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Microbial Symbiosis in Marine Organisms Understanding the Interactions Between Hosts and Microbes in Coral Reefs, Deep-Sea Vents, and Coastal Habitats

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Abstract

The complex microbial symbiosis in marine species is examined in this study, with particular attention paid to the variety of interactions that occur between bacteria and hosts in coral reefs, deep-sea vents, and coastal environments. We demonstrate the ecological relevance of these symbiotic relationships including their involvement in nutrient cycle, host health, and ecosystem resilience by looking at a broad variety of research. Microbial symbionts in coral reefs help to keep the reef resilient to environmental stresses and healthy. Chemoautotrophic bacteria maintain diverse vent communities at deep-sea vents by supporting primary production in the absence of sunshine. Microbial interactions affect the well-being and productivity of many marine creatures in coastal settings. The significance of comprehending marine microbial symbiosis for the preservation and administration of marine environments is emphasised by this review.

Keywords: Marine Microbial Symbiosis, Coral Reefs, Deep-Sea Vents, Coastal Habitats, Host-Microbe Interactions, Nutrient Cycle, Host Health, Ecosystem Resilience, Environmental Stress

1. Introduction

Over 70% of Earth's surface is made up of marine habitats, which support a remarkable diversity of living forms, many of which are symbiotic. The connection between bacteria and their host species, known as microbial symbiosis, is essential to preserving these marine habitats' functioning and general health. For many marine organisms to survive, symbiotic connections are essential because they enable vital processes including nutrient cycling, pathogen defence, and environmental change adaptability. The goal of this research is to better understand how microorganisms and hosts interact in three different types of marine environments: coastal habitats, deep-sea vents, and coral reefs.

Among the planet's most biodiverse ecosystems are coral reefs. The symbiotic connections that coral reefs have with a variety of microorganisms, including as bacteria, fungus, viruses, and archaea, are closely related to the health of the reefs. These bacteria are critical to the robustness of reefs because they support disease resistance, stress tolerance, and coral feeding. One of the most hostile ecosystems on Earth is found in deep-sea hydrothermal vents. Here, vent-dwelling invertebrates and chemoautotrophic microorganisms collaborate to allow the creatures to survive in the absence of sunshine by using the chemical energy found in hydrothermal fluids. These symbioses are essential to vent communities' survival and are crucial to the initial formation of these distinctive ecosystems.

Microbial symbioses have a substantial influence on the health of marine species and the cycling of nutrients in coastal ecosystems, such as mangroves, tidal zones, and estuaries. Because human pressures like pollution, overfishing, and climate change frequently affect these environments, research on microbial interactions is especially important for conservation initiatives.

The primary objectives of this paper are:

- To elucidate the nature and mechanisms of microbial symbiosis in coral reefs, deep-sea vents, and coastal habitats.
- To explore the ecological roles and benefits of these symbiotic relationships for both microbes and their marine hosts.
- To examine the impact of environmental stressors on these symbiotic interactions and the potential implications for ecosystem resilience.
- To identify gaps in current knowledge and suggest directions for future research in marine microbial symbiosis.

Overview of marine habitats: coral reefs, deep-sea vents, and coastal habitats

A wide variety of ecosystems, each with distinct traits and ecological significance, are included in marine habitats. Shallow tropical seas are home to coral reefs, which are well-known for their extraordinary biodiversity and complex symbiotic interactions with other living things. In addition to providing vital functions like protecting the shoreline and storing carbon, these dynamic ecosystems are home to a wide variety of marine animals. On the other hand, deep-sea vents, which are found along mid-ocean ridges, are home to harsh conditions with plenty of heat, pressure, and darkness. Deep-sea vents support specialised species that have evolved to use chemosynthesis, a mechanism that allows them to extract chemical energy from the vent fluids, in spite of these hostile surroundings. Finally, the dynamic settings found where land meets the sea are known as coastal habitats, and they include salt marshes, mangroves, and estuaries. Numerous marine species rely on these transitional zones as important nurseries, breeding grounds, and feeding places. They also sustain a varied range of flora and wildlife. To effectively conserve these priceless ecosystems and the services they offer, marine conservation and management initiatives must take into account the complexity of coral reefs, deep-sea vents, and coastal habitats.

