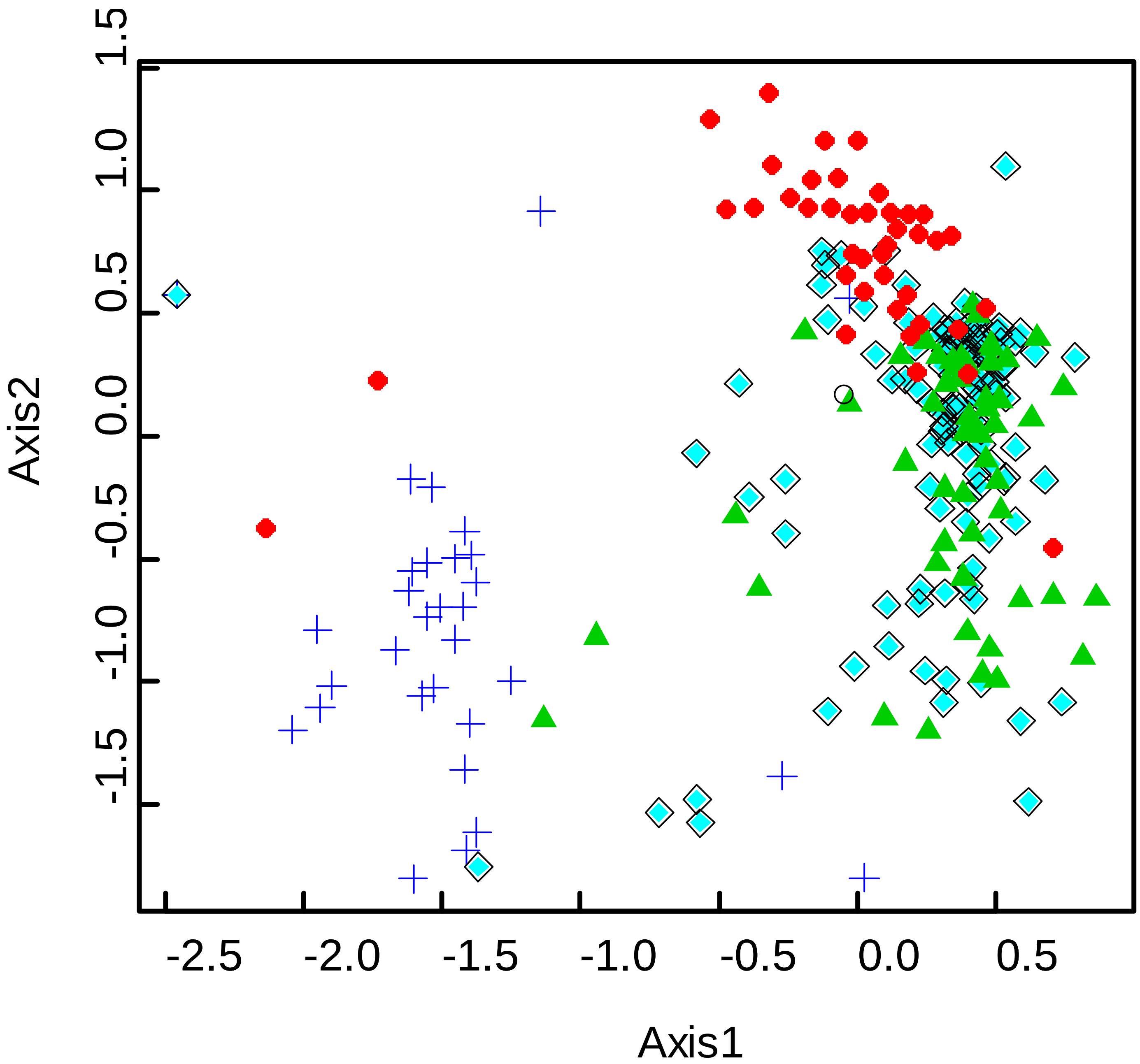
Plant functional trait selection at the community level and implications for modeling environmental change

Outline

- Community-level trait selection
  - Response-effect framework
- Traits that mitigate drought stress
  - Deep roots
  - Deciduous vs. evergreen
- Traits that mitigate heat stress
  - PSII regulation (chlorophyll fluorescence measures
  - VOC emissions

