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Pressemitteilung

Universität Luxemburg - Université du Luxembourg
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14.11.2023
http://idw-online.de/de/news823968

Forschungsergebnisse, Wissenschaftliche Publikationen
Medizin, Umwelt / Ökologie
überregional

Forecasting microbiomes for sustainability and health

Microbial communities, or microbiomes, are essential for safeguarding human and environmental health through the most widely used biotechnological process on our planet: biological wastewater treatment. However, the process itself is subject to constant changes, difficult to sustain over long periods of time and emits significant amounts of greenhouse gases. There is thus an urgent need to predict the behavior of its complex microbiome to better control the process and to improve on its engineering.

Researchers from the Systems Ecology group at the Luxembourg Centre for Systems Biomedicine (LCSB) and the Department of Life Sciences and Medicine of the University of Luxembourg and their international collaborators have now developed a novel modeling approach that can predict the dynamics and functions of such microbial communities several years into the future. The research article is published in the journal Nature Ecology and Evolution alongside a corresponding Research Briefing.

Wastewater treatment plants are essential infrastructure, protecting human and environmental health through water sanitation. However, they are highly complex systems that can be difficult to manage. One immediate challenge is how to accurately predict the dynamics of the microbial communities that drive the treatment process, which is essential to better control it and make it sustainable. In their latest study, a team of researchers has addressed this issue head-on by developing a new framework to make such predictions accurately up to three years into the future.

For their work, the researchers leveraged a unique set of samples, collected weekly at the wastewater treatment plant in Schifflange (Luxembourg) for a year and a half. They then generated a wide range of high-resolution molecular data ("meta-omics") on each sample and combined this with environmental information gathered for the site. Meta-omics allow scientists to study the entire genomes, transcriptomes, and proteomes of a microbial community at once, providing a complete understanding of how the community functions and interacts with its environment. "The meta-omics data covers, in intricate details, information about the abundance, activity, and metabolism of the broad spectrum of microbes living in the treatment plant, both known and unknown," explains Dr Francesco Delogu, first author of the publication.

Using mathematical and statistical modelling, the researchers were able to reduce the vast amounts of data to only 17 fundamental signals. These signals represent the key drivers of the microbial community and can therefore be used to forecast its composition and activity years into the future. This approach could be used to predict when and where potential problems, such as foaming or the emergence of pathogens, are likely to occur and allow countermeasures to be taken. "To consolidate the diverse layers of information, we used a rigorous approach to extract relevant information over time. We used cutting-edge analysis methodologies, including the Prophet open-source forecasting tool from Meta/Facebook, and validated the accuracy of our predictions with additional samples," details Dr Delogu further.
Wastewater sample collection

"Based on our work, the microbiomes driving biological wastewater treatment are no longer a black box," explains Dr Émilie Muller, co-author of the study, former member of the Systems Ecology group and researcher at the GMGM laboratory of the University of Strasbourg and the French CNRS. “This strategy can now be applied to other ecosystems, be it the human gut microbiome or microbial communities in pristine environments facing disturbance. This is highly relevant for predicting microbial ecosystems and how they are affected by global environmental change.”

The new approach has a number of important implications for the future of wastewater treatment and for biotechnological processes that rely on microbiomes in general. The ability to predict and thus avoid problems in biological wastewater treatment plants could lead to an increase in their sustainability and efficiency, reducing costs and environmental impact. This new approach could also lead to the development of new and more effective treatment strategies, improving the overall quality of treated water and contributing to a healthier environment. In addition, these results could have implications for other fields, such as bioenergy production and environmental remediation. By developing a better understanding of microbial responses to environmental conditions, scientists could develop new ways to harness the power of microbes. Finally, the same approach could be used to predict the health and dynamics of the human microbiome in relation to dietary changes, drugs and environmental exposures.

“Our latest study addresses one of our group’s main objectives: to accurately predict the behaviour of microbiomes. As a next important step, we aim to use our forecasting abilities for the rational control of microbiomes in wastewater treatment plants and beyond,” concludes Prof. Paul Wilmes, senior author of the study and head of the Systems Ecology research group at the LCSB.

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URL zur Pressemitteilung: http://Forecasting the dynamics of a complex microbial community using integrated meta-omics - https://doi.org/10.1038/s41559-023-02241-3