IJARSCT ISSN (Online) 2581-9429

International Journal of Advanced Research in Science, Communication and Technology (IJARSCT)

International Open-Access, Double-Blind, Peer-Reviewed, Refereed, Multidisciplinary Online Journal

Impact Factor: 7.53

Volume 4, Issue 3, December 2024

Current and Future Insights from Ecology, Evolution, and Biodiversity

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Abstract: *Microbial ecology, evolution, and biodiversity (EEB) is the study of how bacteria affect ecosystems and the health of humans and the world.EEB is leading the way in understanding the functions of bacteria in the biosphere. The discipline is developing new multidisciplinary tools to study complex microbial communities. The American Society for Microbiology's Council on Microbial Sciences held a virtual retreat in 2023 to discuss the future of EEB. The talks focused on how microbes affect host and environmental health globally. For EEB to reach its full potential, contributions from a variety of scientific fields are required. This necessitates a largescale, multidisciplinary study that integrates numerous datasets and technologies. To propel advancement, international cooperation including the public and scientists is required. EEB and the American Society for Microbiology want to help microbiology enter a new age. They all see a future for the field that is more innovative, collaborative, and relevant to society*

Keywords: Termsmicrobial ecology; Evolutionary biology; Biodiversity interdisciplinary; Anthropocene machine learning

I. INTRODUCTION

As a result of Antonie van Leeuwenhoek's initial studies of microbes, microbiology was born. From the 17th to the 19th centuries, researchers built on his research by examining the diversity and origins of microorganisms. They looked into the ways that microbes affect weather, erosion, and elemental cycles. The earliest environmental microbiologists were these scientists. Their study demonstrated the critical roles that bacteria play in the ecosystems of Earth. This seminal work influenced the development of microbiology as a discipline. They established modern microbial ecology by researching the functions of microorganisms in the environment. Their findings demonstrated the close relationship between microorganisms and ecological systems. A knowledge of the impact of microbes on the earth was made possible by these early studies. Contemporary microbiology continues the work of these early environmental scientists.

Microorganisms play a vital role in maintaining ecological balance and are found throughout nature. Numerous soil bacteria support plant growth, and marine microbes regulate methane and carbon dioxide in the atmosphere. More carbon dioxide is cycled annually by bacteria than by humans. The digestive tracts of most animals rely on microbes to keep them alive and healthy. The world is habitable because bacteria help ecosystems produce bioavailable nitrogen by fixing nitrogen. The estimated number of microorganisms on Earth is one trillion, indicating that their populations are incredibly diverse. Based on this understanding, ideas such as "environmental probiotics" have been created to improve ecosystem health, such helping coral heal from human-caused damage. Additionally, microbes are employed in environmental cleanup to aid in the removal of pollutants. Molecular biology breakthroughs such as CRISPR and highthroughput sequencing have completely changed how we think about microbial diversity. These techniques show how bacteria affect and change their environments at the molecular level.

Microbial ecology, evolution, and biodiversity (EEB) is the subject of a community of researchers supported by the American Society for Microbiology (ASM).EEB researchers look at how bacteria affect human lives and shape ecosystems. This group is learning novel methods that bacteria carry out essential functions like fixing carbon. Additionally, they study how microorganisms "breathe" materials like rocks and fight viruses. Tools for analysing big, complicated data sets are being developed by EEB researchers. By using these methods, microbial activity can be linked to host and environmental health. Microbes play a key role in controlling ecosystems and climate, according to EEB research. Their research illuminates how microbial processes affect the biosphere. Research conducted by the community is expanding our knowledge of the microbial world. The EEB community at ASM is driving developments in microbiology that will have a significant impact.

The transdisciplinary approach of the EEB community facilitates collaboration with various fields of microbiology, including antibiotic resistance, host-microbe biology, and molecular biology. These areas working together can tackle difficult problems related to microbiological data and community interactions. Studies on gastric microbiomes, for example, show links between microbial ecosystems and human health. While the effects of gut microorganisms on health are well documented, less is known about how they respond to changes in the environment, including changes in nutrition. Because of its studies on microorganisms in hostile environments, EEB has experience with these problems. The findings of this investigation led to the discovery of proteins known as heat- and cold shock proteins, which aid bacteria in withstanding fluctuations in temperature. Our understanding of how microbiomes in human, animal, and environmental systems adjust to change may be improved by the tools and methods created by EEB. Our understanding of the biochemistry and physiology of bacteria may be enhanced by collaborating with gastrointestinal and clinical microbiology. Since evolutionary biologists helped identify the causes of infectious diseases during COVID-19, EEB aims to work with other sub-disciplines to establish a strong, multidisciplinary foundation for the future of microbiology.