- “...community-level changes may amplify or dwarf physiological responses, resulting in changes in ecosystem processes that cannot be predicted by the physiology or morphology of individual plants present initially.”
    - Suding et al. 2008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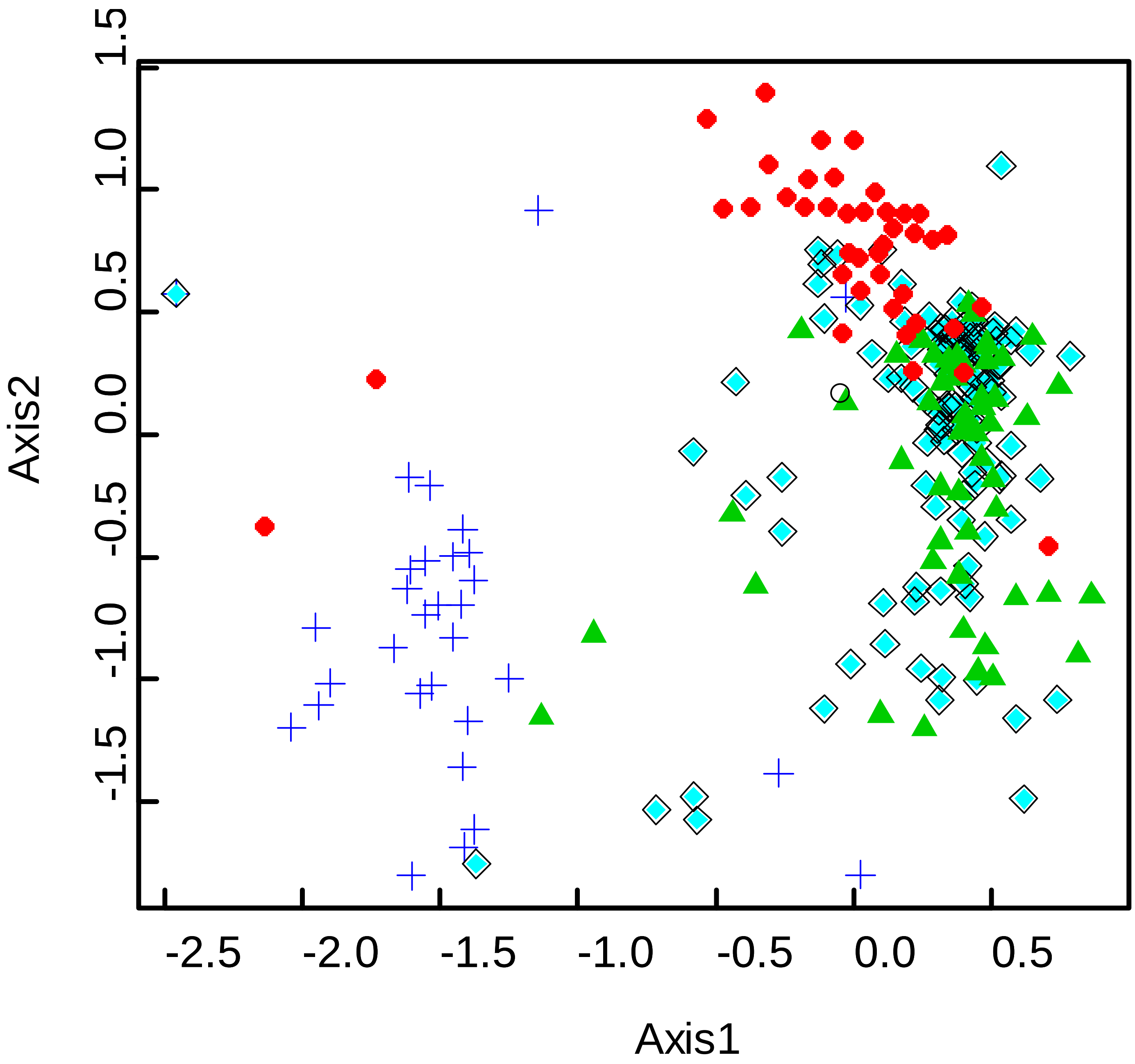
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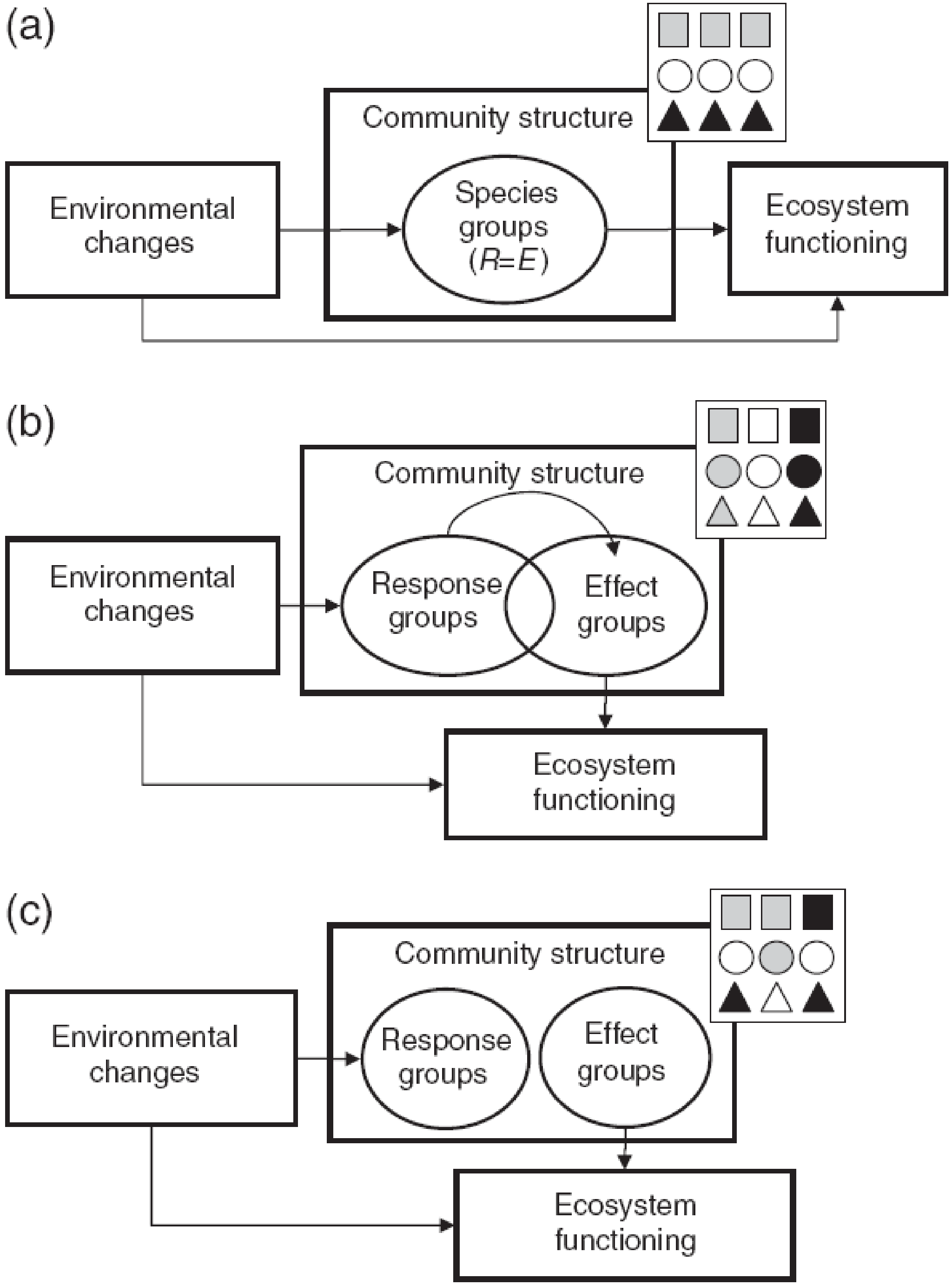
Response-effect framework

- Response traits: Traits that are selected as a response to environmental change.

- Effect traits: Traits that feed back to ecosystem functions.



- Which scenario is most amenable to modeling?

Mechanisms of drought induced mortality

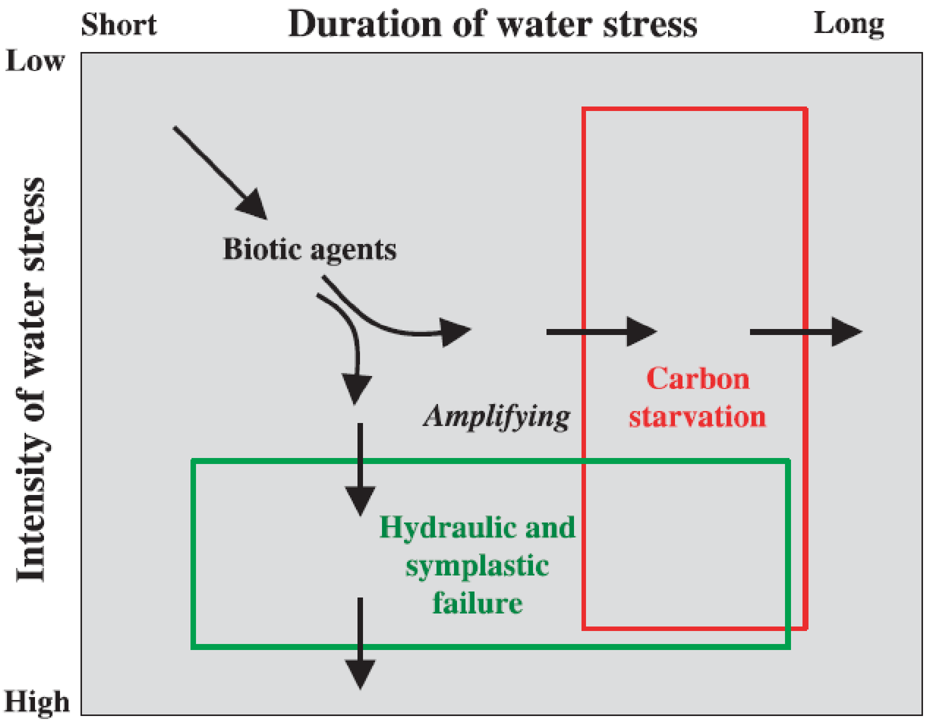


Fig. 3 Theoretical relationship, based on the hydraulic framework, between the temporal length of drought (duration), the relative decrease in water availability (intensity), and the three hypothesized mechanisms underlying mortality. Carbon starvation is hypothesized to occur when drought duration is long enough to curtail photosynthesis longer than the equivalent storage of carbon reserves for maintenance of metabolism. Hydraulic failure is hypothesized to occur if drought intensity is sufficient to push a plant past its threshold for irreversible desiccation before carbon starvation occurs. Biotic agents, such as insects and pathogens, can amplify or be amplified by both carbon starvation and hydraulic failure.

