

SIO 123, Microbial Environmental Systems Biology

Environmental systems biology is the study of the genomic basis for patterns of microbial diversity and adaptation in relation to habitat. This course introduces the microbial genome as a unit of study and surveys introductory principles in microbial genomics and bioinformatics that underlay a range of contemporary research in diverse marine habitats, such as the deep sea and polar regions, as well as studies of biomedical importance including the human microbiome. Three hours of lecture and one hour of recitation. **Prerequisites:** BILD 1 or 2, or ESYS 101, or equivalent coursework in cell biology, biochemistry, or genetics, or consent of instructor.

Grading

- 1) 25% class participation
- 2) 15% final exam
- 3) 30% 3 (2-3 page papers) (pick any 3 topics below)
- 4) 30% 1 (8-12 page paper)

Key Dates

**Short Papers Due 1) Friday October 24 2) Friday November 14 3) Friday December 12
8-12 page paper due, Friday December 5 (proposed topic due Friday October 31)**

Friday Presentations and Short Papers (Short papers can be on 3 of any of the 9 Friday topics and associated papers). Complete course reading list (PDFs) are organized by topic on TED.

1. **Biogeography Distribution Ecology**
2. **Sar11 (or heterotrophic bacterioplankton)**
3. **Prochlorococcus (or photosynthetic microbes)**
4. **Metagenomics**
5. **Single Cell Genomics**
6. **Metatranscriptomics**
7. **Proteomics**
8. **Nitrogen Cycle Related and Metabolomics**
9. **Phytoplankton Bacteria Networks Linkages**

Week 1 (Monday October 6)

M: Darwin to Woese (rRNA diversity and evolution)
W: Woese to Venter (and a brief introduction to Microbiology)
F: Reading/Presentation: Biogeography_Distribution_Ecology

Week 2 (Monday October 13)

M: Bacterioplankton (heterotrophs)
W: Photosynthetic Microbes
F: Reading/Presentation: Sar11 (heterotrophic bacterioplankton)

Week 3 (Monday October 20)

- M: DNA Sequencing
- W: Metagenomics (prokaryotes)
- F: Reading/Presentation: Prochlorococcus (microalgae) *****short paper due*****

Week 4 (Monday October 27)

- M: Genomics/Diversity/Metagenomics (Eukaryotes)
- W: Metagenomics (viruses)
- F: Reading Presentation: Metagenomics

Week 5 (Monday November 3)

- M: Single Cell Genomics (prokaryotic cells)
- W: Single Cell Genomics (eukaryotic cells)
- F: Reading/Presentation: Single Cell Genomics

Week 6 (Monday November 10)

- M: Gene Expression and Regulation
- W: Gene Expression in the Environment
- F: Reading/Presentation: Metatranscriptomics *****short paper due*****

Week 7 (Monday November 17)

- M: Proteomics
- W: Functional Genomics
- F: Reading /Presentation: Proteomics

Week 8 (Monday November 24)

- M: Metabolomics, Genomics and Nitrogen Biogeochemistry
- W: Genomics and Nitrogen Biogeochemistry
- F: Reading/Presentation: Nitrogen Cycle Related and Metabolomics

Week 9 (Monday December 1)

- M: Networks and Linkages
- W: Networks and Linkages
- F: Reading/Presentation: Phytoplankton Bacteria Networks and Linkages ***8-12 page paper due***

Week 10 (Monday December 9)

- M: Environmental Genomics of Southern Ocean Microbes
- W: Deep Sea/Hydrothermal Vent Environmental Genomics
- F: The Secret Life of Diatoms *****short paper due*****