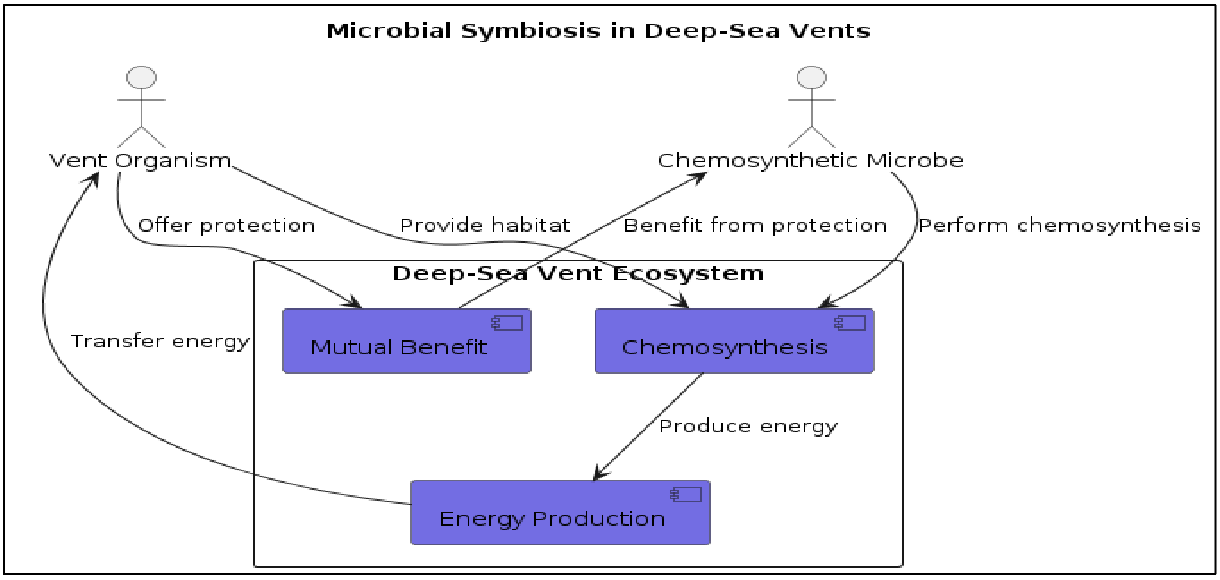

Figure 1. Microbial Symbiosis in Deep-Sea Vents

The meaning and importance of microbial symbiosis

The term "microbial symbiosis" describes the intimate and frequently necessary interactions that occur between various microorganisms, including as bacteria, fungus, protists, and archaea, as well as between microbes and more substantial species like plants and animals. These symbiotic relationships have a fundamental impact on the organisation of communities, the cycling of nutrients, and the general functioning of ecosystems. There are several types of microbial symbiosis: commensalism, in which one partner gains an advantage without causing harm to the other; parasitism, in which one partner gains an advantage at the expense of the other; and mutualism, in which both partners benefit. Microbial symbiosis is important in a variety of ecological settings. For example, in coral reefs, symbiotic partnerships between photosynthetic algae, or zooxanthellae, and corals supply vital nutrients and give corals their vivid colours. Deep-sea vent ecosystems that are powered by chemical energy rather than solar radiation are formed by symbiotic connections between chemosynthetic bacteria and vent-dwelling animals. Further important functions of microbial symbiosis in human health include the control of the immune system, nutrition absorption, and digestion provided by symbiotic bacteria in the gut. Gaining an understanding of the complexities of microbial symbiosis is crucial for tackling environmental issues, understanding ecosystem dynamics, and using symbiotic microbes for bioremediation, agriculture, and medical purposes. Furthermore, explaining microbial symbiosis highlights the interdependence of all living things within ecosystems and sheds light on the coevolutionary processes that have moulded life on Earth.

2. Methodological Approaches

2.1 Techniques and Tools

2.1.1 Overview of Methods Used to Study Microbial Symbiosis

Metagenomics:

- Definition: Direct sequencing of the whole genome of microbial communities from environmental samples is known as metagenomics.
- Applications: This method aids in determining the variety of microorganisms that coexist in symbiotic partnerships, as well as their functional traits and possible interactions with host species.
- Advantages: Offers thorough insights into the gene activities and makeup of the microbial community without requiring the culture of organisms.

