A Trait Based Approach to Exploring the Impacts of Species Diversity and Functional Diversity on Algal Community Productivity

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Project Goals: The LLNL Bioenergy SFA seeks to support sustainable and predictable bioenergy crop production through a community systems biology understanding of microbial consortia that are closely associated with bioenergy-relevant crops. We focus on host-microbial interactions in algal ponds and perennial grasses, with the goal of understanding and predicting the system-scale consequences of these interactions for biomass productivity and robustness, the balance of resources, and the functionality of surrounding microbial communities. Our approach integrates 'omics measurements with quantitative isotope tracing, characterization of metabolites and biophysical factors, genome-enabled metabolic modeling, and trait-based representations of complex multi-trophic biological communities, to characterize the microscale impacts of single cells on system scale processes.

From an energy perspective, eukaryotic microalgae and prokaryotic cyanobacteria (collectively known as algae) have been proposed as a promising commercially viable feedstock for biofuels. Research has been underway for decades to realize the full potential of algal biofuels at the commercial scale; however, open pond algal monocultures are frequently subject to collapse due to a range of factors including grazing, and infection by pathogens or parasites. Recently, there have been calls for the application of ecological principles to overcome such bottlenecks in algal cultivation. One approach is to replace less reliable monocultures with customized polycultures where the algal consortium composition is chosen using theoretical relationships between biodiversity, productivity and stability. For these purposes, measures of functional trait composition have been acknowledged as a better representation of biodiversity than traditional functional group assignments (e.g. based on taxonomy). Functional traits can be morphological, physiological or phenological characteristics that regulate organismal fitness in a given environment.

In order to predict the combinations of functional traits that can lead to sustained biomass yields of algal polycultures, we are taking a trait-based modeling approach, where the high biological complexity of an algal community can be reduced to being represented as members of functional guilds, each defined by distinct combinations of traits related to substrate utilization, growth rate, resource use efficiency and response to environmental factors (e.g. temperature, light). We developed a trait-based dynamic energy budget model (TB-DEB) of microalgal polycultures to explore the relative impacts of microalgal functional diversity and species diversity on productivity across systems with varying and contrasting niches. The projected seasonal variations in algal biomass production were explored using environmental data (summer and winter temperature and photosynthetically active radiation) from operational algal ponds that are part of the ATP^3 consortium and that represent distinct climate zones (https://openei.org/wiki/ATP3_Data). In the first set of simulations, algal communities consisting of 48 algal species were selected based on combinations of physiological traits (e.g. nutrient affinity, maximum uptake rates) constrained by biochemical trade-offs. The trait values (i.e. relating to temperature, light, N and P harvesting) were based on published literature values from laboratory experiments. Trait values relating to N and P harvesting kinetics show allometric scaling as expected, while trade-offs between maximum uptake rate and substrate affinity also follow known relationships. Model simulations tracked community changes over time after starting out with equal amounts of each of the 48 algal species biomass. Simulations mimicking separate summer and winter climate regimes but with constant nutrient loading resulted in emergent community compositions with temperature differences driving the selection of algal strains from the polycultures.

In subsequent simulations, we specifically selected algal species composition based on the relative position of algal species along functional trait axes. First, algal strains were categorized based on their response to environmental temperature through the following traits: (1) optimal growth temperature, (2) minimum growth temperature, (3) maximum growth temperature. Each of these traits directly relates to resource acquisition and growth in response to environmental temperature. Next, we designed *in silico* algal polycultures with increasing functional and species diversity, and simulated growth under summer followed by winter climate regimes. The idea was to explore the manipulation of different levels of complementarity in resource acquisition. Analysis of cumulative system biomass of the designed algal polycultures at the end of winter highlighted the greater positive impact of increasing functional diversity, rather than species diversity, on system productivity, under operational environmental conditions. These simulated outcomes will be tested in ongoing laboratory experiments and further simulations are underway to explore such relationships in the presence of phycosphere-associated heterotrophic bacteria that we hypothesize can further alter algal traits such as nutrient acquisition and response to temperature changes.

This work was performed under the auspices of the U.S. Department of Energy at Lawrence Livermore National Laboratory under Contract DE-AC52- 07NA27344 and supported by the Genome Sciences Program of the Office of Biological and Environmental Research under the LLNL Biofuels SFA, FWP SCW1039.