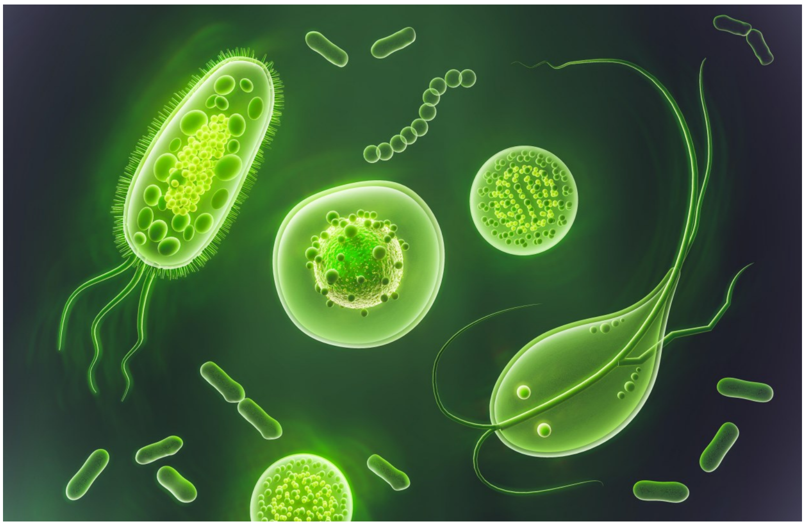
Adaptation of bacteria and its implications in environmental application

Article talks about the additional knowledge for a practicing civil engineer, apart from the curriculum taught

The success of a living organism is how well it adapts to changing environments, and its survival solely depends on the mechanism and success. Bacteria, a living microorganism is no exception to this natural process, and this article discusses in detail how it either can rapidly evolve to acquire drug resistance or to specialize in the consumption of new resources, which are critical for its very survival. These could be considered as environmental fluctuations, which may be even shorter in timescales that preclude adaptation by genetic mutation. For example, considering humans, the fluctuation being shorter than suppose a year (seasonal weather) which may not give us the chance to adapt by genetic evolution.

Bacteria are well known to have sophisticated programs of gene regulations which contribute to decision making with the participation of hundreds of genes and lead to physiological changes, for example, that they can remain dormant for long periods of time when the environmental conditions are not unfavourable. While the bacteria can sense the environmental individually, the information gathered hence may be often very noisy (high uncertainty). The author of the article claims to have found that bacteria sense the environment as a concert of microorganism by quorum sensing (QS) — a process in which they secrete and respond to small molecules in the extracellular environment known as autoinducers. These autoinducers are used by bacteria to specifically estimate population density to control the expression of traits that require coordination. The author establishes his/her observation that while bacteria estimate population density, it simultaneously responds to various environmental fluctuations such as pH change and introduction of antibiotics. This is specifically due to the fact that the bacteria secrete autoinducers not at a constant rate, but a dynamic rate that changes based on the environmental conditions it is exposed to.

The author claims that the bacteria exploit a well-known principle in decision theory; 'the wisdom of crowds'. This is explained in the article through the experimental observation the author made during research studies, specifically that were on how bacteria navigated through periods of feast and famine. Most experiments on bacteria are studied when the bacteria are actively consuming substrates, where as the author claims most bacteria in the environment are in starvation, waiting for a meal. Although one would expect that a starving bacteria would immediately start consuming when substrate become available, yet, rapid resumption of growth makes the bacteria vulnerable to several stressors. On such cases, bacteria should focus more on survival than growth, as substrate is made available.



The time lapse between the fluctuation and the inception of growth phase of starved bacteria is termed as lag-time. The observations from the author showed wide range of lag-times, ranging from immediate growth to a lag time of more than 20 generations, among clonemates (from genetically identical species). In an experiment designed by the author, where he monitored populations of microorganisms after they were exposed to a pulse of antibiotics, the author observed that the organisms that revived immediate growth had lower chances of survival (lower lag-time) and were eliminated by the antibiotic, compared to those who had varied lag-time, which he termed as the wild-type organisms. In conclusion, the author found that intermittent exposure to antibiotics during feast-to-famine cycles lead to the evolution of genotypes that had wide range of lag-time distributions, the concert had more chances of developing resistance to the antibiotic.

