International Research Journal of Natural and Applied Sciences
ISSN: (2349-4077)
Impact Factor 7.032 Volume 11, Issue 01, January 2024
Website- www.aarf.asia, Email : editor@aarf.asia , editoraarf@gmail.com
Association of Academic Researchers and Faculties (AARF)

The Microbiome of Wildlife: Exploring the Symbiotic Relationships, Ecological Impact, and Conservation Implications

[*]Dr.H.Rama Subba Reddy[1], Dr.M.Vijaya kumar [2]
[1]Department of Zoology, SVB. Govt. Degree College, Koilakuntla, Nandyala (D.T)
[2]Department of Zoology, Govt. Degree College, Eluru, Eluru (D.T)
[1]hanumanthu.subbareddy@gmail.com, [2]drvijayakumarzoology@gmail.com

Abstract

The intricate web of microbial life within wildlife bodies, collectively known as the microbiome, plays a pivotal role in shaping symbiotic relationships with their hosts. This article delves into the mutualistic partnerships and potential pathogenic interactions within the wildlife microbiome, highlighting the profound implications for ecological systems and conservation efforts. Examining the ecological impact of the microbiome, we explore its influence on ecosystem functionality and wildlife behaviour, revealing the delicate balance required for healthy biodiversity. As threats to microbial diversity loom in the face of environmental changes, we discuss the conservation implications and strategies that leverage microbiome research for effective wildlife management. By unravelling the mysteries of the microbiome, we uncover new dimensions for understanding and safeguarding the well-being of wildlife and the ecosystems they inhabit. The microbiome, a vast ecosystem of microorganisms inhabiting the bodies of wildlife, constitutes a dynamic and indispensable component of their biology. This article comprehensively investigates the multifaceted relationships existing within the wildlife microbiome, emphasizing both the mutualistic alliances that enhance host functions and the potential threats posed by pathogens. The ecological ramifications of the microbiome extend beyond individual hosts, influencing ecosystem dynamics, nutrient cycling, and even behavioural traits of wildlife. Mutualistic partnerships are explored, shedding light on how microbes contribute to host digestion, nutrient absorption, and defence mechanisms. Conversely, the microbiome can harbour pathogens that pose challenges to wildlife health. The interplay between these symbiotic relationships defines the delicate equilibrium essential for the well-being of both hosts and their microbial counterparts. The ecological impact of the microbiome is scrutinized through its contributions to ecosystem functionality and its role in shaping wildlife behaviour. From nutrient cycling to mediating interspecies interactions, the microbiome is an influential force that intricately weaves itself into the fabric of ecological systems.

Keywords: microorganisms, hosts, ecological systems and microbiome

Introduction

The intricate interplay between wildlife and microorganisms has emerged as a captivating frontier in ecological research, revealing the significance of the microbiome—the diverse community of microorganisms that inhabit the bodies of animals. In recent years, advancements in molecular biology and sequencing technologies have enabled scientists to unravel the complexities of the microbiome, shedding light on the profound influence it wields over the health, behaviour, and ecological interactions of wildlife [1-3]. This burgeoning field has broadened our understanding of symbiotic relationships, illustrating how microbial communities contribute to the overall well-being of their hosts. Within the vast tapestry of the microbiome, mutualistic partnerships between wildlife and microorganisms stand out as essential to host survival and prosperity. These collaborations involve a myriad of microorganisms, including bacteria, fungi, and viruses, working in tandem with their hosts to perform critical functions such as aiding in digestion, synthesizing essential nutrients, and bolstering the host's immune system [4-6]. Conversely, the microbiome is not without its challenges. Pathogenic microorganisms, capable of causing diseases, navigate this complex ecosystem, highlighting the delicate balance between beneficial and potentially harmful interactions. As we embark on this exploration, it becomes evident that the influence of the microbiome extends far beyond individual hosts, reverberating through entire ecosystems. The ecological impact of the microbiome encompasses its role in nutrient cycling, soil health, and the regulation of plant and animal interactions. Furthermore, recent discoveries have unveiled the intriguing connections between the microbiome and wildlife behaviour, hinting at a microbial influence on cognitive and neurobiological aspects of various species. Against the backdrop of these discoveries, the conservation implications of understanding the microbiome become increasingly apparent. The delicate balance of microbial communities is threatened by anthropogenic factors, including habitat degradation, pollution, and climate change. Recognizing the pivotal role of the microbiome in wildlife health and ecosystem stability prompts a revaluation of conservation strategies, urging a more integrated and comprehensive approach to safeguard the intricate relationships that define the microbiome of wildlife. In this article, we embark on a journey to explore these symbiotic relationships, dissect the ecological impact, and illuminate the conservation implications of the fascinating microbiome within the diverse realm of wildlife [7-8].

