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Individual Reflective Essay
CEE 352: Microbial Principles

Algae-Coral Symbiosis & Implications in Electron Transport Modeling

The Environmental Problem:

Algal photophysiology in coral reefs is pivotal for the health and survival of tropical oligotrophic ocean ecosystems because of the symbiotic relationship between corals and endosymbiotic dinoflagellate algae, known as *Symbiodinium*[1]. However, overfishing (leading to removing primary algae consumers and, ultimately, algal blooms), increased UV radiation, and pollution leave this relationship vulnerable to anthropogenic stressors and climate change impacts. I aim to address the protection and conservation of coral reefs by employing microbial principles, including photosynthesis and the electron transport chain–maintaining a strong emphasis on ecological safety– to support and monitor the critical relationship between algae and reefs.

Microbiological Processes and Metabolic Pathways:

The complex algae-coral symbiotic relationships remain crucial to reefs as algae utilize photosynthesis with the assistance of the enzyme ribulose to convert sunlight and CO2 into organic oxygen and carbon for fueling coral growth, calcification, and habitat viability– promoting diverse, nutrient-rich, and effectively regulated ecological systems. Additionally, coral-algae-symbiosis assists in dissipating excess byproducts that otherwise contribute to oxidative stress, coral deterioration, and endangerment[2]. Depicted below is (a) an overhead view of the architecture of a coral reef in Fiji [Figure 1][3]. Images (c) and (d) highlight the genetically identical polyps connected by living tissue within the colonial invertebrates, which serve as hosts for symbiotic dinoflagellates, demonstrating the rich photosynthetic pigmentation and other photosynthetic products provided by algae.

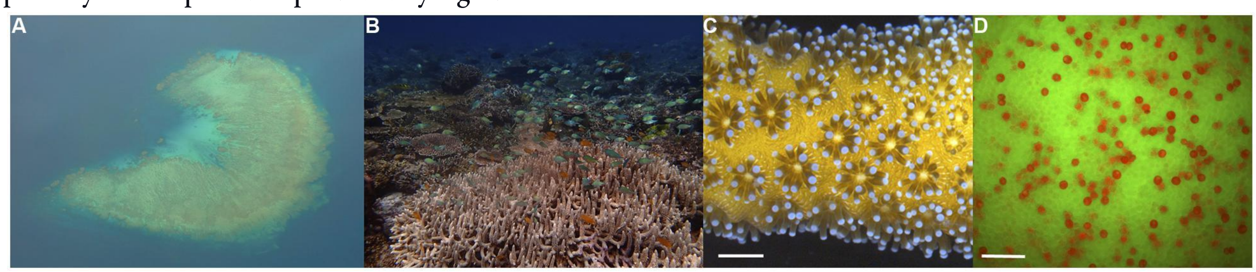

Figure 1: (A) Coral reef architecture in shallow, oligotrophic tropical waters (B) Photo location: Raja Ampat, Indonesia. (C) Scale bar represents 1 cm. (D) fluorescence microscopy image showing a Montipora capitata coral egg (green fluorescence from coral fluorescent proteins) and intracellular Symbiodinium (red fluorescence from chlorophyll). Scale bar represents 50 µm. (Images by M. S. Roth.)

I want to focus specifically on *Clade D Symbiodinium* algae, its photosynthetic (and carbon metabolic) processes, and the mapping of its gene expression. This monophyletic group contains thermally tolerant coral endosymbionts, which assist in resistance to elevated sea temperatures and coral bleaching. The *Symbiodinium* supplies the coral with glucose, glycerol, and amino acids. The coral uses these photosynthesis byproducts to make proteins, fats, and carbohydrates, then harnessing the combination of Bicarbonate Uptake of (HCO3-) and Calcium Ion Uptake of (Ca2+) from surrounding seawater to produce

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[1]Rosenberg E, Kellogg CA, Rohwer F. Coral Microbiology. *Oceanography*. 2007;20(2):146-154. Accessed December 2, 2023. https://www.jstor.org/stable/24860055?seq=1