SIO123 Reading List

Biogeography, Distribution, Ecology

- Brown MV, Lauro FM, DeMaere MZ, Muir L, Wilkins D, Thomas T, Riddle MJ, Fuhrman JA, Andrews-Pfannkoch C, Hoffman JM et al. 2012. Global biogeography of SAR11 marine bacteria. *Molecular systems biology* **8**: 595.
- Bryant JA, Stewart FJ, Eppley JM, DeLong EF. 2012. Microbial community phylogenetic and trait diversity declines with depth in a marine oxygen minimum zone. *Ecology* **93**(7): 1659-1673.
- Ghiglione JF, Galand PE, Pommier T, Pedros-Alio C, Maas EW, Bakker K, Bertilson S, Kirchman DL, Lovejoy C, Yager PL et al. 2012. Pole-to-pole biogeography of surface and deep marine bacterial communities. *Proceedings of the National Academy of Sciences of the United States of America* **109**(43): 17633-17638.
- Hanson CA, Fuhrman JA, Horner-Devine MC, Martiny JB. 2012. Beyond biogeographic patterns: processes shaping the microbial landscape. *Nature reviews Microbiology* **10**(7): 497-506.
- Ladau J, Shapton TJ, Finucane MM, Jospin G, Kembel SW, O'Dwyer J, Koeppl AF, Green JL, Pollard KS. 2013. Global marine bacterial diversity peaks at high latitudes in winter. *The ISME journal* **7**(9): 1669-1677.
- Wilkins D, van Sebille E, Rintoul SR, Lauro FM, Cavicchioli R. 2013. Advection shapes Southern Ocean microbial assemblages independent of distance and environment effects. *Nature communications* **4**: 2457.

SAR11 (heterotrophic bacteria)

- Carini P, Steindler L, Beszteri S, Giovannoni SJ. 2013. Nutrient requirements for growth of the extreme oligotroph 'Candidatus Pelagibacter ubique' HTCC1062 on a defined medium. *The ISME journal* **7**(3): 592-602.
- Carlson CA, Morris R, Parsons R, Treusch AH, Giovannoni SJ, Vergin K. 2009. Seasonal dynamics of SAR11 populations in the euphotic and mesopelagic zones of the northwestern Sargasso Sea. *The ISME journal* **3**(3): 283-295.
- Giovannoni SJ, Cameron Thrash J, Temperton B. 2014. Implications of streamlining theory for microbial ecology. *The ISME journal* **8**(8): 1553-1565.
- Grote J, Thrash JC, Huggett MJ, Landry ZC, Carini P, Giovannoni SJ, Rappe MS. 2012. Streamlining and core genome conservation among highly divergent members of the SAR11 clade. *mBio* **3**(5).
- Tripp HJ. 2013. The unique metabolism of SAR11 aquatic bacteria. *Journal of microbiology (Seoul, Korea)* **51**(2): 147-153.
- Rappé MS. 2013. Stabilizing the foundation of the house that 'omics builds: the evolving value of cultured isolates to marine microbiology. *Current opinion in microbiology* **16**(5): 618-624.
- Vergin KL, Beszteri B, Monier A, Thrash JC, Temperton B, Treusch AH, Kilpert F, Worden AZ, Giovannoni SJ. 2013. High-resolution SAR11 ecotype dynamics at the Bermuda Atlantic Time-series Study site by phylogenetic placement of pyrosequences. *The ISME journal* **7**(7): 1322-1332.

Prochlorococcus (and photosynthetic microbes)

- Malmstrom RR, Rodrigue S, Huang KH, Kelly L, Kern SE, Thompson A, Roggensack S, Berube PM, Henn MR, Chisholm SW. 2013. Ecology of uncultured Prochlorococcus clades revealed through single-cell genomics and biogeographic analysis. *The ISME journal* **7**(1): 184-198.
- Kashtan N, Roggensack SE, Rodrigue S, Thompson JW, Biller SJ, Coe A, Ding H, Martinen P, Malmstrom RR, Stocker R et al. 2014. Single-cell genomics reveals hundreds of coexisting subpopulations in wild Prochlorococcus. *Science (New York, NY)* **344**(6182): 416-420.
- Thompson LR, Zeng Q, Kelly L, Huang KH, Singer AU, Stubbe J, Chisholm SW. 2011. Phage auxiliary metabolic genes and the redirection of cyanobacterial host carbon metabolism. *Proceedings of the National Academy of Sciences of the United States of America* **108**(39): E757-764.

