Utility of Microbes in Space: Revisited L. E. Prufert-Bebout,[1] [1]NASA Ames Research Center, Mailstop 239-4, Leslie.E.Bebout@nasa.gov

Introduction: It is essential to NASA's space exploration goals to achieve an advanced capability to understand, manage, manipulate and utilize microbial ecosystems as we attempt to expand beyond Earth habitation. The importance of determining how microbial ecosystems respond to space environments, is not simply an academic question of curiosity. Rather it is one of utmost practicality for cost-effective, long-term space habitation on the Moon, Mars or beyond. Microbial ecosystems are responsible for support of higher life on Earth through their roles in the cycling of energy and recycling of all major elements. In short the microbes can survive without us. We cannot survive without them.

Many of these transformational activities can be substituted for by technological methods requiring continuous operational costs for transport of supplies, and disposal of waste products. [1] These methods are reliable, and quantifiable, making them ideal for short-term operations. However, for long-term, extended space habitation life support, utilization of the ecosystem-scale recycling methods that support human life on Earth will provide cheap, clean, and virtually waste-free primary support systems. Combination of these cheaper microbial ecosystem technologies in tandem with secondary artificial life support technologies, will relieve pressure on demand for materials needed for the chemical / physical technologies, yet provide for the high degree of reliability and precision demanded in space environments. The combination of microbial methods, with follow on chemical methods are in fact used for optimal, cost effective waste water treatment world-wide. [2]

The great promise of using microbial methodologies for waste-processing and also food production in space were recognized decades ago and investigated extensively in the 1980's [3] and continue today. Despite decades of research and the obvious recognition that our fundamental means of terrestrial life support are microbiological, we cannot as of yet, export this capability; therefore biological technologies are not at the forefront of life support technologies being prepared for space today. Why? Let's face it, though we absolutely depend upon it, biology is messy. Chemistry is quantifiable and we need precision and reliability, in space more than anywhere. However, for long-term habitation, again, cost will come in to play. Humans have an Earth life support that costs us nothing, and if we go to space, we will eventually need to take it with us. Before this was difficult, but today, possible. How can we test this? By starting small.

Higher Organism Life Support: starting small

As opposed to single cell cultures which can only survive until their initial food source runs out (days to weeks), mature microbial ecosystems, such as microbial mats composed of 100's to 1000's of species [4] that recycle nutrients internally are capable of total self-sufficiency, such that these ecosystems can remain viable for years to decades with little or no additional sustenance. [5] Thus, they provide biological systems capable of long-term self-sufficiency, and valuable platforms for long-term study. On Earth, these microbial mat systems completely support higher life forms, including two of demonstrated flight heritage (nematodes and brine shrimp). Microbial mats provide all of the food and transform all of the waste products for these higher life forms, such that many generations can be supported in a single sample.

Yet, so far, nematodes have only been raised in space for short term experiments on single cell (E. coli) food sources and only single species, or two-species cell cultures of environmental microbes have been tested in space environments. Progress has not been much greater on Earth, so this is entirely understandable. To date the complexity of studying single organism systems was daunting enough. However this is situation is now changing at a rapid pace.

New Frontiers: To date, the predictability of metabolic response of single cell or two cell co-cultures have provided so challenging that, these systems have not been incorporated for space life support systems, not to mention multi-component microbial ecosystems which have yet to be even considered. Yet, these complex systems possess higher versatility and resiliency than traditional monocultures and therefore hold great promise for the space life support. Fortunately the ability to better understand and utilize these complex ecosystems on Earth and in Space will fast become reality, due to the current explosion in the area of "systems-biology". The recent rapid development of techniques in molecular microbial ecology,and the combination of those molecular methods with geochemical measurements at relevant spatial scales, are finally enabling far more detailed studies of microbial ecosystems This understanding, coupled with enhanced, predictive models now being developed, will very soon result in the ability to utilize these microbial ecosystems at quantifiable, predictable levels only previously dreamed of. Such "systems biology" approaches are at the cutting edge of science today [6], and should be exploited to the fullest to provide maximum benefit to Space exploration.

Additional Benefits and Rationale: Complex, microbial ecosystems can withstand long periods of

dormancy, in cold, dark or high radiation environments, and upon reactivation, can self-maintain indefinitely making them highly suitable for surviving through launch protocols and remote study. They are compact, yet contain virtually all known biological metabolic pathways needed for higher organism life support. They are highly adapted to extreme environmental stresses and highly reactive to environmental manipulations producing an array of response signals which can be remotely detected, in addition to their value as support for higher life forms.

References:

[1]http://en.wikipedia.org/wiki/Controlled_Ecological_Life_Support_System
[2] http://en.wikipedia.org/wiki/Sewage_treatment
[3] NASA Contractor Report 4297: Controlled Ecological Life Support System (CELSS) Program, 1979-1989; [4] Ley, R.E., et al., (2006) *Appl. and Environ. Micro.* 3685–3695 [5] Bebout, B. M., et al., (2002) *Astrobiology*, 383-402. [6] http://www.systems-biology.org/000/