I. Symbiotic Relationships in the Wild: Symbiotic relationships within the wildlife microbiome form a complex tapestry of interactions that profoundly influence the health and survival of various species. At the heart of this intricate web are mutualistic partnerships,

where microorganisms and wildlife coexist in a synergistic relationship that benefits both parties. Mutualism in the wildlife microbiome refers to mutually beneficial interactions between hosts and their microbial counterparts. Microbes play indispensable roles in the host's digestive processes, aiding in the breakdown of complex substances and facilitating nutrient absorption. Examples abound, from ruminant animals relying on microbial fermentation to extract energy from cellulose to insects hosting specialized bacteria that provide essential amino acids absent in their diet [9].

Digestive Harmony and Nutrient Synthesis: The gastrointestinal tracts of many wildlife species serve as dynamic ecosystems where microbial communities orchestrate digestion. The microbiome contributes enzymes that break down otherwise indigestible compounds, facilitating the extraction of nutrients crucial for the host's well-being. In some cases, microbes actively synthesize vitamins and other essential compounds, acting as nutritional partners in the host's diet.

Defensive Alliances: Beyond nutritional support, mutualistic relationships extend to host defence mechanisms. Microbes contribute to the development and maintenance of the host's immune system, defending against potential pathogens. For example, certain bacteria on amphibian skin produce antimicrobial peptides, providing a line of defence against harmful fungi and bacteria.

Case Studies Illustrating Mutualistic Symbiosis: Examining specific wildlife species highlights the diversity and specificity of mutualistic partnerships. From herbivores relying on gut microbes for cellulose digestion to insects farming symbiotic bacteria for protection against parasites, these case studies showcase the adaptive nature of the microbiome and its coevolution with hosts. Understanding these mutualistic partnerships is fundamental to appreciating the intricate dance of life within the microbiome. As we delve into the nuances of these symbiotic relationships, we gain insights not only into the adaptations that enable wildlife to thrive but also into the delicate balance required for the continued existence of these ecosystems.

Ecosystem Functionality: The impact of the microbiome on wildlife extends beyond individual hosts, permeating ecosystems and influencing their overall functionality. Within this realm, the microbiome plays a crucial role in shaping the intricate relationships that define the health and resilience of entire ecosystems.

Nutrient Cycling and Soil Health: Microbial communities are integral players in nutrient cycling, actively participating in the decomposition of organic matter. Through processes like decomposition and mineralization, microorganisms release essential nutrients into the

environment, enriching the soil and supporting plant growth. This nutrient cycling is vital for the health and productivity of ecosystems, fostering a sustainable balance of resources. 2.

Plant-Microbe Interactions: The symbiotic relationships between plants and microbes contribute significantly to the vitality of terrestrial ecosystems. Mycorrhizal fungi, for instance, form symbiotic associations with plant roots, enhancing nutrient uptake and providing the host plants with increased resistance to environmental stress. Understanding these interactions is crucial for comprehending the resilience of plant communities and their responses to changing environmental conditions.

Microbial Contributions to Wildlife Habitats: Microbes contribute to the formation and maintenance of diverse habitats that support wildlife. In aquatic ecosystems, for example, microbial communities play a central role in nutrient cycling, influencing the availability of resources for aquatic organisms. Additionally, microbial mats in terrestrial environments provide stable surfaces for various invertebrates and contribute to soil structure.