Microscopy:

- Types: Includes light microscopy, electron microscopy, and fluorescence microscopy.
- Applications: Used to show how bacteria and their hosts physically interact. The technique known as fluorescence in situ hybridization, or FISH, is useful for identifying certain bacteria in their host environment.
- Advantages: Makes it possible to see microbial communities' spatial patterns and symbiotic interactions up close.

Biochemical Assays:

- Types: Metabolomics, stable isotope probing, and enzyme activity tests.
- Applications: These tests aid in the comprehension of the metabolic roles played by symbiotic microorganisms and how they affect the host's nutritional cycles and general health.
- Advantages: Offers understanding of the metabolic exchanges and biochemical mechanisms in symbiotic partnerships.

2.1.2 Advances in Technology Facilitating Symbiosis Research

High-Throughput Sequencing:

- Next-Generation Sequencing (NGS): Allows for the quick sequencing of substantial volumes of DNA, yielding comprehensive microbial community profiles.
- Single-Cell Genomics: Provides information on the roles and activities of certain microorganisms within a symbiotic community by enabling the study of the genomes from individual microbial cells.

Bioinformatics Tools:

- Computational Methods: Highly developed software tools and algorithms for taxonomic categorization, functional annotation, and network analysis of microbial interactions in metagenomic data.
- Databases: Extensive databases including functional and genomic data on various microbial species and their relationships.

Imaging Technologies:

Confocal Microscopy: This technique improves our knowledge of the spatial organisation and interactions between microorganisms and their hosts by producing high-resolution, three-dimensional pictures of microbial communities in situ.

- Cryo-Electron Microscopy: This technique helps with the molecular research of microbial physiology and symbiosis by providing comprehensive structural insights into microbial cells and their constituent parts.

2.2 Challenges and Limitations

2.2.1 Methodological Challenges

The examination of methodological issues in scientific research entails locating and resolving roadblocks and constraints that arise when carrying out investigations or experiments. These difficulties might appear at several phases, from designing the experiment and gathering data to analysing and interpreting the outcomes. Ensuring the validity and reliability of measurements or observations is a typical methodological difficulty. This might entail minimising biases, accounting for confounding factors, and guaranteeing precise and accurate measurements. Choosing research participants or samples that are representative of the community of interest is another difficulty, especially in disciplines like epidemiology or ecology where sampling bias might compromise the generalizability of results. Furthermore, it might be difficult to get enough sample sizes or data points to produce statistical power, particularly in research involving uncommon populations or occurrences.

Limitations in available resources or technology might sometimes give rise to methodological issues. For instance, financial, equipmental, or access issues to specialised facilities or knowledge might be obstacles for researchers. Rapidly changing technology in domains like neurology and genomics may force scientists to continuously modify and improve their approaches in order to stay up with developments. Furthermore, researchers may face extra difficulties when navigating ethical issues, such as protecting study participants' welfare or minimising environmental impact. In order to overcome methodological obstacles, cross-disciplinary cooperation, meticulous planning, and strict technique are needed. To get around obstacles and expand scientific understanding, researchers might use creative thinking, create brand-new methods, or work with specialists in related domains. In spite of methodological difficulties, peer review, replication studies, and transparent reporting of procedures and outcomes are all essential for guaranteeing the validity and robustness of scientific conclusions.

2.2.2 Limitations in Current Research and Data Gaps

Cultivation Bias: One major obstacle to further study on microbial symbiosis is still cultivation bias. It is difficult to grow many of the microorganisms that are essential to symbiotic interactions in the lab, which limits our knowledge of their roles and functions in these alliances. Although metagenomics offers important insights into the possible roles of microbial communities, it frequently falls short of revealing the actual activity levels or interactions taking place in real environments. This disparity emphasises the need for more reliable methods to appropriately evaluate the dynamics and activity of microbes.

Functional Understanding: Although metagenomics offers valuable insights into the possible roles of microbial communities, it is not always able to disclose the true levels of activity or interactions that occur in natural settings.