II. RETREAT ORGANIZATION AND DEMOGRAPHIC DIVERSITY

On April 10–11, 2023, the COMS EEB Community had a virtual retreat that drew in over forty-five participants. This group's last retreat was in December 2017, which was five years ago. These five years saw significant advances in EEB research, which presented both new opportunities and challenges. Important ASM leaders, such as Dr. Vincent Young, Dr. Vaughn Cooper, Dr. Denise Akobo, and Dr. Peter Guirguis, arranged the retreat. Rds. Beth Oates, Allen Segal, and Stefano Bertuzzi of ASM provided organizational support for the retreat. Optimal Performance Seekers, LLC's Matt Loeb served as the event facilitator. Direct invitations from the organizing committee were extended to half of the participants. An open invitation was sent to ASM EEB members and organizations such as ASM Young Ambassadors in order to guarantee diversity. Creating a globally representative group from a variety of universities and expertise was the goal of this method. A wide range of participants from the EEB field were successfully attracted by the retreat.

III. HIGHLIGHTS FROM THE EEB RETREAT

Predicting the future of the field, including the scope and impact of its research, was the aim of the 2023 EEB retreat. The retreat's objective was to pinpoint significant areas of microbial ecology, evolution, and biodiversity that could impact microbiology and benefit humanity. Another objective was to look into how ASM can guide and support the development of the EEB field. Increasing ASM EEB involvement and building connections with other ASM groups and professional associations were the retreat's primary goals. One day of the retreat was devoted to the topic of "Microbial Evolution and Ecology in the Anthropocene. "The primary subject for the second day was "The Ecology and Evolution of Polymicrobial Interactions". Top experts gave daily presentations on these subjects and the direction of EEB. A note-taker and moderator participated in the short breakout sessions that followed the talks. It was encouraged for participants to contribute ideas in real time via email or a shared working document. This document allowed for asynchronous discussions and further feedback collection following the retreat.

"Microbial Evolution and Ecology in the Anthropocene": speakers and key outcomes

Dr. Elena Litchman, a scientist from Stanford University, spoke on predicting the dynamics of microbial communities in the modern era. In her statement, she referenced Dr. Vladimir Vernadsky's notion of the "noosphere." The term "noosphere" refers to a future state in which humans and nature live in harmony. Dr. Litchman talked about the potential for microbial responses to environmental changes to help solve global problems. Improving our ability to predict changes in microbes will aid in our understanding of how they react to changes in their surroundings. Her research focuses on how microbes acquire traits like heat tolerance in order to adapt to these changes. Dr. Litchman recommended more research directions to predict the resilience of these communities to ongoing environmental change.

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The rate and direction of evolutionary change in the Anthropocene are determined by multiscale symbioses, according to Dr. Rachel Whitaker of the University of Illinois. Given the fascinating nature of microbial interactions and development, it is time to update the conventional hierarchical perspective of the subject. Indeed, viruses and plasmids are "infectious" components of heredity that have a significant impact on evolutionary change. However, these genetic components have a history of evolution of their own. These intricate co-evolutionary connections are influenced by elements including resource availability and vulnerable hosts. Other than microbial interactions, infectious genetic elements and their hosts can co-evolve. The wider ecological systems have also been impacted.Combining molecular and organismal biology is essential to blurring the boundaries between these two fields and achieving a comprehensive understanding of evolution and the mutual dependence of numerous biological components.

Key outcomes

The complexity of microbial ecology and evolution in the Anthropocene necessitates a more comprehensive evaluation. Obstacles favouring easily agricultural, frequently human-related bacteria over their environmental equivalents are evident in the majority of these research since they are based on model microorganisms that do not accurately represent the wide diversity of microbes. This bias distorts research findings, reducing the possibility of a comprehensive knowledge of how various microbial populations adapt to our changing environment. Perhaps a more accurate picture of how microorganisms interact with their surroundings and humans might result from such improved cooperation across microbial populations, such as environmental and medical microbiology. This kind of multidisciplinary research will also improve methods such as vaccination and "sensor networks," which allow researchers to better understand the connectivity between microbial communities in various environments and the relationship between microbes and human health in the Anthropocene.

