Dying light: detecting tree mortality risk with chlorophyll fluorescence

Megan Giddens, William Hammond, and Henry Adams
Department of Plant Biology, Ecology, and Evolution, Oklahoma State University, Stillwater, OK, USA

Background

Increased greenhouse emissions have altered Earth's climate, and rapid climate change has brought warm droughts—especially in semi-arid regions—leading to forest die-off and dieback[1,2]. Physiological stresses associated with climate change pose a great risk to tree survival, as future climate changes are likely to increase the intensity of droughts[3].

Piñon pines (*Pinus edulis*) have a high drought tolerance[2] but have succumbed to widespread drought-induced mortality in recent decades, likely due to hydraulic failure[4,5]. Xylem hydraulic failure occurs when the water potential surpasses a species-specific threshold and results in xylem embolism[6].

Remotely sensing hydraulic failure is presently not possible. Chlorophyll fluorescence (F_v/F_m) is a proxy frequently used in agricultural systems to detect water stress in plants.

Objectives

- Quantify the relationship between drought stress and chlorophyll fluorescence in *P. edulis.*
- Document variation of chlorophyll fluorescence within and between trees during drought stress.

Methods

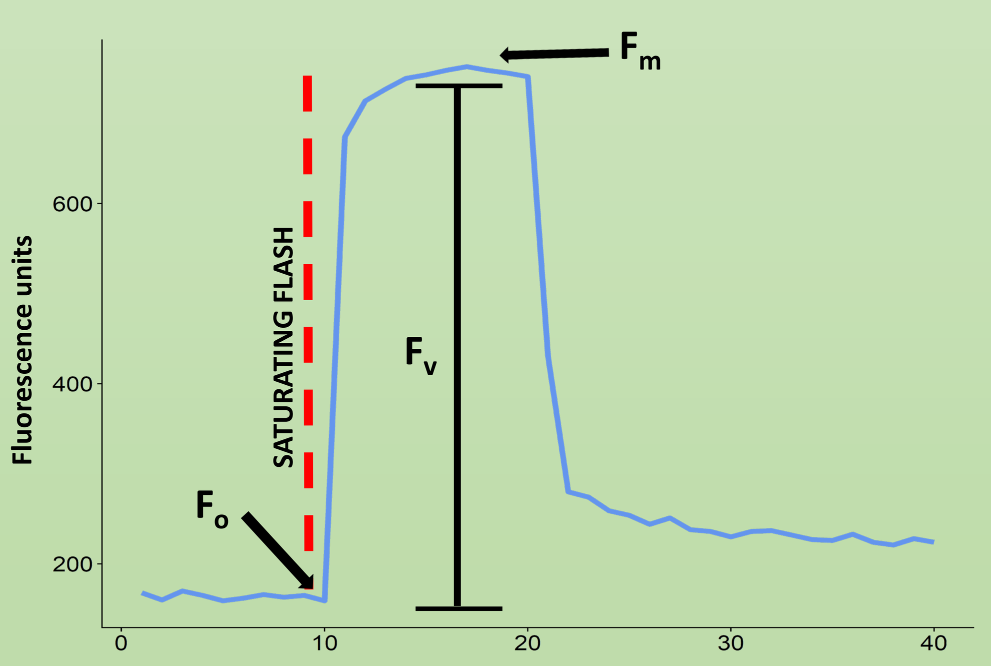

Figure 1: A representative chlorophyll fluorescence trace. F_o represents minimum fluorescence that occurs in the dark. F_m denotes the maximum fluorescence after a high-intensity light has been applied. F_v is the difference between the maximum and minimum fluorescence (calculated $F_m - F_o$).

Figure 2: Sample measurement of a Piñon pine tree (n=50) using an OS30P+ handheld chlorophyll fluorometer. We flagged 5 of the branches per tree for repeated measurement (n=250).

We measured the ratio of fluorescence (F_v/F_m) of each branch (n=5 per tree) and the water potential (MPa) of the tree at pre-dawn, once a week for 9 weeks.