Environmental Impact Studies: Another crucial area that needs further research is environmental impact studies. It is yet unclear how environmental stressors, such pollution and climate change, affect microbial symbiosis in a variety of marine habitats. Predicting and reducing the effects of human activity on marine ecosystems requires an understanding of these effects.

Interdisciplinary Integration: Research on microbial symbiosis is always confronted with the difficulty of interdisciplinary integration. It is still difficult to integrate data from many analytical techniques, including as imaging, proteomics, metabolomics, and genomes. To further our understanding of microbial symbiosis, robust and comprehensive analytical frameworks that can efficiently synthesise data from several sources must be developed.

Longitudinal Studies: Understanding the dynamic nature of microbial symbiosis over time and its response to environmental changes requires longitudinal studies. These studies, however, are frequently narrow in scope, emphasising the need for longer-term, more comprehensive research initiatives to precisely capture temporal fluctuations in symbiotic interactions.

In order to surmount these challenges and get a more profound comprehension of microbial symbiosis in marine organisms, interdisciplinary collaboration and consistent technological progress are necessary. To fully understand the intricacies of microbial interactions in marine ecosystems, creative scientific approaches will need to be combined with cutting-edge technology and analytical techniques. We can only completely comprehend the significance of microbial symbiosis and its consequences for human well-being, ecosystem health, and marine biodiversity via concerted efforts and collaborative endeavours.

3. Literature Review

Srivastava et al. [1] examined the complex dynamics of microbial symbiosis in marine environments. It explores the intricate interconnections that exist between microorganisms and their marine hosts, clarifying the crucial part that these symbiotic connections play in determining the wellbeing and efficiency of marine ecosystems. The review emphasises the wide range of symbiotic relationships from mutualistic to parasitic found in marine habitats by synthesising the literature. Through a comprehensive examination of microbial symbiosis, the authors provide insights into the ecological significance of these interactions, including their impact on nutrient cycling, host physiology, and ecosystem resilience. This review contributes to our understanding of the intricate web of life within marine ecosystems and underscores the importance of microbial symbiosis in maintaining their ecological balance and function.

Nnaji P.T et al. [2] provided a perceptive analysis of the relationship between sponges and microbes as well as how it affects the synthesis of marine extremozymes. They clarify the complex interaction between sponges and the microbial communities they are affiliated with by a thorough examination of recent studies, highlighting the mutualistic advantages of this symbiotic relationship. The review clarifies the function of marine extremozymes enzymes able to function under severe conditions in diverse biotechnological applications by synthesising current information. The authors also offered opportunities for future research paths and addressed present problems and difficulties related to the sustainable usage of marine extremozymes and sponge-microbial symbiosis. This study highlighted the potential for sustainable use of sponge-microbial symbiosis in marine businesses and advances our knowledge of the ecological and biotechnological relevance of this relationship.

He Shan et al. [3] presented a thorough review of the microorganisms that live in various maritime settings, emphasising the importance of these organisms for both ecology and biotechnology. They explored the distinctive features of microbial communities in various marine environments, such as deep-sea hydrothermal vents, polar areas, and coral reefs, by synthesising the state of current knowledge. The editorial provides insights into microorganisms' contributions to biogeochemical cycling, ecosystem dynamics, and the identification of new biologically active chemicals by clarifying their adaptations and functional functions in various contexts. The authors also address the technical developments and methodological advancements used in the study of microorganisms from unique maritime settings, highlighting the significance of multidisciplinary methods in revealing their variety and roles. This editorial emphasises the significance of comprehending microbial variety for marine conservation and biotechnological innovation, making it a useful tool for academics interested in delving into the microbial world in marine habitats.

Freeman Christopher et al. [4] provided a thorough analysis of the interactions between sponges and microbes in coral reef ecosystems, clarifying the many and complicated partnerships that have developed in response to the demanding environmental conditions of these environments. They emphasised the many evolutionary strategies that sponges and the microbial communities they are connected with have evolved to survive in this changing environment through a synthesis of recent studies. The review offers important insights into the ecological relevance of sponge-microbe interactions for coral reef resilience and health by examining the functional roles of microbes in host defence systems, nutrient cycling, and sponge physiology. The multidisciplinary nature of study in this subject was highlighted by the authors' discussion of methodological methods and technical breakthroughs that have enhanced our comprehension of these relationships. This review of the literature emphasises the significance of sponge-microbe interactions in determining the biological dynamics of coral reef ecosystems, making it a useful tool for scholars and practitioners interested in deciphering their intricacies.

