Exploring the Secrets of Insect Biodiversity

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Insects are the most diverse group of animals on Earth, with millions of species inhabiting nearly every terrestrial and aquatic habitat. However, the exact number of insect species remains a mystery, with estimates ranging from 5.5 million to 7 million. As stated in the Convention on Biological Diversity's Secretariat report (2020), approximately 1 million insect species have been formally described and named by scientists. This represents only 20% of the estimated total insect population. Insects perform vital roles in the ecosystem like pollinators, decomposers, and a source of food for other animals. Insect biodiversity is genuinely unique due to the wide range of causes that contribute to their amazing variety. Despite their importance, most insect species remain poorly understood and understudied (Footit and Alder, 2009). To fully grasp the complexities

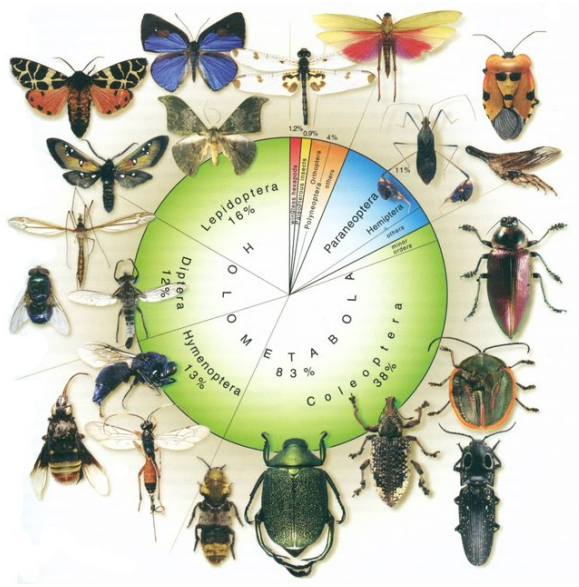

Fig.1: Insect diversity (Grimaldi and Engel, 2005)

and importance of insect biodiversity, it is essential to delve into the fascinating world of these small creatures.

The Significance of Insect Biodiversity: Unveiling the Hidden Ecological Gems

The world of insects is often overlooked and overshadowed by larger, more charismatic animals. However, beneath their tiny exteriors lies a world of immense ecological significance. Insect biodiversity plays a crucial role in sustaining the delicate balance of ecosystems around the globe. Insects, despite their often-underestimated stature, play a fundamental role in the intricate web of life, especially as pollinators, with approximately 75% of flowering plants relying on them for successful reproduction (Klein et al., 2007). These tiny creatures, ranging from the tiniest bees buzzing between blossoms to the mesmerizing butterflies fluttering through meadows, act as nature's diligent workers, diligently transferring pollen between flowers. This process allows plants to flourish, contributing to the diverse ecosystems in which they thrive.

Recent studies further highlight the critical importance of insect pollinators in various aspects. For global food security, research by Potts et al. (2016) estimates that insect pollinators contribute to the production of 35% of the world's food crops, underscoring their vital role in ensuring the stability of global food supplies. In terms of plant diversity, insect pollination promotes the diversification of plant communities, leading to richer and more resilient ecosystems (Ollerton et al., 2019). Additionally, the economic benefits of insect pollination are estimated to be in the trillions of dollars annually, highlighting the immense financial impact of these tiny creatures on agriculture and food production (Gallai et al., 2009). Therefore, safeguarding and preserving insect populations is crucial for maintaining healthy ecosystems, ensuring biodiversity, and safeguarding global food security.

Fig. 2: Pollination by bees (https://www.milgro.eu)

Fig. 3: Flightless Dung Beetle (www.shamwari.com)

Besides, insects also serve as efficient decomposers. Wood-boring beetles, dung beetles, and termites are just a few examples of insects that break down organic matter, recycle nutrients, and maintain soil fertility. Insects play a crucial role in the Earth's natural decomposition process, ensuring the efficient breakdown of organic matter and preventing the accumulation of waste, a vital function that would be severely hindered without their presence. Quantifying the impact of waste accumulation without insects is challenging due to the complexity of ecological systems, but insights from various studies provide valuable perspectives. Estimates suggest that the Earth's terrestrial ecosystems produce around 200 billion metric tons of dry plant matter annually, and a significant portion of this biomass requires decomposition to return nutrients and energy to the ecosystem (Bar-On et al., 2018). Studies have demonstrated that insect-mediated decomposition is significantly faster than decomposition driven by other factors like fungi and bacteria, with invertebrate detritivores accelerating the process by up to 20 times compared to microbial activity alone (Gessner et al., 2010).

Based on these estimations, the potential annual accumulation of undecomposed organic matter in the absence of insects could reach tens or even hundreds of billions of metric tons, significantly impacting the global carbon cycle and disrupting nutrient availability in ecosystems. The consequences of such waste accumulation would be profound, including disrupted nutrient cycling as undecomposed organic matter locks up essential nutrients like nitrogen and phosphorus, limiting their availability for plant growth and overall ecosystem productivity. Furthermore, the increased accumulation of organic matter without

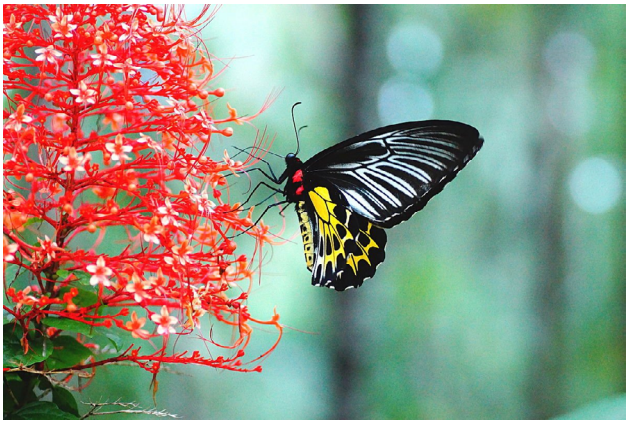

Fig. 4: Southern Birdwing Butterfly (https://twitter.com/amabirdman/status/1666644316759130112)

insects could lead to higher methane emissions during decomposition processes, contributing to climate change.