McDowell et al 2008

Deep roots

- Deep roots buffered water stress for 3 years of drought manipulation (Markewitz et al 2010).
- Evergreen forests NE Brazil maintain evapotransp during 5mo dry period by deep soil water uptake >8m (Nepstad et al 1997)
  - Up to 18m deep in forest!
- Deep roots also found in soil shafts at less seasonal (Manaus) and more seasonal (Paragominas) sites, and in Surinam (Nepstad et al 1997).
  - A common phenomenon around Amazon?

Implications of deep roots

- Response or effect trait?

Implications of deep roots

- Amazon soil profiles
- Water stress durations
- Continued transpiration during dry periods
- Continued, maybe amplified, photosynthesis during dry periods

Ishida et al 2006: Tropcial deciduous vs evergreen trees in Thailand

- As rainfall decreases, deciduousness increases (in Neotropics) (Medina 1995).
- High stomatal conductivity in deciduous trees
  - Due to large diameter vessels (Sobrado 1993)
- Short wet season

Franco 2005, Cerrado forrest

- Deciduous leaves had 50% higher CO2 uptake rates (per leaf mass) than evergreen leaves
  - Photoinhibition avoidance
- High specific leaf area (SLA) in deciduous
- Highly plastic stomatal regulation in deciduous
- Leafless period only 1-2 months
- Evergreen species showed decline in CO2 assimilation and stomatal conductance during dry season when VPD was highest
  - Photoinhibition tolerance
- Higher annual CO2 assimilation in deciduous trees?

Drought in Amazon floodplains (Parolin 2000, 2010)

- Some floodplain species evolved from savanna habitats
- Flooding is analogous rainfall seasonality.
- Adaptive traits to flooding overlap with drought tolerance traits
- Most Amazonian floodplain tree species have small, thick leaves, with wax coatings to limit transpiration
- Waxes may primarily serve to prevent water influx during inundation (dual drought/flood purpose)

Drought in Amazon floodplains (Parolin 2000, 2010)

- Flooding reduces water status, which initiates leaf dropping.
- Leaf production remains low during flooding, but photosynthesis continues—a plastic response.
- Similar responses occur during the dry periods.

Implications: Deciduous vs. evergreen

- Response or effect trait?

Implications: Deciduous vs. evergreen

- Duration of dry period
  - Stomatal regulation plasticity
- Timing of carbon uptake
- Alteration of transpiration regimes

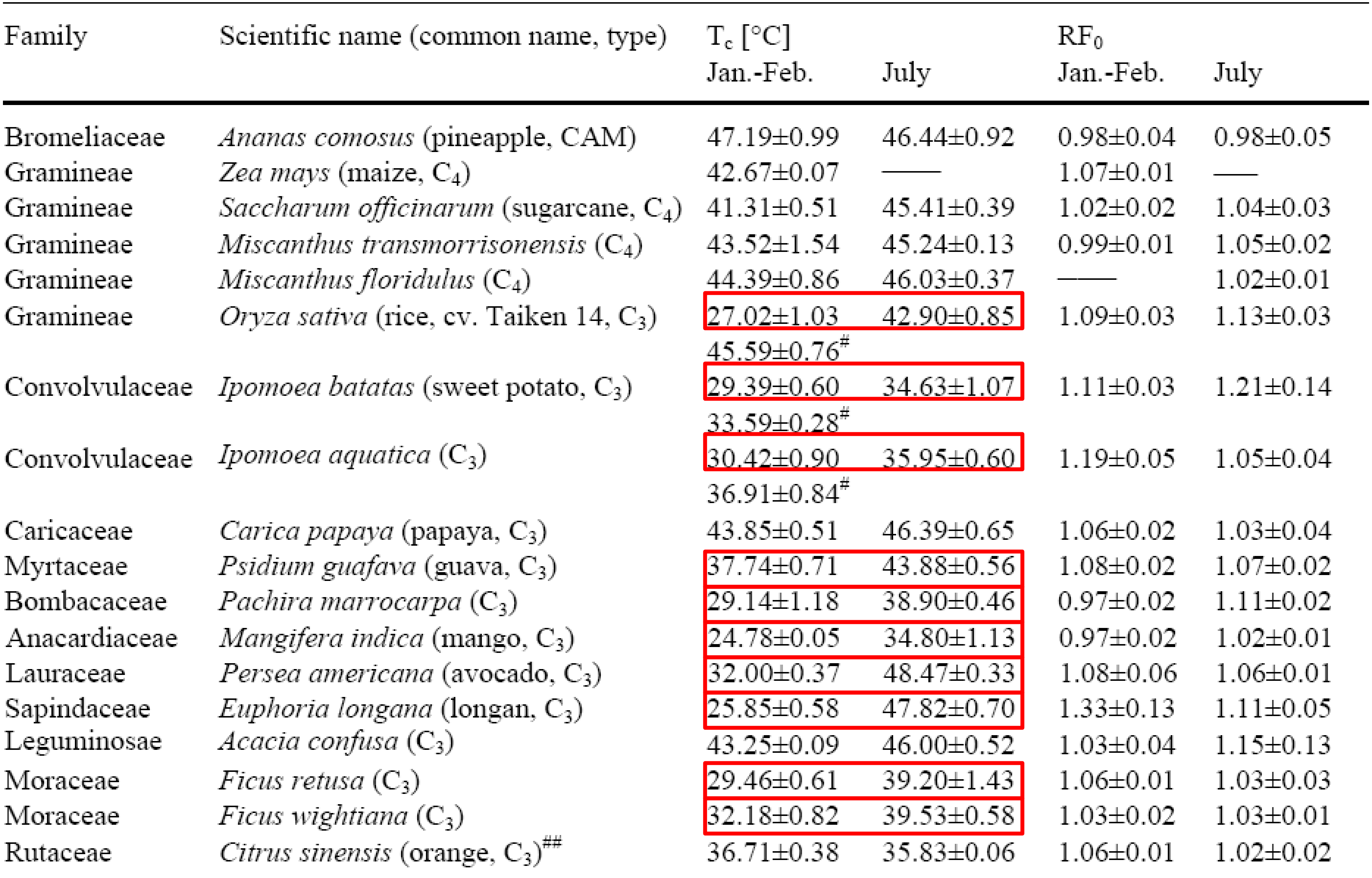
Chlorophyll fluorescence

- Draw chlorophyll fluorescence
- Critical temperature (T_c) = T at which dark fluorescence (F_0) dramatically increases.
- Thermal damage also assessed by Fv/Fm
  - Related to maximum efficiency of PSII, ideally around .83 (Maxwell and Johnson 2000)
  - Also see Weng & Lai (2005)

Inducing T_c increase

- Critical temperature only a few degrees C above actual in situ temperatures.
- and showed only marginal increases in T-crit when grown in elevated temps (Krause et al. 2010).
- Are other plants more plastic?