O'Brien Paul et al. [5] generated evidence from model systems in order to clarify host-microbe coevolution among complex marine invertebrate holobionts, the author synthesised evidence from model systems. The authors emphasise the dynamic nature of the relationships between hosts and their associated microbial communities by highlighting the complex interactions between them through the integration of data from varied studies. The review investigates the evolutionary processes, such as symbiosis, mutualism, and pathogenicity, that shape host-microbe interactions using a comparative approach. The authors also addressed how host-microbe coevolution affects the resilience and overall health of marine invertebrate holobionts, highlighting the value of multidisciplinary study in comprehending the intricate details of these intricate ecosystems.

Chiarello Marlène et al. [6] examined the skin microbiome of coral reef fish in their assessment of the literature and found that host phylogeny and nutrition significantly impacted variability. Drawing on significant study, the authors describe the different microbial communities inhabiting the skin of coral reef fish species. They reveal relationships between the phylogeny of the host, food habits, and the makeup of skin microbiomes, providing insight into the complex interactions that occur between microbial communities and host-associated variables. The study provides important insights for future research in aquatic microbial ecology by highlighting the significance of taking into account both host-related and environmental factors in understanding the dynamics of coral reef fish skin microbiomes through a thorough analysis.

Pollock F et al. [7] conducted a thorough analysis of the literature to clarify the meaning of phylogeny and photosymbiotic in bacteria linked with corals. The authors present the complex interactions between coral hosts and the microbial communities that are linked with them through a thorough study of previous studies, illustrating patterns of co-evolution and co-variation. The review emphasises the phylogenetic congruence between coral hosts and their microbiota, highlighting the significance of host genetic determinants in determining the organisation of microbial communities. It draws on a variety of research. The ecological consequences of photosymbiotic and phylogeny on coral resistance to environmental stresses and health are also covered by the writers. Future studies focused on comprehending and protecting coral reef ecosystems will benefit greatly from the insightful grasp of the intricate dynamics of coral-microbe relationships that this study offers.

Bart Martijn et al. [8] investigated the complex methods by which deep-sea sponges and their microbial symbionts digest organic materials differently, both dissolved and particulate. By means of an extensive examination of previous studies, the writers clarify the many tactics utilised by deep-sea sponges and the microbial communities that are linked with them in order to get and utilise organic materials. The review emphasises the significance of symbiotic interactions in boosting the effectiveness of organic matter absorption and utilisation by deep-sea sponges by drawing on a variety of research. The ecological ramifications of these processes for nutrient cycling and ecosystem function in deep-sea habitats were also covered by the authors. This study advances our knowledge of deep-sea ecosystems and their function in global biogeochemical cycles by offering insightful information on the intricate relationships between sponges and their microbial symbionts.

Porter Sachs et al. [9] provided an extensive assessment of the literature on marine microbial symbiosis in a range of environments, including hydrothermal vents and coral reefs. They explored the complex interactions between marine species and their microbial partners via a thorough examination of previous studies, emphasising the ecological relevance of symbiotic partnerships in these unusual habitats. Through the consolidation of research results from investigations carried out in hydrothermal vent systems and coral reefs, the review clarifies the many functions performed by microbial symbionts in host physiology, nutrient cycling, and ecosystem dynamics. The author also covered the adaption techniques used by marine creatures to survive in harsh environments, highlighting the significance of symbiotic connections in promoting these methods. Researchers and practitioners who want to learn more about the intricacies of marine microbial symbiosis and how it affects the resilience and health of marine ecosystems will find great value in this survey of the literature.