“The Ecology and Evolution of Polymicrobial Interactions”: speakers and key outcomes

Dr. Katrine Whiteson, an associate professor at the University of California Irvine, discussed human polymicrobial infections as an example of how microbial ecology dynamics relate to clinical issues and treatment. These communities' ecology includes all microorganisms, pathogens and non-pathogens, as well as their diversity and density, and goes well beyond their pathogenicity. All of the actual interactions between microorganisms are reflected in the resulting ecological patterns, including the ways in which non-pathogenic bacteria might affect the pathogenic community through resource competition and other means. Using airway infections and people with cystic fibrosis as examples, she explained how certain bacteria can affect other people's physiology through physical and molecular interactions." When studying microbial communities, ecological aspects must be taken into account because of the complex interactions between polymicrobial ecosystems. It is well recognized that ecological processes influence individual diversity, and there are methods to "shape" these ecological interactions. To name only three examples, Treatments are supported by fibre-rich diets, probiotics, vomit transplants, and antibiotics because they have both immediate and long-term effects on microbial ecology. Though there are still many unanswered questions in microbiology research, reproducibility and individual variation, as well as the establishment of technical and methodological norms, make the interaction of microbial and human ecology a fascinating subject of study.In order to improve our knowledge of these intricate interactions, the biomedical and environmental microbiological research communities must coordinate and collaborate more broadly.

Dr. Jessica Metcalf, an associate professor at Princeton University, gave a talk about microbial immunity, how it varies over time and in different environments. She stressed that "the vaccine is crucial to maintain broad immunity among the human population to contain outbreaks that rage." It is difficult to sustain vaccine coverage, and figuring out what causes an outbreak is much more difficult. Disease effects, microbial (co)evolution, and the host defence are all impacted by interactions between various microbial species. In order to understand how these organisms influence human health, particularly immune illnesses, we must acknowledge that it is imperative to characterize the microbial/viral ecological dynamics within hosts. Certain aspects of host evolution, such as dietary changes and physical changes, can be determined by microbes and impact the host's immunity, tolerance, and long-term health after a specific amount of exposure. To better understand host-microbe interactions in disease, forecasting that combines immune system dynamics with ecological and evolutionary principles can be employed. Still, in order to improve our knowledge of host-microbe interactions, the modelling will require inclusive and varied data regarding human populations, microbial communities, and immunology. Establishing worldwide observatory repositories would be necessary for building reliable data banks.

Key outcomes

Although our understanding of microbial systems has advanced, there are still several areas that require improvement. In fact, the integration of rich historical data setssuch as genomes, geochemical measurements, and physical data like flow rates and temperatures is essential to the study of polymicrobial systems. Utilizing these publicly accessible databases to their full potential has been limited by a lack of tools for the appropriate co-analysis of various data kinds and a lack of contextual data (metadata). In order to do this, ASM may support initiatives to create "best practices" for research of polymicrobial communities and serve as a liaison with other scientific fields, including earth scientists, anthropologists, and public health experts.who have the necessary skills in creating theoretical and statistical methods that could be applied to gather and combine data from several sources. Also, to encourage creativity and cooperation among scientists, ASM might host community-wide workshops centred on the critical evaluation of genotype-tophenotype predictions.

In order to address the issues of exceptional environmental change, the increasing impact of civilization on the biosphere, and the growing threat of pandemics and other epidemics, the speakers underlined the separate linkages between microbes and humans and called for interdisciplinary methods. The presenters also underlined the need to overcome ongoing financial, institutional, and cultural barriers that impede interdisciplinary cooperation. This problem is especially serious when it comes to international cooperation since there may not be enough backing for truly global partnerships to tackle our biggest problems.

IV. KEY DISCUSSION OF SCIENTIFIC TRENDS

The 2023 EEB Retreat confirmed calls for improved science communication, emphasized the need for more inclusive representation in microbial ecological study settings, stated that we as a community must encourage more inter and broad work, and highlighted the potential for microbiology to undergo a transformation due to the advancements in large language models and artificial intelligence. The community also emphasized how important it is to connect human health and microbial ecosystems in light of our rapidly evolving planet. The EEB Community's future may be guided by these observations and recommendations for action, which would include more extensive and in-depth communication with other microbiological communities both inside and outside the Society. The following suggestions made at the retreat are equally crucial.

Advancing microbiology through artificial intelligence and medicine learning

AI and ML have huge potential to spur significant advancements in microbiology. Large language models and other AI applications are evolving quickly, and there are currently many models available in the fields of biochemistry and molecular biology (e.g., AlphaFold [34]). However, there are issues with the implementation of these technologies that might damage trust in them if left uncontrolled. Standards for data that could "benchmark" the results of any computer models, for example, are lacking. Also, not every investigator has quick access to the computer infrastructure required to utilize these tools to their full potential. Even while there is a wealth of data that may be significantly enhanced by these technologies, not all of them are naturally suitable. This could combine sparse and huge data sets, perhaps leading to inaccurate results. Furthermore, it is very hard to discern between data of high and low quality, which could result in incorrect outputs. Without properlylabelled training data sets that have also been technically validated, for example, attempting to predict microbial gene function may result in output of poor quality.