Seasonal T_c variability



Family	Scientific name (common name, type)	T_c [°C] Jan.-Feb.	T_c [°C] July	RF_0 Jan.-Feb.	RF_0 July
Bromeliaceae	*Ananas comosus* (pineapple, CAM)	47.19±0.99	46.44±0.92	0.98±0.04	0.98±0.05
Gramineae	*Zea mays* (maize, C_4)	42.67±0.07	——	1.07±0.01	——
Gramineae	*Saccharum officinarum* (sugarcane, C_4)	41.31±0.51	45.41±0.39	1.02±0.02	1.04±0.03
Gramineae	*Miscanthus transmorrisonensis* (C_4)	43.52±1.54	45.24±0.13	0.99±0.01	1.05±0.02
Gramineae	*Miscanthus floridulus* (C_4)	44.39±0.86	46.03±0.37	——	1.02±0.01
Gramineae	*Oryza sativa* (rice, cv. Taiken 14, C_3)	27.02±1.03	42.90±0.85	1.09±0.03	1.13±0.03
		45.59±0.76#			
Convolvulaceae	*Ipomoea batatas* (sweet potato, C_3)	29.39±0.60	34.63±1.07	1.11±0.03	1.21±0.14
		33.59±0.28#			
Convolvulaceae	*Ipomoea aquatica* (C_3)	30.42±0.90	35.95±0.60	1.19±0.05	1.05±0.04
		36.91±0.84#			
Caricaceae	*Carica papaya* (papaya, C_3)	43.85±0.51	46.39±0.65	1.06±0.02	1.03±0.04
Myrtaceae	*Psidium guafava* (guava, C_3)	37.74±0.71	43.88±0.56	1.08±0.02	1.07±0.02
Bombacaceae	*Pachira marrocarpa* (C_3)	29.14±1.18	38.90±0.46	0.97±0.02	1.11±0.02
Anacardiaceae	*Mangifera indica* (mango, C_3)	24.78±0.05	34.80±1.13	0.97±0.02	1.02±0.01
Lauraceae	*Persea americana* (avocado, C_3)	32.00±0.37	48.47±0.33	1.08±0.06	1.06±0.01
Sapindaceae	*Euphoria longana* (longan, C_3)	25.85±0.58	47.82±0.70	1.33±0.13	1.11±0.05
Leguminosae	*Acacia confusa* (C_3)	43.25±0.09	46.00±0.52	1.03±0.04	1.15±0.13
Moraceae	*Ficus retusa* (C_3)	29.46±0.61	39.20±1.43	1.06±0.01	1.03±0.03
Moraceae	*Ficus wightiana* (C_3)	32.18±0.82	39.53±0.58	1.03±0.02	1.03±0.01
Rutaceae	*Citrus sinensis* (orange, C_3)##	36.71±0.38	35.83±0.06	1.06±0.01	1.02±0.02

Weng & Lai 2005

Air temp vs leaf temp

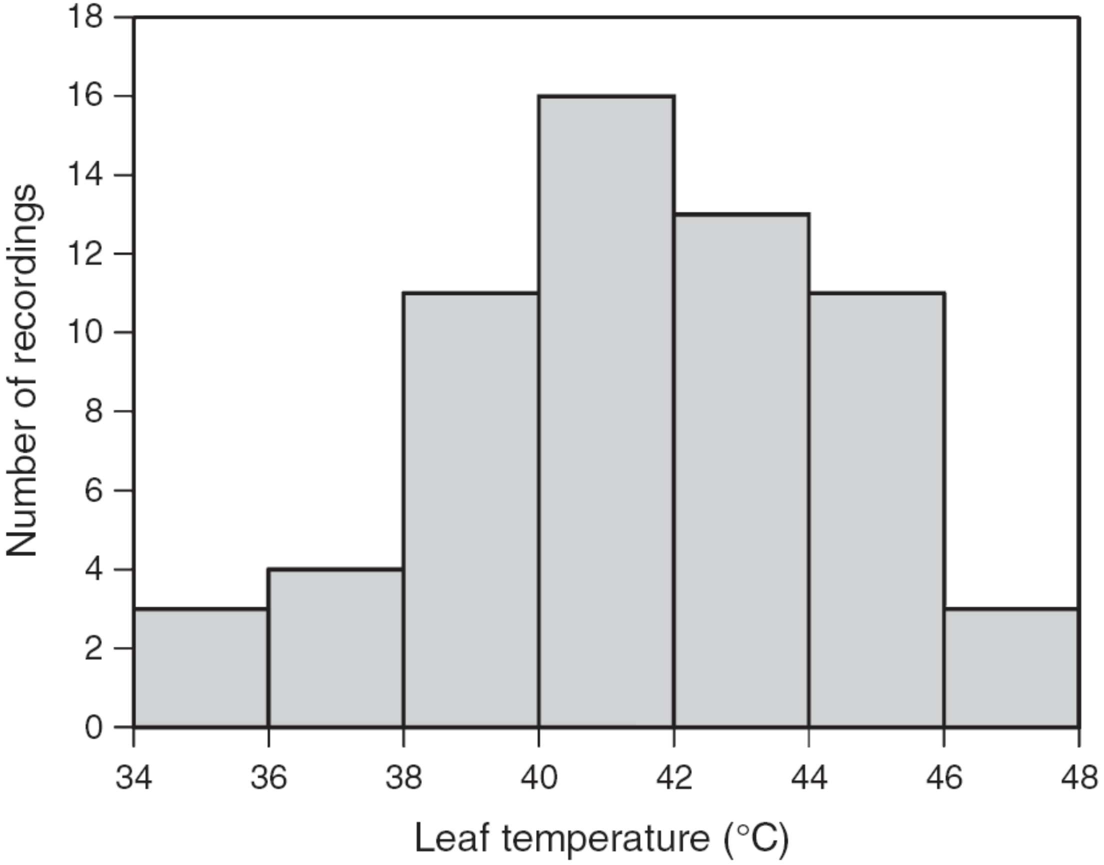


Fig. 3. Temperature of canopy sun leaves of *Ficus insipida* under high solar irradiance at high air temperature. Random measurements were done under low wind conditions in the late dry season (30 March 2009, ~1400 hours) on the upper (adaxial) side of fully sun-exposed mature leaves on a tall tree. PAR was around 2000 μmol photons m^{-2} s^{-1}; local maximum air temperature was 33.7°C.

(Krause et al 2010)

Air temp vs leaf temp

- How do air temperature and solar irradiance contribute in concert to surface temperature?
- Will increasing air temp cause an increase in full-sun leaf surface temps?