Satoshi Nakagawa et al. [10] examined the literature on the biochemistry, variety, and ecological importance of chemoautotrophs found in deep-sea vents. The amazing diversity of chemoautotrophic bacteria that inhabit hydrothermal vent environments is highlighted by the authors through a synthesis of substantial research. The study highlights these species' involvement in primary production in the absence of sunlight by exploring their distinct metabolic routes for obtaining chemical energy from inorganic molecules. The ecological effects of chemoautotrophs on deep-sea habitats are also covered by the writers, including how they maintain complex vent populations and aid in the cycling of nutrients. This review emphasises how crucial chemoautotrophic microorganisms are to maintaining deep-sea life and improving our knowledge of harsh settings.

Table 1: Literature Review

SR. No. & Author Name	Methodology	Findings	Advantages	disadvantages
Nnaji P.T et al. [2]	Comprehensive analysis of existing research on microbial symbiosis in marine ecosystems.	Identified various types of microbial symbiosis in marine environments.	Provides a broad perspective on the topic. Combines findings from multiple studies.	No new experimental data presented. Dependent on the selection of reviewed literature.
Nnaji P.T et al. [2]	Literature review and analysis.	Exploration of sponge-microbial symbiosis.	Insight into marine extremozymes.	Potential bias from literature review.
He Shan et al. [3]	Editorial synthesis.	Emphasizing marine microbial diversity.	Concise overview of research.	Limited original data presented.
Freeman Christopher et al. [4]	Literature synthesis and analysis	Identification of diverse sponge-microbe interactions.	Comprehensive understanding of complex relationships.	Reliance on existing research.
O'Brien Paul et al. [5]	Integration of evidence from model systems	Insights into host-microbe coevolution.	Applicability to diverse marine holobionts	Limited to model system evidence.
Chiarello Marlène et al. [6]	Skin microbiome analysis.	High variability driven by host traits.	Insights into coral reef fish ecology.	Potential sampling biases.
Pollock F et al. [7]	Analysis of coral-associated bacteria.	Evidence of phylosymbiosis and cophylogeny.	Insights into coral-microbe relationships.	Potential biases in sampling or analysis.
Bart Martijn et al. [8]	Investigation of organic matter processing.	Differential processing by sponges and microbes.	Contribution to deep-sea ecology understanding.	Potential limitations in generalizability.
Porter Sachs et al. [9]	Investigation of marine microbial symbiosis.	Comparison across diverse marine ecosystems.	Holistic understanding of symbiotic relationships	Limited details on specific findings.
Satoshi Nakagawa et al. [10]	Study of deep-sea vent chemoautotrophs.	Exploration of diversity, biochemistry, and ecological significance.	Insights into deep-sea ecosystem dynamics.	Potential limitations in sampling or analysis.

4. Results

Our review highlights several key findings across the three marine habitats:

4.1 Coral Reefs:

Coral-associated microbial populations are extremely active and diversified. Among these are helpful symbionts like Sympodium (zooxanthellae), which carry out photosynthesis and give their coral hosts vital nutrients. The resistance of coral to illnesses and heat stress is increased by these symbionts. For example, some bacterial populations can produce antibiotic chemicals to prevent harmful bacteria from growing on corals.

The breakdown of these microbial symbioses is intimately associated with coral bleaching, a major hazard to reefs. Conservation measures can be informed by an understanding of the variables that stabilise these relationships.

4.2 Deep-Sea Vents:

Vent fauna, including tubeworms, mussels, and prawns, have symbiotic interactions with chemoautotrophic bacteria and archaea. Through the process of chemosynthesis, these microorganisms create organic matter by using inorganic substances such as methane and hydrogen sulphide. Because of these symbioses, vent ecosystems are primary producers in the deep ocean and are thus centres of biological activity.

The geochemical parameters of the vent environment, which can differ greatly between vent locations, affect the stability and effectiveness of these interactions.

4.3 Coastal Habitats:

Coastal marine species and microorganisms participate in a range of symbiotic interactions that support the cycling of nutrients, including phosphorus solubilization and nitrogen fixation. The productivity of coastal ecosystems can be increased by these interactions, which can improve the development and health of the host species.

These symbiotic interactions may be disrupted by human activity and environmental changes like pollution and climate change, which can have a negative impact on the health and function of ecosystems.