Metagenomics

- Ganesh S, Parris DJ, DeLong EF, Stewart FJ. 2014. Metagenomic analysis of size-fractionated picoplankton in a marine oxygen minimum zone. *The ISME journal* **8**(1): 187-211.
- Rusch DB, Halpern AL, Sutton G, Heidelberg KB, Williamson S, Yooseph S, Wu D, Eisen JA, Hoffman JM, Remington K et al. 2007. The Sorcerer II Global Ocean Sampling expedition: northwest Atlantic through eastern tropical Pacific. *PLoS biology* **5**(3): e77.
- Sheik CS, Jain S, Dick GJ. 2014. Metabolic flexibility of enigmatic SAR324 revealed through metagenomics and metatranscriptomics. *Environmental microbiology* **16**(1): 304-317

- Yooseph S, Neelson KH, Rusch DB, McCrow JP, Dupont CL, Kim M, Johnson J, Montgomery R, Ferriera S, Beeson K et al. 2010. Genomic and functional adaptation in surface ocean planktonic prokaryotes. *Nature* **468**(7320): 60-66.
- Yooseph S, Sutton G, Rusch DB, Halpern AL, Williamson SJ, Remington K, Eisen JA, Heidelberg KB, Manning G, Li W et al. 2007. The Sorcerer II Global Ocean Sampling expedition: expanding the universe of protein families. *PLoS biology* **5**(3): e16.

Single Cell Genomics

- Stepanauskas R. 2012. Single cell genomics: an individual look at microbes. *Current opinion in microbiology* **15**(5): 613-620.
- Swan BK, Martinez-Garcia M, Preston CM, Sczyrba A, Woyke T, Lamy D, Reinthaler T, Poulton NJ, Masland ED, Gomez ML et al. 2011. Potential for chemolithoautotrophy among ubiquitous bacteria lineages in the dark ocean. *Science (New York, NY)* **333**(6047): 1296-1300.
- Swan BK, Tupper B, Sczyrba A, Lauro FM, Martinez-Garcia M, Gonzalez JM, Luo H, Wright JJ, Landry ZC, Hanson NW et al. 2013. Prevalent genome streamlining and latitudinal divergence of planktonic bacteria in the surface ocean. *Proceedings of the National Academy of Sciences of the United States of America* **110**(28): 11463-11468.
- Yoon HS, Price DC, Stepanauskas R, Rajah VD, Sieracki ME, Wilson WH, Yang EC, Duffy S, Bhattacharya D. 2011. Single-cell genomics reveals organismal interactions in uncultivated marine protists. *Science (New York, NY)* **332**(6030): 714-717.

Metatranscriptomics

- Gifford SM, Sharma S, Booth M, Moran MA. 2013. Expression patterns reveal niche diversification in a marine microbial assemblage. *The ISME journal* **7**(2): 281-298.
- Gifford SM, Sharma S, Moran MA. 2014. Linking activity and function to ecosystem dynamics in a coastal bacterioplankton community. *Frontiers in microbiology* **5**: 185.
- Marchetti A, Schrueth DM, Durkin CA, Parker MS, Kodner RB, Berthiaume CT, Morales R, Allen AE, Armbrust EV. 2012. Comparative metatranscriptomics identifies molecular bases for the physiological responses of phytoplankton to varying iron availability. *Proceedings of the National Academy of Sciences of the United States of America* **109**(6): E317-325.
- Moran MA, Satinsky B, Gifford SM, Luo H, Rivers A, Chan LK, Meng J, Durham BP, Shen C, Varaljay VA et al. 2013. Sizing up metatranscriptomics. *The ISME journal* **7**(2): 237-243.
- Satinsky BM, Crump BC, Smith CB, Sharma S, Zielinski BL, Doherty M, Meng J, Sun S, Medeiros PM, Paul JH et al. 2014. Microspatial gene expression patterns in the Amazon River Plume. *Proceedings of the National Academy of Sciences* **111**(30): 11085-11090