Results

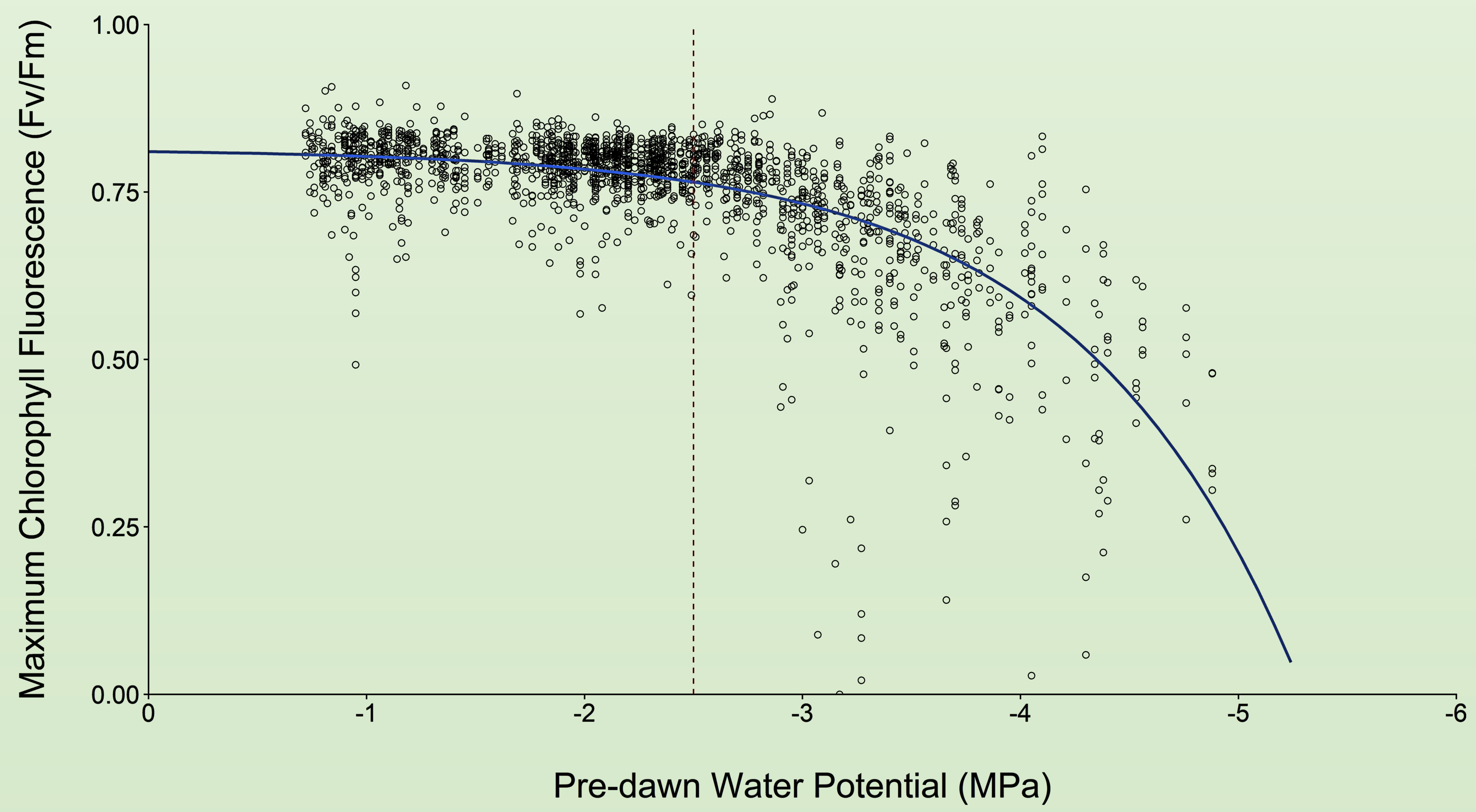

Figure 3. We compiled all 2, 250 of the data points from throughout the experiment and graphed the ratios of chlorophyll fluorescence (F_v/F_m) as a response to the tree's respective water potential (MPa) measurement. We fit the data with an exponential equation (blue line) to indicate the relationship between water potential and F_v/F_m. The dashed line at -2.5 MPa indicates the pre-dawn water potential at which trees began to experience moderate drought.