Ecological Resilience: The biodiversity and composition of the microbiome contribute to the resilience of ecosystems in the face of disturbances. Diverse microbial communities enhance the stability of ecosystems, as they can provide redundant functional traits that support ecosystem functions even when faced with environmental changes. This resilience is vital for ecosystems to adapt to disturbances such as climate change or human-induced alterations. As we unravel the intricate connections between the microbiome and ecosystem functionality, it becomes evident that these microbial communities are architects of the environments in which wildlife thrives. Their contributions to nutrient cycling, plant-microbe interactions, habitat formation, and ecological resilience underscore the interconnected nature of life within ecosystems, emphasizing the importance of preserving the delicate balance maintained by the microbiome.

Behavioural Influences: Beyond its role in physiological processes, the microbiome exerts a fascinating influence on the behaviour of wildlife species. The intricate connections between microbial communities and the nervous system of hosts highlight a new dimension in understanding the behavioural ecology of various organisms.

1. Microbiome-Brain Axis: Recent research has uncovered the existence of a bidirectional communication system known as the microbiome-gut-brain axis. This axis facilitates communication between the gut and the central nervous system, influencing various aspects of behaviour. In wildlife, this connection is evident in the modulation of feeding behaviours, predator-prey interactions, and responses to environmental stressors.

2. **Cognitive Function and Learning:** The microbiome has been implicated in influencing cognitive function and learning abilities in wildlife. Studies on rodents, for instance, suggest that the composition of the gut microbiota can impact neurodevelopment, affecting cognitive processes such as spatial learning and memory. Understanding these connections may unveil novel insights into the behavioural adaptations of wildlife to their environments.

3. **Social Interactions:** Microbial communities play a role in shaping the social behaviours of certain wildlife species. In social animals like primates, the microbiome has been linked to social hierarchies and affiliative behaviours. Variations in microbial composition have been observed to correlate with social status and the nature of social interactions within groups. The microbiome has been implicated in modulating stress responses and anxiety-like behaviours in wildlife. Changes in microbial composition can influence the production of neurotransmitters and hormones that regulate stress and anxiety. Understanding these connections is crucial for comprehending how wildlife cope with environmental changes and anthropogenic disturbances. The exploration of behavioural influences within the wildlife microbiome unveils a dynamic interplay between microorganisms and the neurological aspects of hosts. The microbiome not only participates in the regulation of basic physiological processes but also contributes to the adaptive behaviours that enable wildlife to navigate complex ecosystems. As we continue to uncover the intricacies of the microbiome-brain axis, a deeper understanding of the behavioural ecology of wildlife emerges, offering novel perspectives on the adaptive strategies and responses of diverse species [10-15].