The article specifically speaks about the adaptation of bacteria to environmental fluctuations and its implications on effective treatment of antibiotics. I wish to talk about the implication it may have on our wastewater and water treatment systems which engineer bacteria for removal of pollutants. Most of our water and wastewater treatment systems are engineered based on continuous supply of substrate to microorganisms and that we base our models and rely on the function of the treatment system, that has been stabilized in performance. In the quest to find the design parameters for a stabilized system and then to analyse the robustness of the stabilized systems to shocks (environmental fluctuations) the systems are redesigned so as to withstand the shock, and maintain the stabilized performance conditions. However, should we employ the shocks (environmental fluctua-

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tions) to enhance the performance of the system? Let me discuss this aspect with the findings I have from my experimental studies on nitrogen removal in stormwater bioretention basins.

Although both rapid sand filters and stormwater biofilters are typically similar in constituents, as opposed to the continuous stabilized mode of operation of rapid sand filters (often employed in water treatment systems), stormwater biofilters are constructed to temporarily store and transfer stormwater runoff, are intermittent in operation. For example, stormwater biofilters receive stormwater runoff form paved surfaces during storm events, and typically retain water for couple of hours, before it is transported to either groundwater recharge or channeled to a surface water resource through drainage systems. Stormwater biofilters would therefore operate under wetted condition during and a little extended period during a storm event and then it operates under dried condition for a prolonged period of time. The operation of stormwater biofilter would be therefore intermittent in nature, under fluctuating environmental conditions.

Nutrients are quite rampant in stormwater runoff, particularly depending on the catchment characteristics. More particularly, nitrogen and phosphorus are of serious concern and need to be controlled so as to control eutrophication of water resources. Systems such as stormwater biofilters are therefore inevitably required to remove nitrogen and phosphorus from stormwater runoff, in addition to quantitative management of stormwater runoff. Nitrogen removal in particular, is of complex nature, involving multiple processes that require different environmental conditions owing to oxygen availability. For example, nitrification process requires oxic conditions while denitrification requires anoxic conditions. Both processes are mediated by microorganisms, absence of which would effectively stop the processes. Therefore, removal of nitrogen species emphatically depends on microorganisms, which are again dependent on environmental conditions.

When we consider rapid sand filters, employed in water treatment systems, which are extensively studied and documented, we are well informed about ripening of filter material. This refers to a period during which the filter attains stabilization in performance, monitored based on the turbidity (correspond to total solids). During this period, the turbidity in the effluent increases and the decreases to attain the performance concentrations, due to washoff of solids in the filter, after a backwash or new installation. This has nothing to do with microorganism as rapid sand filters are not necessarily designed to include biological treatment. A similar trend was observed when I conducted experiments in stormwater biofilters, looking at the dynamics of concentration in solids and nitrogen and organic carbon. I will not discuss the observations made on the solids, as they merely correspond to physical processes, rather, will discuss the observations made on the nitrogen and organic carbon dynamics.

In stormwater treatment systems, the lapse between two rainfall events is termed as antecedent dry days (ADD), where higher ADD indicate longer dry phase of stormwater bioretention operation. It was observed from the experiments, that too short an ADD (typically less than 2 days) had a more stable, yet less removal percentages of nitrogen and organic carbon. Simultaneously, in events that had much higher ADD (typically more than 7 days) also had a lower removal, while ADDs in between (2 – 7 days) had dynamic, yet higher removal percentages. Throughout the experiments however, the ripening period did not change significantly (remained approximately at 30 minutes) observed from the concentration of nitrogen and organic carbon. The ripening period of the stormwater biofilter, observed from the concentration does not correspond to the lag-time of bacterial growth, and this phenomenon is caused by the physical (hydraulic) attribute of stormwater biofilters. However, the indication of 2 – 7 ADD may have some indication of the lag-time of the concert of microorganisms that involved in removal of nitrogen and organic carbon.

In conclusions, it is my perspective, that the water treatment systems and wastewater treatments could further engineer the behaviour of microorganisms used in biological treatment systems, to enhance removal efficiencies, instead of the conventional stabilized systems. Particularly, intermittent feat-famine cycles of microorganisms have the capacity to develop more robust communities of microorganisms, with varied lag-times that can not only withstand environmental shocks (organic loading rate shocks), but also may improve the performance of removal.

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Adopted from: 'How bacteria navigate varying environments', New Scientist, November 25, 2022, page 46.