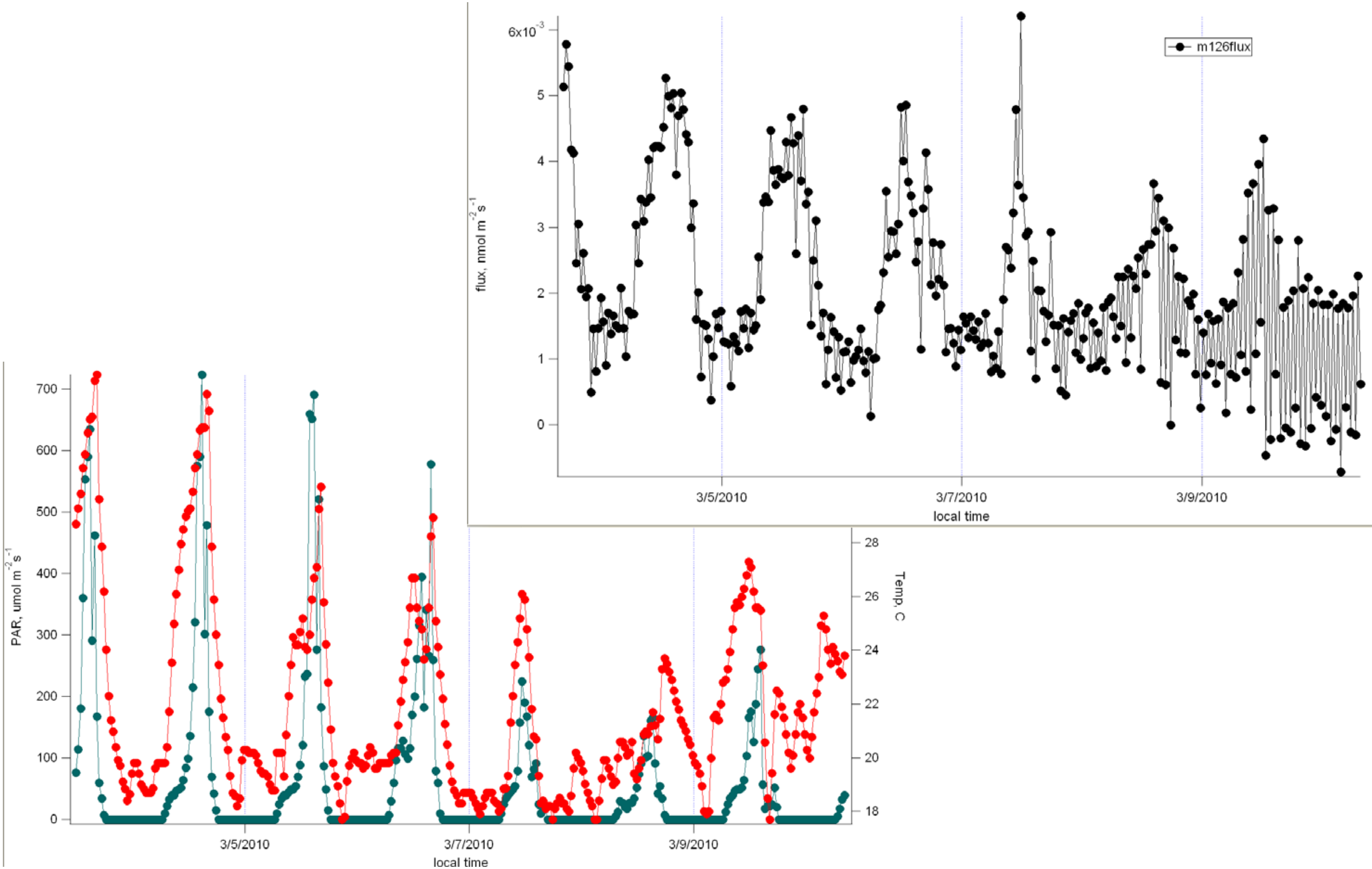
Implications: thermal tolerance plasticity

- Response or effect trait?

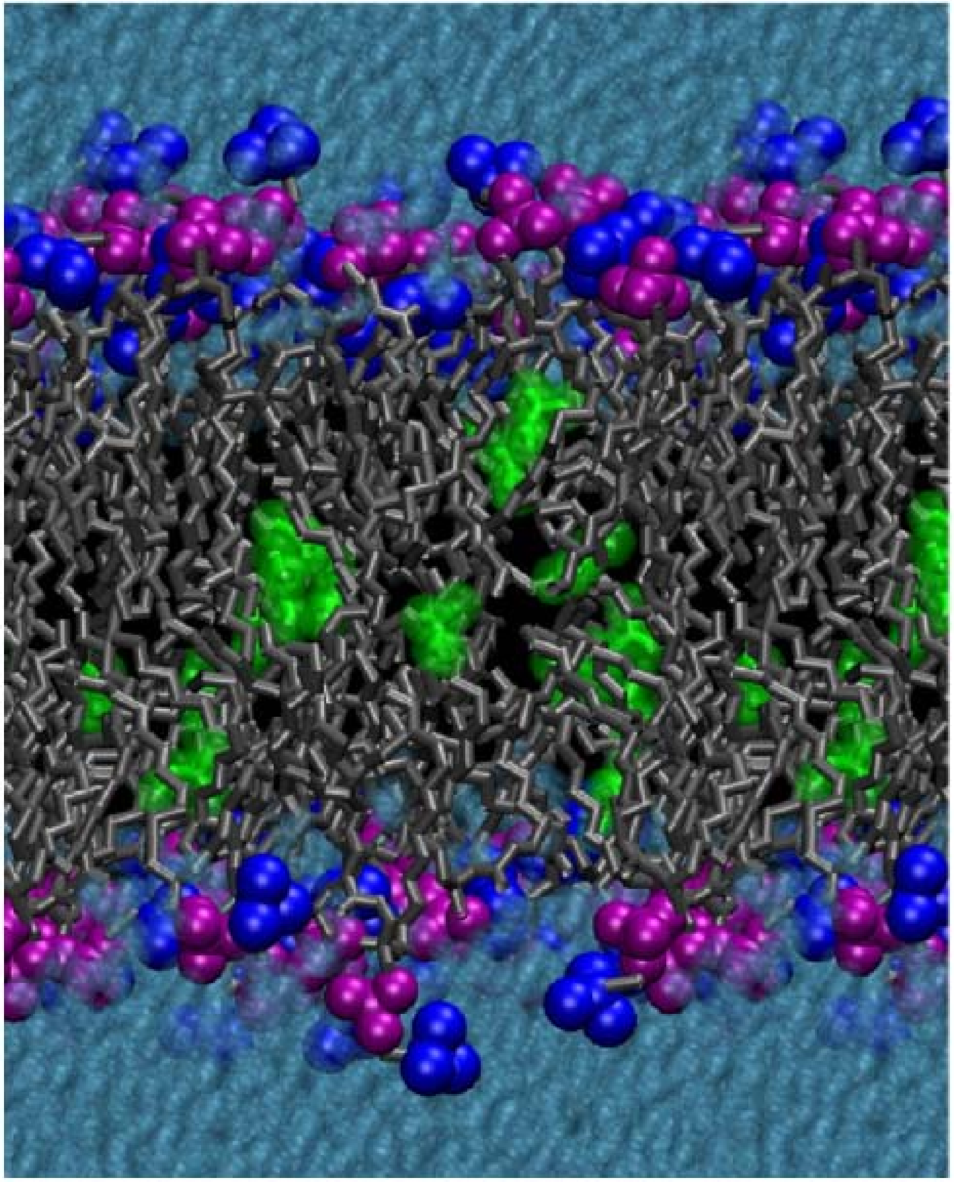
Isoprene emission (e.g., Penuelas 2005)

