Transport effects on *trichodesmium* nitrogen fixation and colony formation

Final report

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Trichodesmium is a genus of marine bacteria that is a key organism in the global nitrogen cycle, with some estimates attributing up to 50% of global organic nitrogen sequestration to these bacteria. Managing the global nitrogen cycle is one of the 14 engineering grand Challenges listed by the U.S. National Academy of Engineering, thus understanding *trichodesmium* is a national priority. An important step in managing this cycle is understanding how physical and chemical factors control its distribution and productivity. It is currently thought that colony formation (Fig. 1) protects *Trichodesmium* from smaller grazers and thus allow the cells to fix more nitrogen. *Trichodesmium* typically grows in nutrient-poor regions of the ocean and exhibits large blooms at times and locations in ways that are not understood and cannot currently be predicted. One potential reason for this is associated with difficulty culturing *trichodesmium*. Professor Eric Webb in the Department of Biology at USC has been culturing *trichodesmium* since 1999 and maintains a collection that contains both tuft and puff colony types and one clonal strain that forms both. This exploratory work studied the effect of the physical environment, specifically the flow field, on *Trichodesmium* colony formation and N_2 fixation in a controlled way. While a small-scale laboratory apparatus obviously cannot simulate all of the flow scales present in the oceans, a carefully chosen one can simulate the most critical ones, i.e. the smallest scales of turbulence at which the contributions to the hydrodynamic strain rate are highest.

One difficulty with most experimental apparatuses used to assess the effect of transport is that the mean flow speed and wall shear rate are linearly related, *i.e.* coupled to each other. A very well-characterized system in which the shear and mean flow can be decoupled is *Taylor-Couette* (TC) flow in the annulus between two concentric cylinders. The TC apparatus allows *completely independent* control of the mean flow (via the rate of axial injection of nutrients or other compounds), the mean shear (via the difference between the inner and outer cylinder rotation rates and the turbulent shear (rotating only the outer cylinder produces simple shear; rotating only the inner cylinder produces large-scale vortices; counter-rotating the cylinders produces featureless turbulence.)

Figure 2 shows a block diagram and a photograph of the experimental apparatus that was built. This system was built with careful attention to controlling materials and contamination that might adversely affect the survivability of the *Trichodesmium*. Computer-controlled stepper motors were used to rotate the cylinders at the desired rates. Trichodesmium samples grown in Prof. Webb's laboratory were carried to Prof. Ronney's laboratory and introduced into the Taylor-Couette apparatus. Light scattered by the colonies from a sheet of argon-ion laser light was used to image the colonies in the TC flow system. Figure 3 shows a

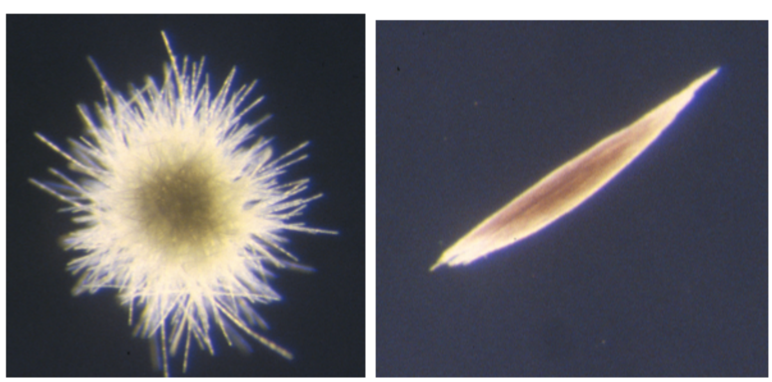

Figure 1. Examples of the two dominant trichodesmium colony types (size ≈ 4 mm) found in the ocean. Left: puff of *T. thiebautii;* right: *tuft of T. erythraeum.*

comparison of *Trichodesmium* grown in a simple shear flow with a control group in a quiescent medium. In the quiescent medium, long strands form (the motivation for the name "sea sawdust" given to *Trichodesmium* blooms by Captain James Cook in 1770 is apparent in this photograph) whereas in the presence of even moderate shear flow (≈ 10/s in Figure 3), such large strands do not form.