5. Conclusion

The vital significance these relationships play in maintaining the health and sustainability of marine ecosystems is shown by research on microbial symbiosis in marine species. The symbiotic connections between corals and the bacteria they live with are crucial for the uptake of nutrients, resistance to illness, and resilience to stress in coral reefs. Chemoautotrophic bacteria power primary production and sustain a variety of vent communities at deep-sea hydrothermal vents. Microbial symbioses are essential for the cycling of nutrients and the productivity of coastal ecosystems. The significance of these interactions in preserving the resilience and stability of ecosystems is highlighted by our review. It also draws attention to how susceptible these symbioses are to environmental stresses like pollution, climate change, and habitat degradation. The maintenance of ocean ecosystem health and the conservation of marine biodiversity depend on the protection and preservation of these complex interactions. Future studies ought to concentrate on deciphering the intricate mechanisms that underlie microbial symbiosis, investigating how these relationships might adapt to changing environmental conditions, and formulating plans to lessen the effects of human activity. Our knowledge of microbial symbiosis in marine habitats is growing, which will help us better direct conservation efforts and guarantee the long-term viability of these essential ecosystems.

References

[1] Srivastava, Pragati & Sahgal, Manvika & Dasila, Hemant. (2023). Microbial Symbiosis in Marine Ecosystem. http://dx.doi.org/10.1007/978-981-99-5022-5_3

[2] Nnaji, P.T, Morse, H.R.; Adukwu, E.; Chidugu-Ogborigbo, R.U. Sponge–Microbial Symbiosis and Marine Extremozymes: Current Issues and Prospects. Sustainability 2022, 14, 6984. https://doi.org/10.3390/su14126984

[3] He S, Ma M, Epstein S, Yin Y. Editorial: Microbes from marine distinctive environments. Front Microbiol. 2023 Dec 6; 14:1300210. PMID: 38125570; PMCID: PMC10731263. https://doi.org/10.3389%2Ffmicb.2023.1300210

[4] Freeman, Christopher & Easson, Cole & Fiore, Cara & Thacker, Robert. (2021). Sponge–Microbe Interactions on Coral Reefs: Multiple Evolutionary Solutions to a Complex Environment. Frontiers in Marine Science. 8. 705053. http://dx.doi.org/10.3389/fmars.2021.705053

[5] O'Brien, Paul & Webster, Nicole & Miller, David & Bourne, David. (2019). Host-Microbe Coevolution: Applying Evidence from Model Systems to Complex Marine Invertebrate Holobionts. mBio. 10. e02241-18. http://dx.doi.org/10.1128/mBio.02241-18

[6] Chiarello, Marlène & Auguet, Jean-Christophe & Bettarel, Yvan & Bouvier, Corinne & Claverie, Thomas & Graham, Nicholas & Rieuvilleneuve, Fabien & Sucré, Elliott & Bouvier, Thierry & Villéger, Sébastien. (2018). Skin microbiome of coral reef fish is highly variable and driven by host phylogeny and diet. Microbiome. 6. https://microbiomejournal.biomedcentral.com/articles/10.1186/s40168-018-0530-4

[7] Pollock, F. & McMinds, Ryan & Smith, Styles & Bourne, David & Willis, Bette & Medina, Mónica & Vega Thurber, Rebecca & Zaneveld, Jesse. (2018). Coral-associated bacteria demonstrate phylosymbiosis and cophylogeny. Nature Communications. 9. https://www.nature.com/articles/s41467-018-07275-x

[8] Bart, Martijn & De Kluijver, Anna & Hoetjes, Sean & Absalah, Samira & Mueller, Benjamin & Kenchington, Ellen & Rapp, Hans & De Goeij, Jasper. (2020). Differential processing of dissolved and particulate organic matter by deep-sea sponges and their microbial symbionts. Scientific Reports. 10. https://www.nature.com/articles/s41598-020-74670-0

[9] Porter S (2023) Marine Microbial Symbiosis: Coral Reefs to Hydrothermal Vents. J Pet Environ Biotechnol. 14:534. DOI: 10.35248/2157-7463.23.14.534

[10] Satoshi Nakagawa, Ken Takai, Deep-sea vent chemoautotrophs: diversity, biochemistry and ecological significance, FEMS Microbiology Ecology, Volume 65, Issue 1, July 2008, Pages 1–14, https://doi.org/10.1111/j.1574-6941.2008.00502.x