- Most common trait linked to heat tolerance
- ~15% of vascular plants produce isoprene
- Raises membrane thermotolerance
- Reduces endogenous and exogenous oxidants
  - Other VOCs may play the same role

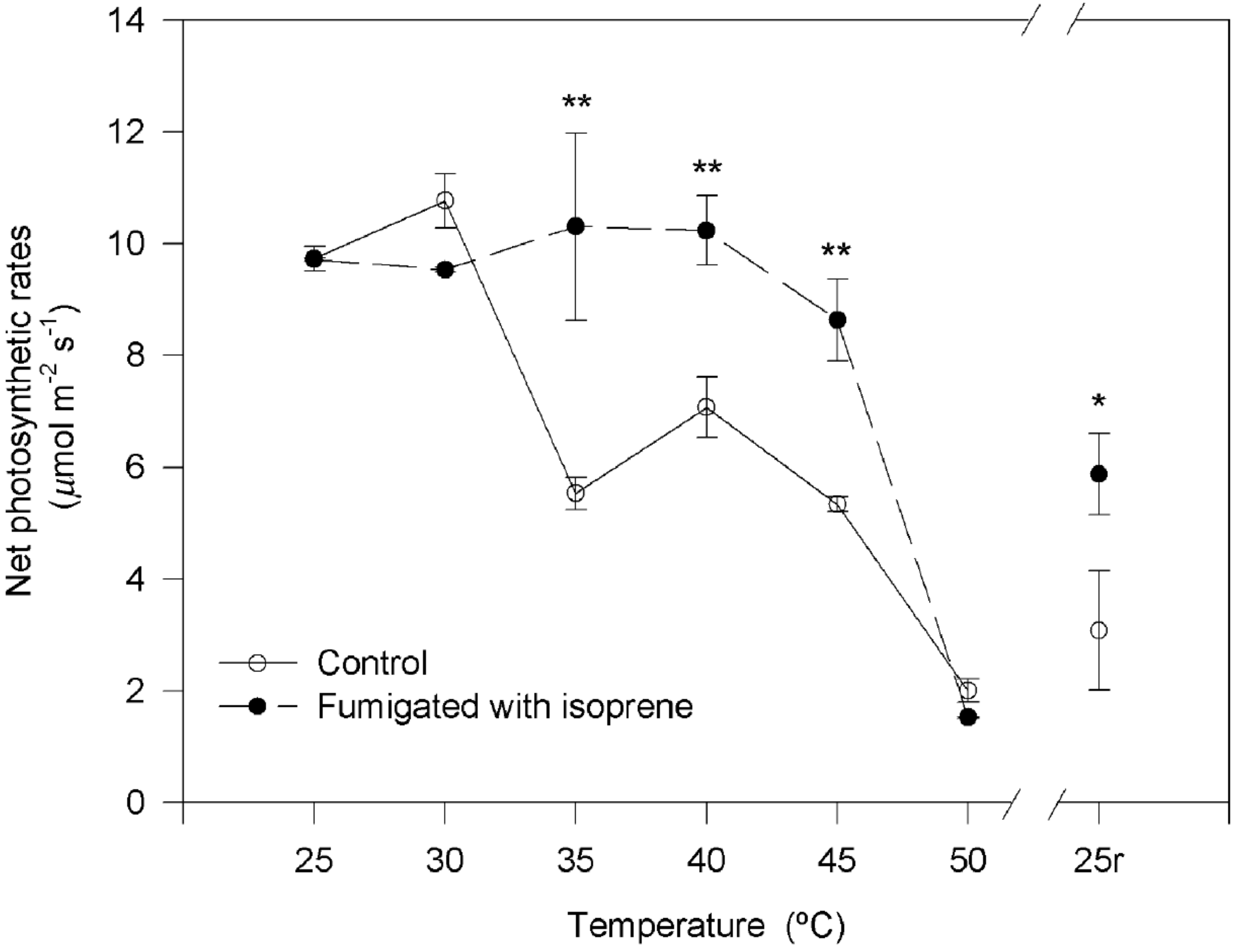
VOC emission tracks PAR and Temp

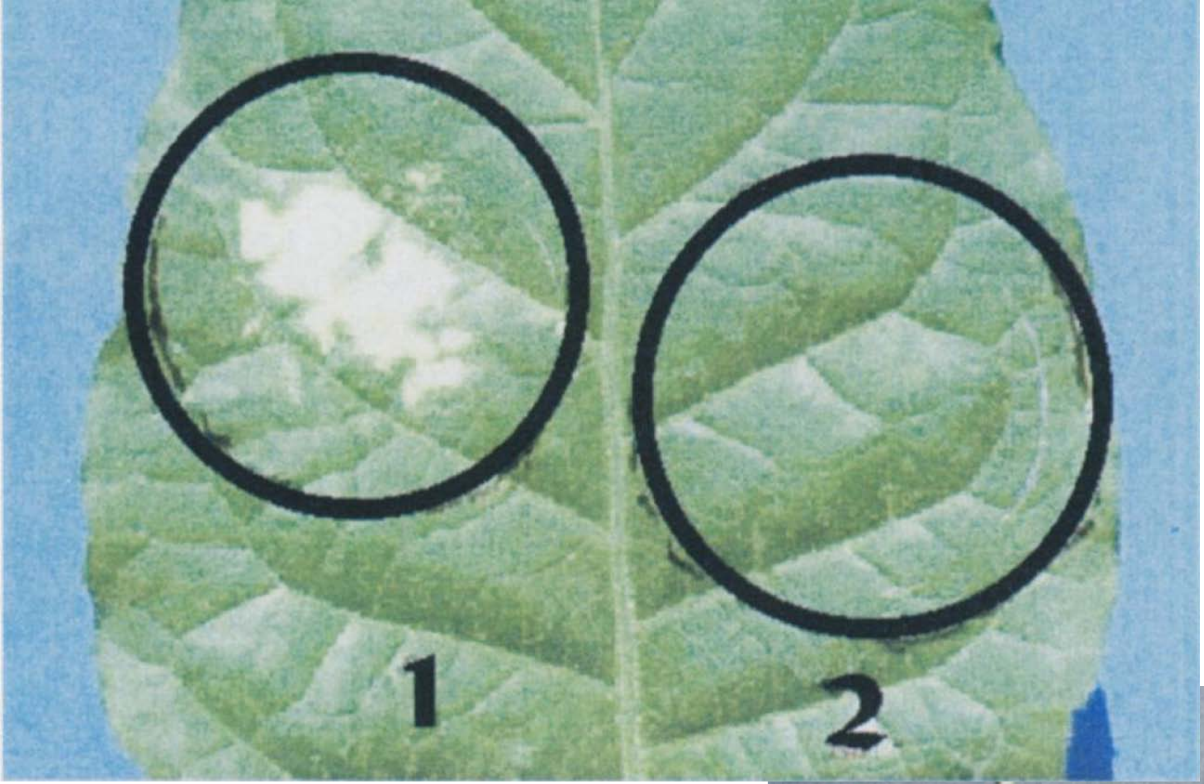


Isoprene increases membrane tail hydrophobicity (Siwko et al. 2007)