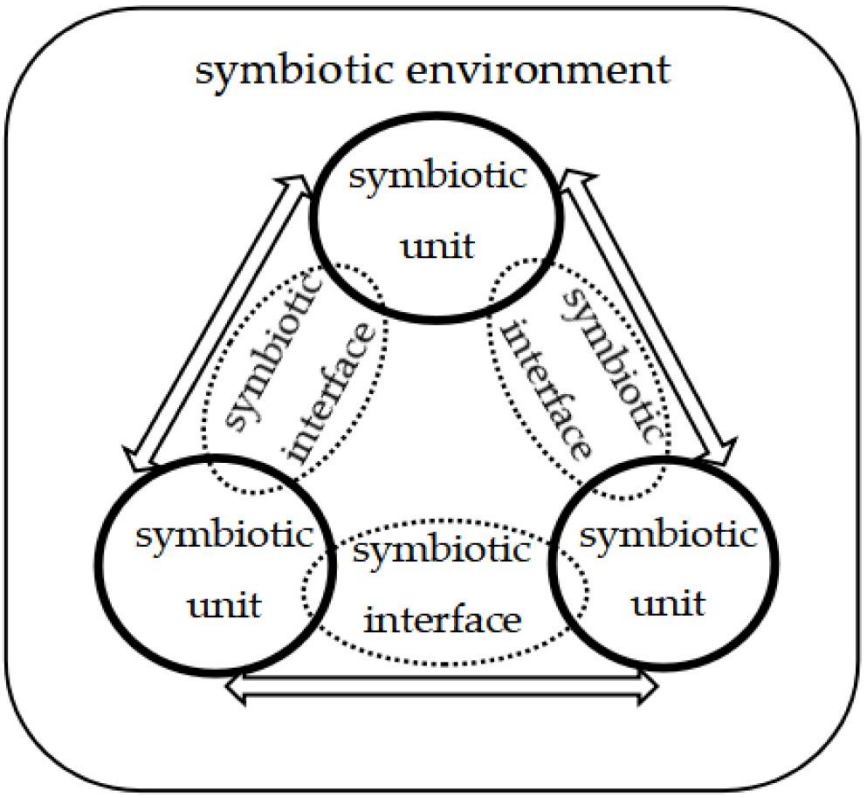

Fig 1. Source MDPI: *Sustainability* **2022**, *14*(5), 3094; **https://doi.org/10.3390/su14053094** [26]

A. Threats to Microbial Diversity: Microbial diversity within the wildlife microbiome faces a myriad of threats, many of which are anthropogenic in nature. As human activities continue to reshape landscapes and alter environmental conditions, the delicate balance of microbial communities is increasingly jeopardized, with far-reaching consequences for the health and functioning of ecosystems. 1. Habitat Destruction: One of the foremost threats to microbial diversity is habitat destruction, driven by activities such as deforestation, urbanization, and agricultural expansion. As natural habitats are converted or fragmented, the diverse niches that support unique microbial communities are lost. This disruption can lead to a decline in microbial diversity, affecting the stability and functionality of ecosystems. Pollution, whether from industrial effluents, agricultural runoff, or plastic waste, poses a significant threat to microbial communities. Contaminants can alter the composition and abundance of microbial populations, leading to the dominance of certain taxa that may be less beneficial or even harmful to the host organisms [16]. Changes in microbial diversity can cascade through ecosystems, impacting nutrient cycling and overall ecosystem health.

The ongoing changes in global climate patterns have profound effects on microbial diversity. Shifts in temperature, precipitation, and other climate parameters can alter the distribution and abundance of microorganisms. These changes, in turn, affect the relationships between

hosts and their microbial symbionts, disrupting finely tuned ecological balances that have evolved over millennia. The overuse and misuse of antibiotics and agrochemicals in agriculture, aquaculture, and veterinary practices can have detrimental effects on microbial diversity. Widespread use of antimicrobial agents can lead to the emergence of resistant strains, altering the dynamics of microbial communities [17]. The loss of microbial diversity can compromise the ability of hosts to resist pathogens and maintain essential mutualistic relationships.

Invasive Species and Altered Land Use: The introduction of invasive species and changes in land use patterns can have cascading effects on microbial diversity. Invasive species may disrupt established microbial communities, and altered land use practices, such as monoculture farming, can reduce the diversity of microbial habitats. These changes can have repercussions on ecosystem functioning and the health of wildlife populations. Recognizing and addressing these threats to microbial diversity is crucial for maintaining the intricate balance within the microbiome and ensuring the resilience of ecosystems [18]. Conservation efforts must extend beyond charismatic megafauna to consider the microbial life that underpins ecological processes. Mitigating these threats requires a holistic approach that integrates microbial conservation into broader biodiversity and ecosystem conservation strategies.

Wildlife Health and Conservation: The health of wildlife is intricately linked to the well-being of their microbiome, and recognizing this connection is paramount for effective conservation strategies. Understanding the role of the microbiome in wildlife health not only provides insights into the adaptation and resilience of species but also offers innovative approaches to conservation efforts. The composition and diversity of the microbiome serve as valuable indicators of the overall health of wildlife populations. Changes in microbial communities can be early signs of environmental stress, pollution, or disease. Monitoring the microbiome allows conservationists to detect and respond to emerging threats before they manifest as visible signs of illness in wildlife populations [19].

Disease Resistance and Resilience: A diverse and well-balanced microbiome is crucial for wildlife in resisting diseases and maintaining overall health. Conservation strategies that focus on preserving microbial diversity contribute to the development of resilient populations capable of withstanding infectious agents. This is particularly relevant in the face of emerging diseases and changing environmental conditions.