Proteomics

- Bertrand EM, Allen AE, Dupont CL, Norden-Krichmar TM, Bai J, Valas RE, Saito MA. 2012. Influence of cobalamin scarcity on diatom molecular physiology and identification of a cobalamin acquisition protein. *Proceedings of the National Academy of Sciences of the United States of America* **109**(26): E1762-1771.
- Nunn BL, Faux JF, Hippmann AA, Maldonado MT, Harvey HR, Goodlett DR, Boyd PW, Strzepek RF. 2013. Diatom proteomics reveals unique acclimation strategies to mitigate Fe limitation. *PloS one* **8**(10): e75653.
- Rosenwasser S, Graff van Creveld S, Schatz D, Malitsky S, Tzfadia O, Aharoni A, Levin Y, Gabashvili A, Feldmesser E, Vardi A. 2014. Mapping the diatom redox-sensitive proteome provides insight into response to nitrogen stress in the marine environment. *Proceedings of the National Academy of Sciences of the United States of America* **111**(7): 2740-2745.
- Saito MA, Bertrand EM, Dutkiewicz S, Bulygin VV, Moran DM, Monteiro FM, Follows MJ, Valois FW, Waterbury JB. 2011. Iron conservation by reduction of metalloenzyme inventories in the marine diazotroph *Crocospaera watsonii*. *Proceedings of the National Academy of Sciences of the United States of America* **108**(6): 2184-2189.
- Saito MA, McIlvin MR, Moran DM, Goepfert TJ, DiTullio GR, Post AF, Lamborg CH. 2014. Multiple nutrient stresses at intersecting Pacific Ocean biomes detected by protein biomarkers. *Science (New York, NY)* **345**(6201): 1173-1177.

Nitrogen Cycle and Metabolomics

- Bombar D, Heller P, Sanchez-Baracaldo P, Carter BJ, Zehr JP. 2014. Comparative genomics reveals surprising divergence of two closely related strains of uncultivated UCYN-A cyanobacteria. *The ISME journal* 10.1038/ismej.2014.167.
- Thompson A, Carter BJ, Turk-Kubo K, Malfatti F, Azam F, Zehr JP. 2014. Genetic diversity of the unicellular nitrogen-fixing cyanobacteria UCYN-A and its prymnesiophyte host. *Environmental microbiology* 10.1111/1462-2920.12490.
- Thompson AW, Foster RA, Krupke A, Carter BJ, Musat N, Vault D, Kuypers MM, Zehr JP. 2012. Unicellular cyanobacterium symbiotic with a single-celled eukaryotic alga. *Science (New York, NY)* **337**(6101): 1546-1550.
- Tripp HJ, Bench SR, Turk KA, Foster RA, Desany BA, Niazi F, Affourtit JP, Zehr JP. 2010. Metabolic streamlining in an open-ocean nitrogen-fixing cyanobacterium. *Nature* **464**(7285): 90-94.
- Hilton JA, Foster RA, Tripp HJ, Carter BJ, Zehr JP, Villareal TA. 2013. Genomic deletions disrupt nitrogen metabolism pathways of a cyanobacterial diatom symbiont. *Nature communications* **4**: 1767.

Phytoplankton, Bacteria, Networks, Linkages

- Amin SA, Parker MS, Armbrust EV. 2012. Interactions between diatoms and bacteria. *Microbiology and molecular biology reviews* : *MMBR* **76**(3): 667-684.
- Buchan A, LeCleir GR, Gulvik CA, Gonzalez JM. 2014. Master recyclers: features and functions of bacteria associated with phytoplankton blooms. *Nature reviews Microbiology* **12**(10): 686-698.
- Sher D, Thompson JW, Kashtan N, Croal L, Chisholm SW. 2011. Response of *Prochlorococcus* ecotypes to co-culture with diverse marine bacteria. *The ISME journal* **5**(7): 1125-1132.
- Steele JA, Countway PD, Xia L, Vigil PD, Beman JM, Kim DY, Chow CE, Sachdeva R, Jones AC, Schwalbach MS et al. 2011. Marine bacterial, archaeal and protistan association networks reveal ecological linkages. *The ISME journal* **5**(9): 1414-1425.
- Teeling H, Fuchs BM, Becher D, Klockow C, Gardebrecht A, Bennke CM, Kassabgy M, Huang S, Mann AJ, Waldmann J et al. 2012. Substrate-controlled succession of marine bacterioplankton populations induced by a phytoplankton bloom. *Science (New York, NY)* **336**(6081): 608-611.