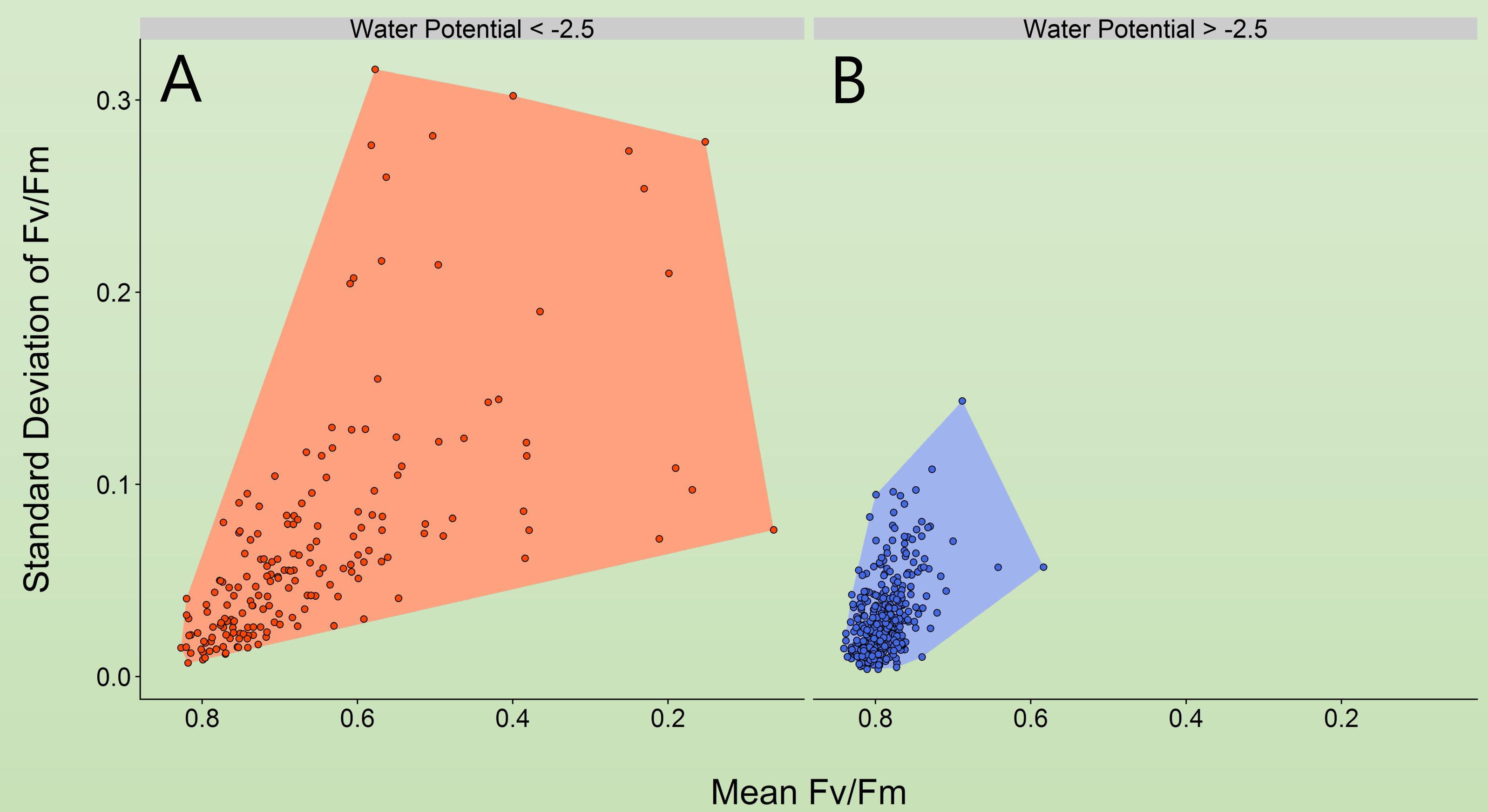

Figure 4. Variation of chlorophyll fluorescence within a tree after undergoing drought stress. Panel A demonstrates the variation of F_v/F_m within a tree in the trees that are undergoing moderate to severe drought-induced water stress. Panel B shows the variation of F_v/F_m within trees that are undergoing mild to no drought-induced water stress.