Conservation Initiatives Leveraging Microbiome Research: Integrating microbiome research into conservation initiatives enhances the effectiveness of wildlife management

strategies. For example, in captive breeding programs, understanding the microbial requirements of endangered species can improve the success of reintroduction efforts. Similarly, conservationists can employ probiotics or microbiome restoration techniques to enhance the health of individuals or populations facing threats. 4. Habitat Restoration and Microbial Communities: Efforts aimed at habitat restoration play a crucial role in preserving microbial diversity. Restoration activities that focus on reestablishing natural ecosystems help recreate the diverse niches essential for a healthy microbiome. Conserving microbial communities alongside broader biodiversity contributes to the overall resilience of ecosystems. **One Health Approaches:** Recognizing the interconnectedness of human, animal, and environmental health, the One Health approach emphasizes a holistic perspective that includes the microbiome. Conservation initiatives adopting this approach acknowledge the importance of healthy microbial communities not only for wildlife but also for the broader ecosystem and human well-being. The conservation of wildlife goes hand in hand with the preservation of microbial diversity and the health of the microbiome. By incorporating microbiome research into conservation strategies, we enhance our understanding of the intricate relationships between microorganisms and their hosts, paving the way for more nuanced and effective approaches to safeguarding biodiversity [20-21]. As we strive to protect the planet's wildlife, recognizing the vital role of the microbiome is essential for fostering resilient ecosystems capable of withstanding the challenges of a rapidly changing world. Health, and the regulation of plant and animal interactions. The delicate balance of these microscopic organisms shapes the functionality and stability of diverse ecosystems, underscoring their significance in maintaining biodiversity and ecosystem resilience. This interconnected web of relationships emphasizes the intricate nature of life within the natural world, where the microbiome serves as an often-overlooked architect of the environments that support wildlife. However, the microbiome faces threats from anthropogenic activities, such as habitat destruction, pollution, and climate change. These challenges compromise the delicate balance within microbial communities and pose risks to the health and adaptability of wildlife. Recognizing the threats to microbial diversity is essential for formulating effective conservation strategies. Integrating microbiome research into conservation initiatives offers a more comprehensive understanding of the intricate relationships that define the microbiome of wildlife. By doing so, we unlock novel opportunities to enhance conservation efforts, not only for charismatic species but for the entire ecosystems that depend on the health of their microbial inhabitants. In the pursuit of

preserving global biodiversity, acknowledging and safeguarding the microbiome of wildlife becomes an integral component of holistic and sustainable conservation practices [22].

Microbiome of wildlife

The establishment and maintenance of symbiotic relationships are orchestrated through intricate mechanisms that underscore the adaptability of both hosts and microbes. Mutualistic interactions, a fundamental mechanism, involve a reciprocal exchange of benefits between the host organism and its microbial inhabitants. Microbes contribute to the host's digestive processes, aiding in the breakdown of complex compounds and facilitating nutrient absorption. In return, hosts provide a suitable environment and essential nutrients for the microbial community [23]. Chemical signalling serves as another crucial mechanism, enabling communication between hosts and microbes. Hosts release signalling molecules that influence microbial behaviour, regulating processes like gene expression and metabolism within the microbial community. This intricate dance of mutualism is a testament to the finely tuned mechanisms that have evolved over time, shaping the coexistence of wildlife and their microbial partners. The ecological impact of the microbiome extends to the very fabric of ecosystems, driven by mechanisms such as nutrient cycling and intricate plant-microbe interactions. Nutrient cycling, facilitated by microbial communities, involves the breakdown of organic matter and the release of vital nutrients into the environment. Microbes act as decomposers, breaking down complex compounds into simpler forms that can be utilized by plants and other organisms. Plant-microbe interactions, mediated by mechanisms like mycorrhizal associations, enhance nutrient uptake by plants and contribute to their resilience against environmental stressors [24-25]. These mechanisms collectively shape the health and functioning of ecosystems, highlighting the microbiome's role as a key player in maintaining biodiversity and ecological stability. Understanding these mechanisms is essential for formulating effective conservation strategies that address the intricate relationships between microorganisms and the broader ecological context.