A concerted effort to find a "common scientific language" is urgently needed in light of these problems in order to make the most trustworthy and effective use of computing advancements. Individual hosts and large-scale environmental microbiomes are among the scales at which EEB members operate.and they can use their unique skills to create data sets that are appropriate for computer analysis. Strong data standards can be created, and both the code and the data produced by this process must be readily available. Additionally, scientists should have the proper training in machine learning and artificial intelligence so that users are aware of the benefits and drawbacks of these computational technologies. In order to achieve this, retreat attendees suggested ASM-led training sessions and cooperation with other organizations, including the Institute of Electrical and Electronics Engineers (IEEE), the Society for Industrial and Applied Mathematics (SIAM), and Applied Microbiology International (AMI), in order to create data standards and actively support working groups centred on artificial intelligence.Even while there is a wealth of data that may be significantly enhanced by these technologies, not all of them are naturally suitable. This could combine sparse and massive data sets, perhaps leading to inaccurate results. Furthermore, it is very hard to discern between data of high and low quality, which could result in incorrect outputs. Without properly labelled training data sets that have also been mechanistically validated, for example, attempting to predict microbial gene function may result in output of poor quality.

A concerted effort to find a "common scientific language" is urgently needed in light of these problems in order to make the most trustworthy and effective use of algorithmic advancements. EEB members can use their unique skills to create data sets appropriate for computational analysis, and they operate at sizes ranging from individual hosts to large-scale environmental microbiomes. Strong data standards can be created, and both the code and the data produced by this process must be freely accessible. Additionally, scientists should have the proper training in machine learning and artificial intelligence so that users are aware of the benefits and drawbacks of these computational technologies. In order to achieve this, retreat attendees suggested supporting AI-focused working groups and developing data standards through ASM-led training sessions and partnerships with other societies, including the Society for Industrial and Applied Mathematics (SIAM), Institute of Electrical and Electronics Engineers (IEEE), and Applied Microbiology International (AMI).

Expanding ecological and environmental diversity

Currently, researchers headquartered in North America, Europe, and Asia lead the majority of microbial ecology studies, which are geographically biased toward the Northern Hemisphere. This is further demonstrated by the unequal distribution of studies on soil microbial ecology conducted worldwide to inform ecosystem functioning and biodiversity. 36. As a result, we don't fully comprehend microbial ecology on a global scale. The main cause of this bias has been the cultural and institutional obstacles that prevent more extensive, genuine international cooperation. In contrast to other regions, Africa has comparatively few coordinated research networks, which might be attributed to the lack of science programs and policies for microbiome research (35). Pointed out the importance of setting up research facilities related to including facilities for sequencing. In Africa and other countries in the Southern Hemisphere, the establishment of coordinated research networks may allow scientists to share resources and gain access to cutting-edge technology like advanced decoding capabilities. Such efforts have been proposed to increase the study of soil biodiversity (36). EEB representatives who attended the retreat pointed out that the scientific community would benefit from more opportunities to work with researchers from countries in the Southern Hemisphere. According to the participants, the majority of funding opportunities do not allow monies to be distributed to researchers abroad, and programs that promote international collaborations are typically limited to promoting cooperation between countries with abundant resources. The retreat urged the international microbiological community to become more involved, more inclusive, and more sincere.

Fostering civic engagement

Generally speaking, the general public was born with prejudice and lacked microbiological scientific literacy. Participants in the session pointed out that the validity and significance of the EEB community's efforts can turn into a topic of contention. This may make it more difficult to solve the ecological and evolutionary problems facing the world. Promoting more fruitful interaction between the scientific community and the general public is essential in the face of these obstacles. For instance, by producing content that highlights the importance of bacteria in preserving our planet, ASM may increase its investment in public communication. ASM may create more content about the role of microorganisms in everyday life by collaborating with the EEB Community. This includes household septic systems, gardens, the function of bacteria in preserving the quality of the air and water, and more. The aforementioned vacuum can be filled by ASM's wealth of engagement and education resources, extra assistance in spreading them, and the creation of newer materials for our members and the general public. Furthermore, ASM can support its continued efforts to advocate for microbial sciences in the eyes of politicians. The focus on microorganisms in environmental health, especially the understanding of microbial responses to natural/anthropogenic disasters and climate change, is improved when more members of the EEB community interact with policymakers. In particular, scientists from a range of professional, social, and economic backgrounds must be participated in these initiatives. Second, ASM might co-sponsor webinars that provide further information on how researchers might improve their standing in their communities. Finally, in order to increase the general public's understanding of microbiology, ASM can lead grassroots initiatives to highlight the importance and implications of microbial ecology and evolution in elementary school courses. ASM would be instrumental in bridging the gap between public comprehension and scientific knowledge through these and other initiatives. In order to make the fundamental nature of bacteria widely known and essential to the health and well-being of our planet, that is a critical first step. Engage with the public. ASM engages in many ways with the community of microbial scientists. Each method of engagement can be leveraged for different uses for different audiences; all of these uses aim to make understanding microbes, specifically environmental microbes, easier to comprehend and associate with day-to-day life.