Isoprene fumigation (Penuelas et al 2005)



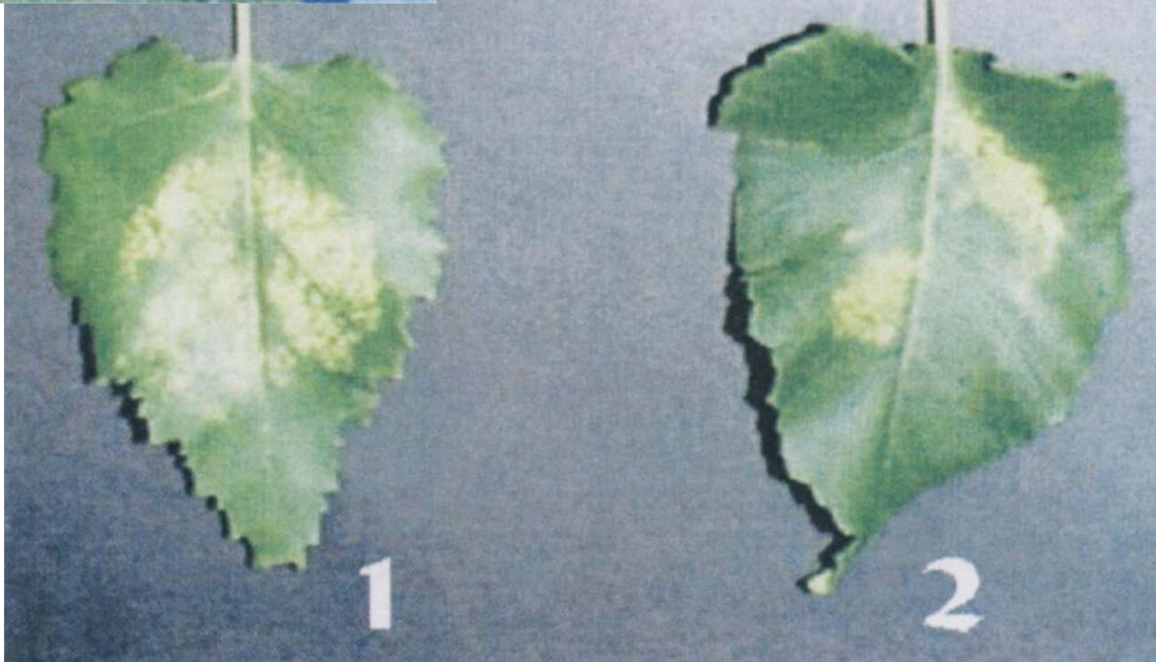


Loreto et al 2001

Fumigation treatments

1 = ozone

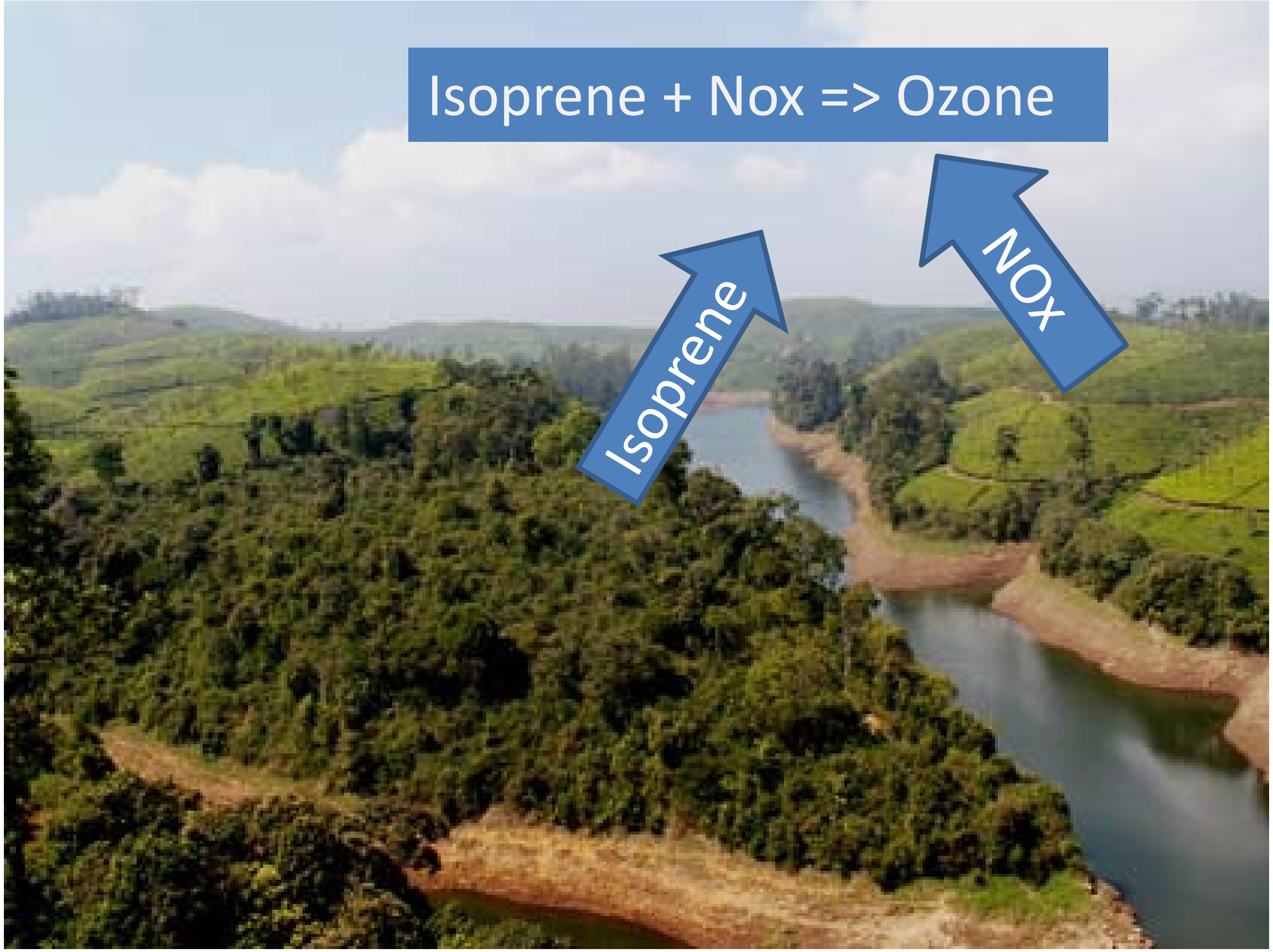
2 = ozone + isoprene



Has isoprene emission been selected for in our B2 TRF?