Conclusion

The exploration of the microbiome of wildlife unveils a captivating world where microorganisms intricately intertwine with the health, behaviour, and ecological dynamics of diverse species. The symbiotic relationships within the wildlife microbiome showcase the resilience and adaptability of both hosts and microbes, emphasizing the coevolutionary processes that have shaped life on Earth. The ecological impact of the microbiome extends far beyond individual organisms, influencing the functionality and stability of entire

ecosystems. Microbial communities contribute to nutrient cycling, soil health, and the regulation of plant and animal interactions, revealing their indispensable role as architects of the environments that support wildlife. This interconnected web of life underscores the importance of preserving microbial diversity as an integral component of broader conservation efforts. However, the micro biome faces imminent threats from human-induced activities, posing risks to the delicate balance within microbial communities and, consequently, the health of wildlife. Habitat destruction, pollution, and climate change challenge the adaptability of these microscopic organisms and the species they support. Recognizing and addressing these threats is paramount for sustaining the intricate relationships within the microbiome and, by extension, ensuring the resilience of ecosystems. In the realm of conservation, the integration of microbiome research offers a novel and holistic approach. Understanding the microbial intricacies enables conservationists to formulate more nuanced and effective strategies that consider not only the charismatic megafauna but also the microbial communities that underpin ecosystem health. By acknowledging the microbiome's role in wildlife conservation, we embark on a path towards safeguarding biodiversity in its entirety. Ultimately, the microbiome of wildlife represents a frontier of scientific discovery and a critical piece of the puzzle in our efforts to preserve the rich tapestry of life on Earth. As we continue to explore and unravel the mysteries of this microscopic world, we gain valuable insights that will shape the future of conservation, ensuring the well-being of wildlife and the ecosystems they inhabit for generations to come.

References

[1]. Trevelline, B. K., Fontaine, S. S., Hartup, B. K., & Kohl, K. D. (2019). Conservation biology needs a microbial renaissance: a call for the consideration of host-associated microbiota in wildlife management practices. *Proceedings of the Royal Society B, 286*(1895), 20182448.

[2]. West, A. G., Waite, D. W., Deines, P., Bourne, D. G., Digby, A., McKenzie, V. J., & Taylor, M. W. (2019). The microbiome in threatened species conservation. *Biological Conservation*, *229*, 85-98.

[3]. Williams, C. L., Caraballo-Rodríguez, A. M., Allaband, C., Zarrinpar, A., Knight, R., &Gauglitz, J. M. (2018). Wildlife-microbiome interactions and disease: exploring opportunities for disease mitigation across ecological scales. *Drug Discovery Today: Disease Models*, *28*, 105-115.

[4]. Jiménez, R. R., & Sommer, S. (2017). The amphibian microbiome: natural range of variation, pathogenic dysbiosis, and role in conservation. *Biodiversity and conservation*, *26*, 763-786.

[5]. Daskin, J. H., & Alford, R. A. (2012). Context-dependent symbioses and their potential roles in wildlife diseases. *Proceedings of the Royal Society B: Biological Sciences*, *279*(1733), 1457-1465.

[6]. Ingala, M. R., Simmons, N. B., Wultsch, C., Krampis, K., Speer, K. A., & Perkins, S. L. (2018). Comparing microbiome sampling methods in a wild mammal: fecal and intestinal samples record different signals of host ecology, evolution. *Frontiers in Microbiology*, *9*, 803.

[7]. Sandifer, P. A., Sutton-Grier, A. E., & Ward, B. P. (2015). Exploring connections among nature, biodiversity, ecosystem services, and human health and well-being: Opportunities to enhance health and biodiversity conservation. *Ecosystem services*, *12*, 1-15.

[8]. Peixoto, R. S., Voolstra, C. R., Sweet, M., Duarte, C. M., Carvalho, S., Villela, H., ... & Berg, G. (2022). Harnessing the microbiome to prevent global biodiversity loss. *Nature Microbiology*, *7*(11), 1726-1735.

[9]. Couch, C. E., & Epps, C. W. (2022). Host, microbiome, and complex space: applying population and landscape genetic approaches to gut microbiome research in wild populations. *Journal of Heredity*, *113*(3), 221-234.

[10]. Wei, F., Wu, Q., Hu, Y., Huang, G., Nie, Y., & Yan, L. (2019). Conservation metagenomics: a new branch of conservation biology. *Science China Life Sciences*, *62*, 168-178.