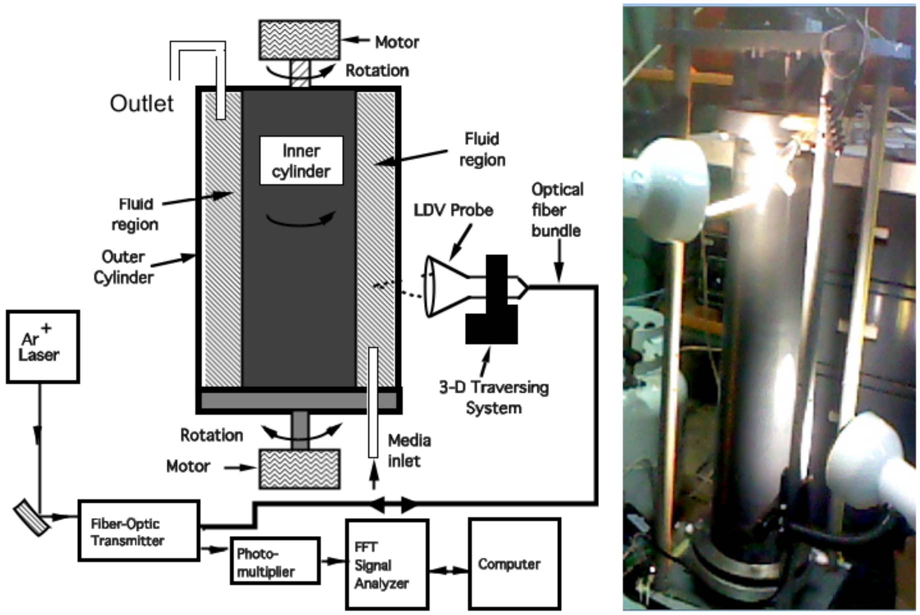

Figure 2. Left: Schematic diagram of Taylor-Couette apparatus; right: photograph of the TC apparatus.

Future work will determine the effect of the experimental parameters (*Trichodesmium* species and phenotype, mean flow, mean shear, turbulent shear, nutrient type and concentration) on the colony formation and N_2 fixation. The results obtained by this research program will be invaluable to modeling of the nutrient formation and consumption in the ocean biome. As such, we will propose a collaboration with Prof. Scott Doney of the Woods Hole Oceanographic Institution. Prof. Doney is a key participant in the NSF Science and Technology Center for Microbial Oceanography Research and Education, whose efforts include modeling of the ocean ecosystem but do not include obtaining fundamental data of the type that can be generated with our experimental facility. Moreover, we will sustain this work far beyond the period of this grant via proposals supported by the NSF Ecosystem Science or Emerging Topics in Biogeochemical Cycles programs.

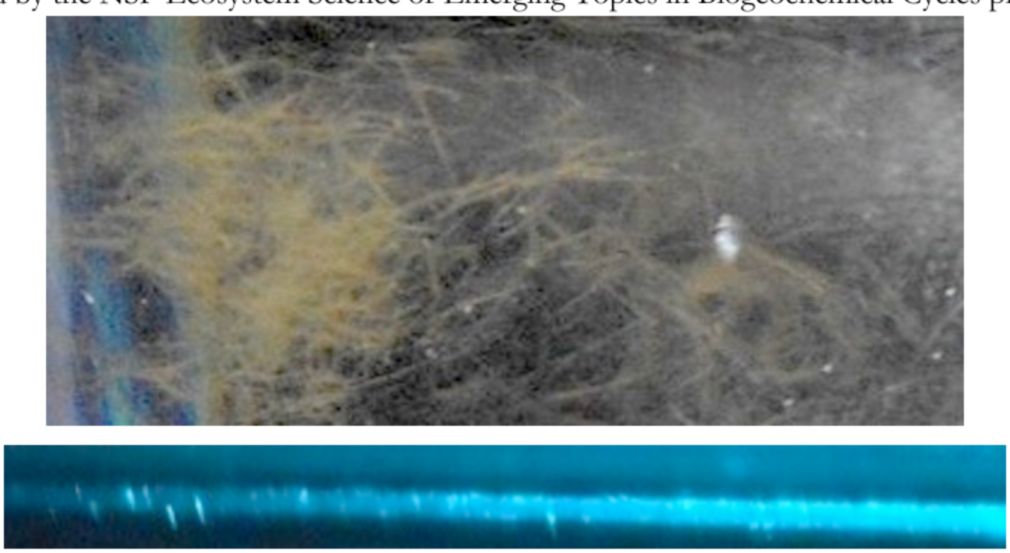

Figure 3. Top: Direct photograph of trichodesmium grown in a quiescent environment; bottom: trichodesmium in the Taylor-Couette cell in the simple-shear mode (colonies appear as streaks in this image, which is rotated 90° from the orientation of the apparatus shown in Fig. 2.)