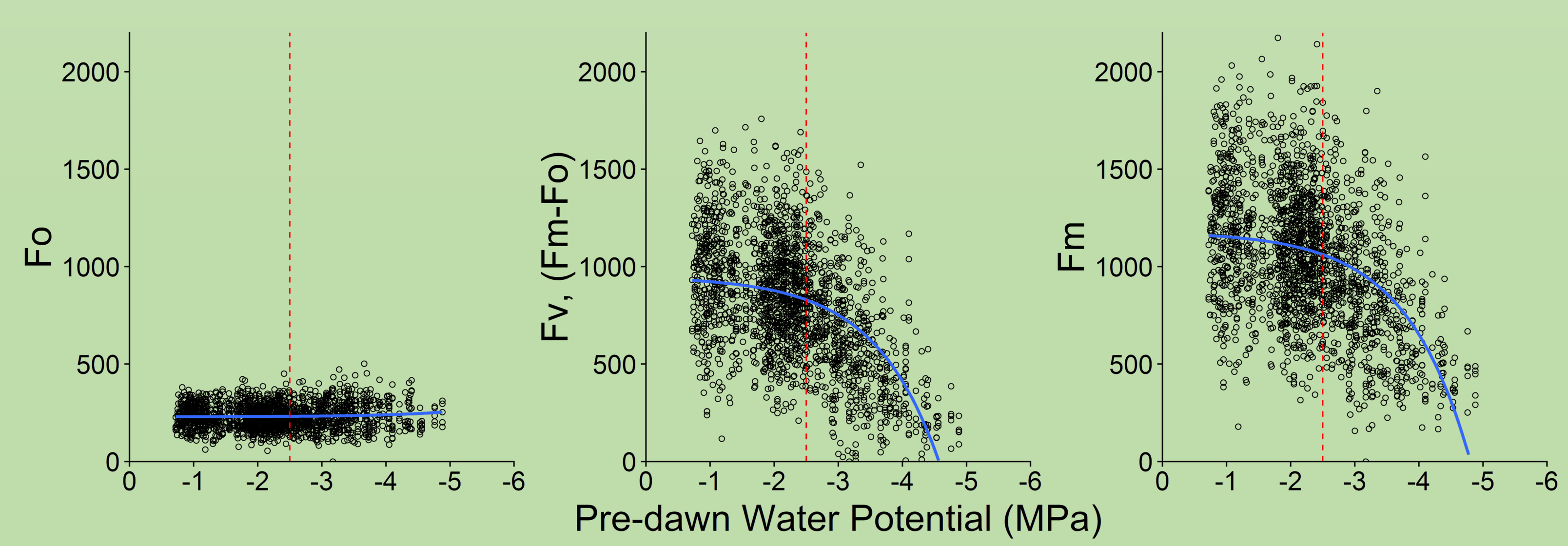

Figure 5. Scatter plots showing the individual F_o, F_v, and F_m data points in response to the tree's pre-dawn water potential (MPa) measurement. We fit the data with an exponential equation (blue line) to show the trend between the fluorescence and water potential measurements. A vertical line at -2.5 MPa was added to represent the pre-dawn water potential at which drought stress induced stomatal closure.

Discussion & Predictions

- Our data indicates that chlorophyll fluorescence is an indicator of drought-induced water stress in *P. edulis*. Our results also indicated that variation in chlorophyll fluorescence increases within a tree the longer drought stress prolongs.
- With further observations, we predict F_v/F_m will decrease exponentially as drought continues and will be a useful proxy of hydraulic failure, and therefore useful for determining if a tree will survive after drought stress is relieved.
- Continued research may allow us to quantify a lethal limit of drought stress as well as predict which trees will undergo the phenomenon of dieback and then recover rather than face mortality.

Impact

- While our study was focused on the photosynthetic capacity of dark-adapted samples, solar-induced fluorescence (SIF) could be used to predict chlorophyll fluorescence remotely. Future satellite observations of SIF could provide means of linking this research to ecosystem measurements.
- Continued research on drought-induced tree mortality will improve our ability to more accurately predict models of tree mortality. Refining predictions of tree mortality will further our understanding of climate change impacts on forests and feedbacks between terrestrial vegetation and climate.

Literature Cited

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