[11]. Clayton, J. B., Gomez, A., Amato, K., Knights, D., Travis, D. A., Blekhman, R., ... & Johnson, T. J. (2018). The gut microbiome of nonhuman primates: Lessons in ecology and evolution. *American journal of primatology*, *80*(6), e22867.

[12]. Hu, Y., Hu, Y., Zhou, W., & Wei, F. (2023). Conservation Genomics and Metagenomics of Giant and Red Pandas in the Wild. *Annual Review of Animal Biosciences*, *12*.

[13]. Zhou, Z., Tang, L., Yan, L., Jia, H., Xiong, Y., Shang, J., ... & Zhang, D. (2022). Wild and captive environments drive the convergence of gut microbiota and impact health in threatened equids. *Frontiers in Microbiology*, *13*, 832410.

[14]. Chalifour, B. N., Elder, L. E., & Li, J. (2023). Diversity of gut microbiome in Rocky Mountainsnail across its native range. *Plos one*, *18*(11), e0290292.

[15]. Ohmer, Michel EB, David Costantini, Gábor Á. Czirják, Cynthia J. Downs, Laura V. Ferguson, Andy Flies, Craig E. Franklin et al. "Applied ecoimmunology: using immunological tools to improve conservation efforts in a changing world." *Conservation Physiology* 9, no. 1 (2021): coab074.

[16]. Sehnal, L., Brammer-Robbins, E., Wormington, A. M., Blaha, L., Bisesi, J., Larkin, I., ... &Adamovsky, O. (2021). Microbiome composition and function in aquatic vertebrates: small organisms making big impacts on aquatic animal health. *Frontiers in Microbiology*, *12*, 567408.

[17]. Mana, P. W., Wang-Bara, B., Mvondo, V. Y. E., Bourou, S., &Palaï, O. (2023). Evaluation of the agronomic and technological performance of three new cotton varieties in the cotton zone of Cameroon. *Acta Botanica Plantae*, *2*, 28-39.

[18]. Mallott, E. K., & Amato, K. R. (2021). Host specificity of the gut microbiome. *Nature Reviews Microbiology*, *19*(10), 639-653.

[19]. Dallas, J. W., & Warne, R. W. (2023). Captivity and animal microbiomes: potential roles of microbiota for influencing animal conservation. *Microbial ecology*, *85*(3), 820-838.

[20]. Comizzoli, P., & Power, M. (2019). Reproductive microbiomes in wild animal species: a new dimension in conservation biology. *Reproductive sciences in animal conservation*, 225-240.

[21]. Mana, P. W., Wang-Bara, B., Mvondo, V. Y. E., Bourou, S., &Palaï, O. (2023). Evaluation of the agronomic and technological performance of three new cotton varieties in the cotton zone of Cameroon. *Acta Botanica Plantae*, *2*, 28-39.

[22]. Lindsay, E. C., Metcalfe, N. B., & Llewellyn, M. S. (2020). The potential role of the gut microbiota in shaping host energetics and metabolic rate. *Journal of Animal Ecology*, *89*(11), 2415-2426.

[23]. Murphy, K. M., Le, S. M., Wilson, A. E., & Warner, D. A. (2023). The Microbiome as A Maternal Effect: A Systematic Review on Vertical Transmission of Microbiota. *Integrative and Comparative Biology*, icad031.

[24]. Weinstein, S. B., Martínez-Mota, R., Stapleton, T. E., Klure, D. M., Greenhalgh, R., Orr, T. J., ... & Dearing, M. D. (2021). Microbiome stability and structure is governed by host phylogeny over diet and geography in woodrats (Neotoma spp.). *Proceedings of the National Academy of Sciences*, *118*(47), e2108787118.

[25]. Ogori, A. F., Eke, M. O., Girgih, T. A., & Abu, J. O. (2022). Influence of Aduwa (Balanites aegyptiaca. del) Meal Protein Enrichment on the Proximate, Phytochemical, Functional and Sensory Properties of Ogi. *Acta Botanica Plantae. V01i03*, 22-35.

[26]. Xu, J.; Wu, H.; Zhang, J. Innovation Research on Symbiotic Relationship of Organization's Tacit Knowledge Transfer Network. *Sustainability* **2022**, *14*, 3094. https://doi.org/10.3390/su14053094