[2]Rädecker N, Pogoreutz C, Gegner HM, et al. Heat stress destabilizes symbiotic nutrient cycling in corals. *Proceedings of the National Academy of Sciences*. 2021;118(5):e2022653118. doi:https://doi.org/10.1073/pnas.2022653118

[3] Roth MS. The engine of the reef: photobiology of the coral-algal symbiosis. Frontiers in Microbiology. 2014;5. doi:https://doi.org/10.3389/fmicb.2014.00422

calcium carbonate (CaCO3) for fueling coral growth and calcification. "Corals that host algae can deposit calcium carbonate [the skeleton that forms reefs] up to 10 times faster than non-symbiotic corals[4]." An algae study examining the transcriptome within juvenile corals by RNA-sequencing revealed that *Clade D Symbiodinium* consists of genes with enriched pathways to carbon metabolism and biosynthesis of amino acids. Upregulation of genes encoding how coral processes carbon compounds and the building of proteins to grow, maintain, and regulate functions of the cell (like photosynthesis and nitrogen recycling)[5] indicates an increase in the expression of these pathways– meaning the corals were actively using these pathways, increasing coloration [as seen in Figure 1 (c) and (d)] and the quality of photosynthesis. The research investigation detected increased activity and metabolic changes via heat maps showing expression patterns of genes in aposymbiotic corals and two Clades of *Symbiodinium* (C & D), as seen below [Figures 2 & 3][6].

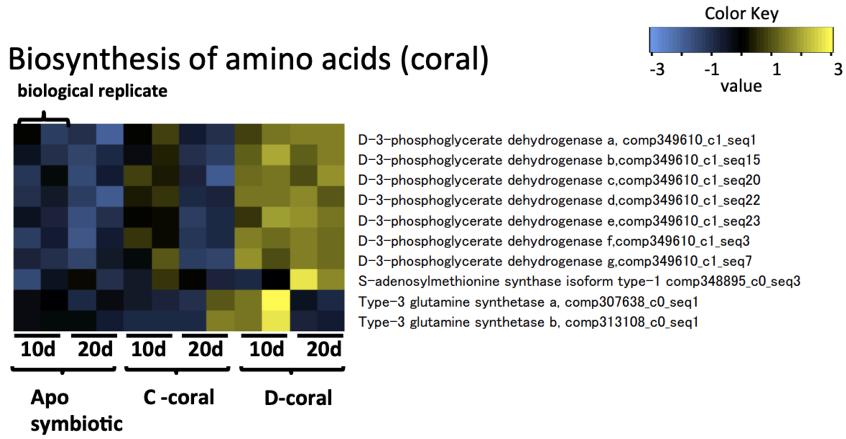

Figure 2: Heat map of expressions of genes related to the biosynthesis of amino acids

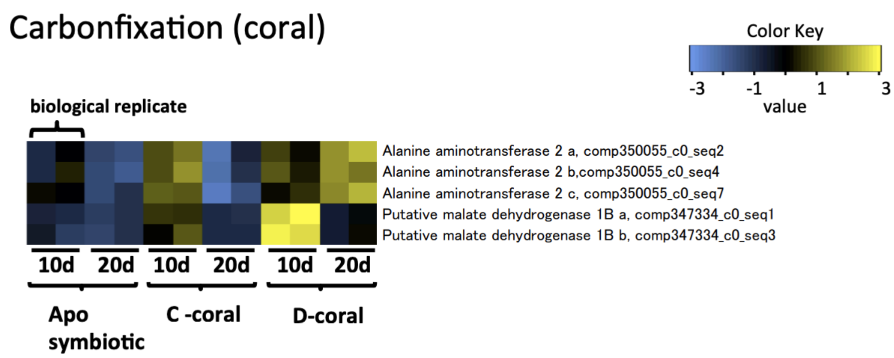

Figure 3: Heat map of expressions of genes related to carbon fixation

Addressing the Problem:

Figures 2 and 3 demonstrate the increased activity of the set of RNA molecules associated with the biosynthesis of amino acids and carbon fixation, respectively. In both cases, corals colonized by Clade D demonstrated heightened utilization of those genes related to biosynthesis and carbon fixation pathways. Implementing this information into reef conservation, using these RNA-Seq. and gene expression technologies would assist in identifying other beneficial symbiotic algae. For instance, recognizing genes

