PROJECT INFORMATION

Project title:	**Next-generation modelling of the biosphere – Including new data streams and optimality approaches (MIND)**
Project ID:	223
Contact person:	Laura Marqués // laura.marques@usys.ethz.ch Benjamin Stocker // Benjamin.Stocker@usys.ethz.ch

PROJECT DESCRIPTION

The MIND project aims to understand the causes of changes in tree mortality and the implications for past and future trends in forest tree density. Specifically, we want to test the Grow-Fast-Die-Young hypothesis to investigate the links between leaf-level assimilation and stand dynamics. Elevated atmospheric carbon dioxide (eCO_2) has been reported to enhance photosynthesis by increasing both light-use efficiency (LUE, the ratio of photosynthesis rates over absorbed light) (1,2) and water-use efficiency (WUE, the ratio of photosynthesis over transpiration rates) (3). Consequently, tree growth rates and stand density are expected to improve (4). Tree growth enhancement could be translated into an increase in biomass stocks or could be associated with a reduction in the longevity of trees, thus reducing the ability of forest ecosystems to act as carbon sinks over long timescales (5,6). These links between growth and mortality, and the implications for forest stand density and self-thinning relationships are still debated (7). In this project we will combine simulations from a mechanistic model (LM3-PPA) with empirical analysis to identify links between leaf-level physiology, CO_2 fertilization and their effects on stand dynamics and future forest C storage projections.

The LM3-PPA8 is a cohort-based vegetation model which simulates vegetation dynamics and biogeochemical processes. The model allows for evaluation of a series of organizational scales: physiological (photosynthetic carbon gain), individual (stem diameter, height growth rates), population (size structure, population densities), community (species-level successional dynamics), and ecosystem (C storage, Net Primary Productivity (NPP)).

The model is able to link photosynthesis standard models (9) with tree allometry and stand dynamics using the Perfect Plasticity Approximation (PPA)10. The PPA assumes that tree crowns are organized into discrete canopy layers, within which all plants receive the same incoming radiation, allowing the model to predict the competitive strategies (Fig. 1a). The key links between leaf-level assimilation and stand dynamics depend on the carbon turnover time. In this sense, we will investigate alternative mortality assumptions about the functional dependence of mortality based on (a) tree size: high mortality rate for large trees; (b) tree C balance: carbon starvation as a decreasing factor in the cohort's non-structural carbohydrates (NSC) levels; (c) growth rate: high mortality rate for fast growing trees. A constant self-thinning mortality rate will be also formulated to be used as a reference in the model outputs. Rising LUE and WUE conditions will modify the self-thinning relationship, subjected to the alternative mortality assumptions invoked. Changes in this relationship are expected to show a shift upwards or a change in the slope leading to denser stands and/or bigger trees, or to keep the relationship constant (Fig. 1b).

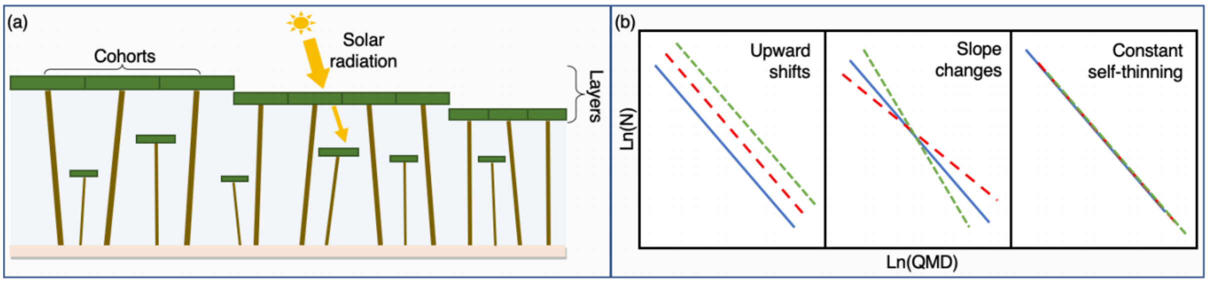

Figure 1. (a) Representation of cohorts and forest layers in LM3-PPA. Adapted from Weng et al. 2015. (b) Implications for the self-thinning relationship (Density (N) vs. Quadratic Mean Diameter (QMD) at log-scale) expected to be derived from the different mortality assumptions.

The ICP Forests data will be used to provide empirical support to these simulations. At the stand level, we will evaluate how trends in self-thinning relationships change over time and when growth rate increases. Unmanaged plots will be selected when possible to ensure that mortality is attributed to disturbances or to competition. The empirical data will be analysed fitting linear mixed-effects models (11), which allow to control for confounding factors. Stand density will be the dependent variable, while quadratic mean diameter (QMD), calendar year and tree growth will be the fixed factors and plot ID the random factor. This empirical analysis will be compared with the simulations obtained from LM3-PPA to identify temporal trends in forest density and growth-density relationships. The self-thinning law (12) in forest stands describes that the number of individuals declines with their average size. This is due to progressive mutual shading as tree crowns expand, with negative effects of shaded individuals' C balance and a resulting increase in their mortality. Our aim addresses that elevated atmospheric CO_2 and its fertilizing effect on leaf-level photosynthesis positively affects the C balance of trees and thereby alleviates light competition leading to denser stands. This data-supported mortality-modelling will help to identify links between forest responses and environmental changes at the leaf, tree and stand levels and yields new insight into the causes of currently observed terrestrial carbon sinks and future responses.

References

(1) Mousseau M and Saugier B (1992) J Exp Botany 43, 1121–1130.
(2) Herrick JD and Thomas RB (1999) Tree Physiology 19, 779–786.
(3) Keenan TF et al (2013) Nature 499, 324–327.
(4) Huang JG et al (2007) Critical Reviews in Plant Sciences 26(5-6), 265-283.
(5) Körner C (2017) Science 355, 130–131.
(6) Bugmann H and Bigler C (2011) Oecologia 165, 533–544.
(7) Kubiske ME et al (2019) Journal of Forestry 117, 38–45.
(8) Weng ES et al (2015) Biogeosciences 12, 2655–2694
(9) Farquhar GD et al (1980) Planta 149, 78–90.
(10) Purves DW et al (2008) Proc Natl Acad Sci USA, 105, 17018–17022.
(11) Zuur AF et al (2009) Springer.
(12) Yoda K et al. 1963. J Biol Osaka City Univ 14, 107–129