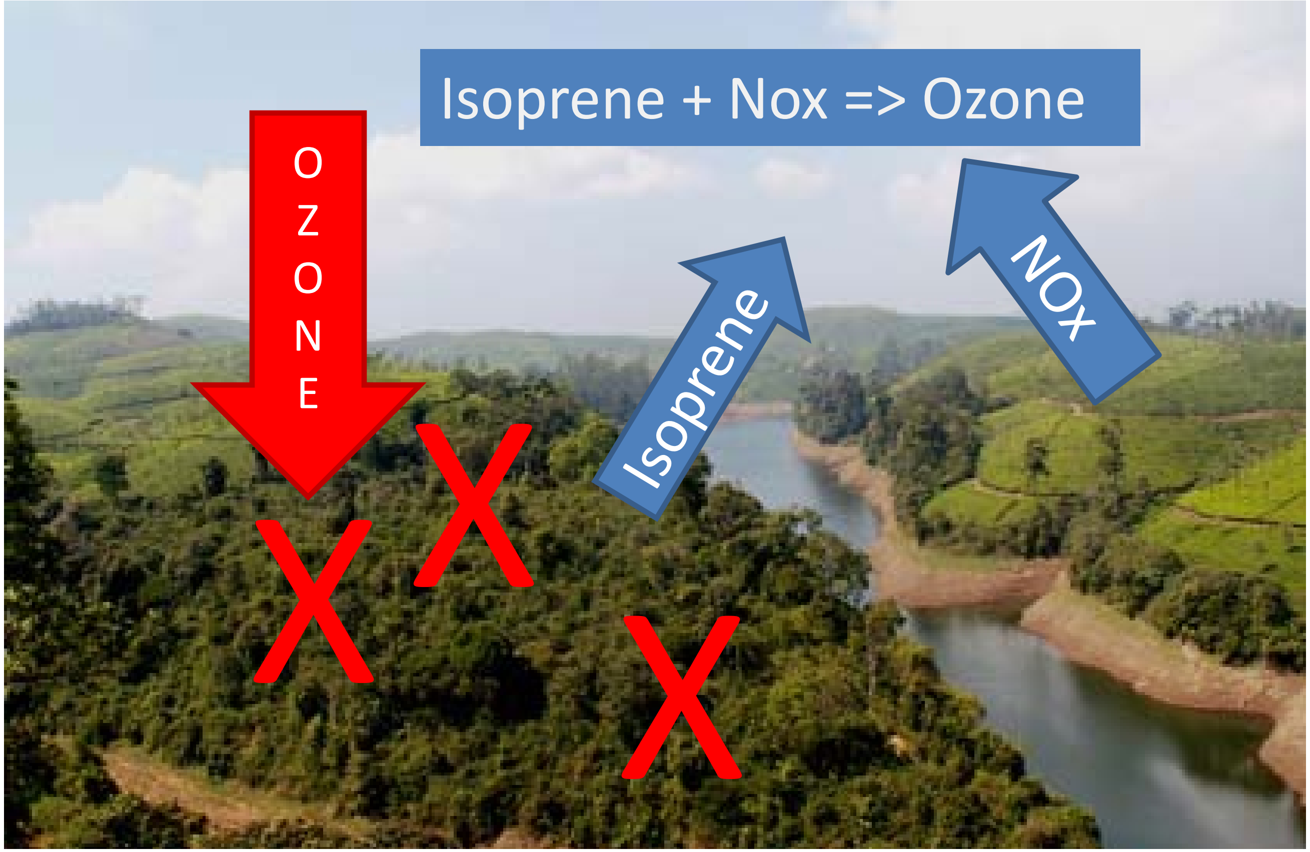
- At six Amazon forest sites, % of isoprene emitting species = 25-57% (Harley et al 2004)
- Literature search: 10/14 = 71% of B2 TRF species produce isoprene.

Isoprene increases ozone



Isoprene + Nox => Ozone

Isoprene increases ozone



- Community selection for isoprene emitters
-

Isoprene reduces ozone

OZONE

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Isoprene reduces ozone

Isoprene

OZONE

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Isoprene reduces ozone

Implications: VOC emissions

- Response or effect trait?

Other important traits?

- Seedling survival
- Fire
- Fungal endophytes
- HSPs
- Endogenous antioxidants
- C4
- Isohydric vs anisohydric (Rosie Fisher – Caxiuana)
- Wood density

Citations

- Franco AC, Bustamante M, Caldas LS, et al. 2005. Leaf functional traits of Neotropical savanna trees in relation to seasonal water deficit. 19:326-335.
- Harley P, Vasconcellos P, Vierling L, et al. 2004. Variation in potential for isoprene emissions among Neotropical forest sites. 10(5):630-650.
- Ishida A, Diloksumpun S, Ladpala P, et al. 2006. Contrasting seasonal leaf habits of canopy trees between tropical dry-deciduous and evergreen forests in Thailand. . 26(5):643-56.
- Krause GH, Winter K, Krause B, et al. 2010. High-temperature tolerance of a tropical tree , Ficus insipida: methodological reassessment and climate change considerations. 37:890-900.
- Loreto F, Mannozzi M, Maris C, et al. 2001. Ozone quenching properties of isoprene and its antioxidant role in leaves. 126(3):993-1000.
- Markewitz D, Devine S, Davidson Ea, Brando P, Nepstad DC. 2010. Soil moisture depletion under simulated drought in the Amazon: impacts on deep root uptake. 187(3):592-607.
- Maxwell K, Johnson GN. 2005. Chlorophyll fluorescence--a practical guide. 51(345):659-68.
- McDowell N, Pockman WT, Allen CD, et al. 2008. Mechanisms of plant survival and mortality during drought: why do some plants survive while others succumb to drought? 178(4):719-39.
- Medina, E. 1995. Diversity of life forms of higher plants in neotropi- cal dry forests. In Seasonally Dry Tropical Forests. Eds. S.H. Bull-ock, H.A. Mooney and E. Medina. Cambridge University Press, Cambridge, pp 221–242.
- Nepstad DC, Carvalho CR, Davidson EA, et al. 1994. The role of deep roots in the hydrological and carbon cycles of Amazonian forests and pastures. 372:666-669.
- Parolin P. 2000. Phenology and CO2-assimilation of trees in Central Amazonian floodplains. 16:465-473.
- Parolin P, Lucas C, Piedade MT, Wittmann F. 2010. Drought responses of flood-tolerant trees in Amazonian floodplains. . 105(1):129-39.
- Peñuelas J, Llusià J, Asensio D, Munne-Bosch S. 2005. Linking isoprene with plant thermotolerance , antioxidants and monoterpene emissions. 28:278-286.
- Siwko ME, Marrink SJ, de Vries AH, et al. 2007. Does isoprene protect plant membranes from thermal shock? A molecular dynamics study. 1768(2):198-206.
- Sobrado MA. 1993. Trade-off between water transport efficiency and leaf life-span in a tropical dry forest. 96:19-23.
- Suding KN, Lavorel S, Chapin FS, et al. 2008. Scaling environmental change through the community-level: a trait-based response-and-effect framework for plants. 14(5):1125-1140.
- Weng J, Lai M. 2005. Estimating heat tolerance among plant species by two chlorophyll fluorescence parameters. 43(3):439-444.