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[4]Zandonella C. When corals met algae: Symbiotic relationship crucial to reef survival dates to the Triassic. Princeton University. Published November 2, 2016.
https://www.princeton.edu/news/2016/11/02/when-corals-met-algae-symbiotic-relationship-crucial-reef-survival-dates-triassic

[5] Wang JT, Douglas AE. Essential amino acid synthesis and nitrogen recycling in an alga-invertebrate symbiosis. *Marine Biology*. 1999;135(2):219-222. doi:https://doi.org/10.1007/s002270050619

[6]Yuyama I, Ishikawa M, Nozawa M, Yoshida M, Ikeo K. Transcriptomic changes with increasing algal symbiont reveal the detailed process underlying establishment of coral-algal symbiosis. *Scientific Reports*. 2018;8(1). doi:https://doi.org/10.1038/s41598-018-34575-5

related to increased nutrient regulation, bioremediation of pollutants, UV resilience[7], and additional pivotal transcriptomes of endosymbiotic dinoflagellate algae.

Taking advantage of this RNA-sequencing and heat mapping technology, I propose exploring its applications regarding a microbial sensor that monitors and assesses electron transport efficiency in coral reefs, providing early warning signs of stress. This practical application would allow the annotation of genes involved in electron transport, photosynthesis, and related metabolic pathways and subsequent quantification of the expression levels. Expanding this proposal to real-world integration would take proper execution of the following 10-step plan.

Pathway to Implementation:

Utilizing funding from research scholarships (like the Mary Gates Undergraduate Research Scholarship), the Interdisciplinary Honors Program experiential learning financing, and partnerships with the Jodi N. Young Lab [collaborating on marine microalgae contributions to carbon fixation], UW PacBio Sequencing Services [for services in preparing sequencing libraries], and the UW Wang Laboratory [concerning increasing electron transport chain understanding] I would:

Getting Started (Lab Environment):

1. **Sample Collection and RNA Extraction:** Collect symbiotic algae samples, extract RNA to capture the transcriptome, and establish sequencing libraries.
2. **RNA-Seq Analysis:** Analyze RNA-Seq data to identify genes with differential expression under varying conditions (e.g., temperature or light changes).
3. **Gene Annotation and Quantification:** Annotate genes related to electron transport (ET), photosynthesis, and pathways, quantifying their expression levels.
4. **Heat Map Visualization:** Create heat maps to visualize ET gene expression patterns, comparing maps across conditions to identify environmental response patterns.
5. **Integration and Spatial Mapping:** Integrate RNA-Seq with environmental data, spatially mapping gene expression to correlate changes with environmental conditions and reef locations.

Expanding (Field):

1. **Temperature Overlay and Gradient Identification:** Overlay heat map data with real-time/historical temperature data, identifying gradients impacting gene expression under various conditions.
2. **Resilience Assessment Under Heat Stress:** Evaluate how ET gene expression changes under heat stress to identify resilient algae-coral symbiotic relationships.
3. **Biomarker Identification:** Use heat map data to pinpoint biomarkers indicative of coral health or stress, specifically genes associated with healthy ET processes.
4. **Threshold Establishment:** Establish thresholds and alerts based on heat map data to signal potential harmful disruptions in electron transport.
5. **Guiding Restoration Efforts:** Utilize data to guide coral restoration by selecting symbiotic algae strains with gene profiles promoting efficient electron transport and stress resilience.

Conclusion:

Through combining the microbial principles of photosynthesis and carbon metabolisms, the crucial role of Clade D *Symbiodinium* in conferring thermal tolerance to corals (aiding in resistance to elevated sea temperatures and coral bleaching), establishing diverse collaborative partnerships, and the practical application of an Electron Transport monitoring system, we can enhance our understanding of coral-algae symbiosis and contribute to conservation and protection of these vital marine ecosystems.

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[7] Reis-Mansur MCPP, Cardoso-Rurr JS, Silva JVMA, et al. Carotenoids from UV-resistant Antarctic Microbacterium sp. LEMMJ01. *Scientific Reports*. 2019;9(1). doi:https://doi.org/10.1038/s41598-019-45840-6

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