Role of EEB within the ASM organization

Microbiologists have been researching the connections between activities at the cellular, community, and ecosystem scales for more than a century. Because of its inherent interdisciplinarity and trans disciplinarity, the EEB community is in a unique position to assist other communities in connecting biological findings to external chemical and physical components. The variety of techniques and tools used to improve our comprehension of microbiological processes is growing across all populations as microbiology becomes increasingly transdisciplinary and inter-disciplinary. The frequency and scope of interconnections among ASM communities are restricted, despite the fact that distinct technologies arise in various groups. As a result, the advantages of technology sharing throughout ASM's numerous communities are not being fully realized. The EEB Community could, for instance, discuss the most recent methods for genetically altering non-model species or growing difficult creatures. Our peers in other communities might find this useful. Naturally, the opposite is also true, and many of the technologies utilized in clinical and biological microbiology could be advantageous to the EEB Community. ASM might try to promote technology sharing between the various communities even further. ASM might, for example, promote the application of methods such as immune surveillance to close the gap between surveys particular to microorganisms and statistics specific to diseases. By establishing these "sensor networks," scientists might gain a deeper comprehension of the interconnectedness of microbial communities in various settings.

The retreat guests recognized two other significant obstacles to transdisciplinary microbiology: financing and communication. As a result, a number of feasible ideas were found to enhance participation within ASM Communities. Opportunities for ASM members to get training on the advantages and difficulties of inter- and transdisciplinary research could be provided by ASM. Sharing the cultural norms of our discipline, such as jargon and customs within each field, is an important activity that can help us get past the difficulties caused by our disciplinary "language barriers." Collaboration between EEB scientists and other, more biomedically oriented scientists may also be sparked by these workshops. The cooperation amongst ASM journals would improve communication between communities even more. Last but not least, holding an EEB mixer at the ASM meetingsparticularly the ASM Microbe meetingwill offer a vibrant platform for advancing research and expertise within the EEB Community. It will also give attendees a chance to network and exchange information in order to promote engagement throughout the ASM. In addition to improving the opportunities of in-person mixers, virtual meetups held throughout the year will give members another inclusive platform to interact and network.

V. CONCLUSION

Under a nutshell, the ecology and evolution of microorganisms under the Anthropocene are intricate and varied. The conversations sparked by the EEB retreat underscore the complex issues confronting the community and the need for increased inclusivity, more work to adopt new technologies and evaluate their effectiveness, more international partnerships, increased public involvement, and the advancement of interdisciplinary approaches. Similar to the essay by Lennon et al that highlighted the need for varied collaborations on the subject of the role microbes play in climate change, this was repeated for the retreat regarding the future of science being through transdisciplinary collaboration. similar to the paper by Lennon et althat highlighted the need for a variety of partnerships about the role microbes play in climate change. Building varied, cooperative teams can therefore aid in overcoming and confronting the demanding demands of the microbiological sciences. The majority of the issues and suggestions raised during the retreat are dependent on interdisciplinary cooperation, including enhancing the usefulness of diverse data sets, creating and implementing strong data standards, and making AI-powered tools more widely available. However, understanding and the foundation of a "common scientific language" are necessary for the full exploitation of collaborative benefits.

Components for the future of Ecology, Evolution, and Biodiversity (EEB) Community. Visual representation of the foundational elements of the EEB community (top section), focusing on microbial organisms within diverse environments such as the human body, soil, and water (upper centre). During the retreat, three major themes were identified as critical for the future of EEB: the impact of the Anthropocene, interdisciplinary and transdisciplinary collaborations (building external connections), and the complexity of polymicrobial interactions in various environments (lower centre). The retreat also pinpointed specific areas for targeted recommendations to achieve the highest impact on the EEB community (bottom section).

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