The ripple effects of insect absence would extend to reduced biodiversity, as a decline in nutrient availability and altered ecosystem functioning could negatively impact various species dependent on

decomposed organic matter, ultimately leading to a potential decrease in biodiversity (Ghosh, 1996). Thus, insects emerge as essential components of healthy ecosystems, playing a pivotal role in decomposition processes crucial for waste prevention and nutrient cycling. Their absence would have devastating consequences for the environment, affecting biodiversity, nutrient availability, and potentially contributing to climate change. Therefore, conservation efforts aimed at protecting insect populations are imperative for maintaining a healthy and balanced planet.

In addition to their vital ecological roles, insects are also a vital food source for countless other animals. Birds, reptiles, amphibians, mammals and even other arthropods rely on insects as a primary source of nutrition. From the captivating aerial displays of insectivorous birds to the agile leaps of insect-eating frogs, it is clear that these tiny creatures are essential for sustaining the wider web of life.

Unraveling the Mysteries: What Makes Insect Biodiversity So Unique?

Insect biodiversity is influenced by a variety of variables, making insect biodiversity genuinely

Fig. 5: Termite Colony (https://www.istockphoto.com)

unique. One key factor is their ability to adapt and thrive in diverse habitats, from the depths of oceans to the highest mountaintops. This adaptability allows insects to occupy various niches, resulting in an astounding array of forms, colors, and behaviors. From the brilliantly colored beetles to the velvety wings of moths, each insect has evolved distinct adaptations that enable them to survive and thrive in their specific environments.

Furthermore, the remarkable reproductive capabilities of insects contribute to their incredible biodiversity. Insect colonization is a triumph of rapid reproduction, facilitated by several fascinating adaptations. Another fascinating aspect of insect biodiversity is their incredible range of ecological interactions. Insects have evolved complex relationships with plants, other animals, and even with each other. These complicated relationships contribute to the general stability and functioning of ecosystems, ranging from mutualistic partnerships in which insects give significant services to their host plants to predatory interactions in which insects play an important role in regulating populations of other animals.

Moreover, the study of insect biodiversity with surrounding nature has led to exciting discoveries of new chemical compounds with potential applications in medicine, agriculture, and industry. Insects produce a vast array of bioactive compounds, some of which have been found to possess antimicrobial, antitumor, and anti-inflammatory properties. By delving into the secrets of insect biodiversity, scientists unlock new possibilities for developing innovative therapies, sustainable farming practices, and eco-friendly technologies.

Insect Powerhouse: Exploring adaptability, reproduction, ecology, and potential applications:

Insects, as the undisputed powerhouses of the animal kingdom, showcase a remarkable combination of adaptability, reproductive prowess, intricate ecological interactions, and diverse potential applications. They are survival masters, demonstrating their ability to thrive in diverse environments, from scorching deserts to frigid tundras (Gibbs and Van Der Leeuw,

2018). Furthermore, their evolutionary marvels contribute to their exceptional success, allowing them to adapt to changing environments and evolve rapidly, maintaining their long reign as Earth's dominant life form (Futuyma, 2013).

These survival skills are complemented by the exquisite innovations displayed by insects, ranging from camouflage and mimicry to the development of complex social structures and communication systems, all of which enhance their survival and reproduction (Wilson, 1979). In terms of reproductive prowess, insects possess exceptional capabilities that lead to exponential population growth, allowing them to quickly repopulate and recover from environmental disturbances (Chapman, 2013). The diversity in their reproductive strategies, including parthenogenesis and complex mating rituals, ensures the continued existence of various insect species (Gullan and Cranston, 2010). This prolific reproduction, in turn, plays a vital role in food webs and ecosystem balance, supporting diverse predator populations and influencing plant dispersal (Price, 2012).

Many insects exhibit high reproductive potential, with some species laying hundreds or even thousands of eggs at once. For instance, termite colonies can reach millions of individuals as a single queen lays up to 30,000 eggs per day (Vargo, 2007). Additionally, the short life cycles of many insects, such as houseflies completing their entire life cycle in as little as 10 days (Krafsur, 2009), enable them to swiftly increase their populations. Some insects further benefit from multiple reproduction cycles within a year, allowing them to adapt quickly to changing environmental conditions and exploit newly available resources; mosquitoes, for example, can go through several generations in a single summer (Gubler, 2012). Moreover, non-sexual reproduction mechanisms contribute significantly to insect colonization. Certain species can reproduce asexually through parthenogenesis, establishing new populations even without a mate.

Several intriguing examples highlight the diversity of insect reproductive strategies. Aphids, tiny insects capable of giving birth to live young without mating, can reproduce asexually for hundreds of generations, enabling them to swiftly take over new environments (Simon, 2016). Social insects like army ants form massive colonies with millions of individuals, capable of travelling long distances and quickly depleting an area of its food resources. Additionally, locusts, as swarming grasshoppers, can reach massive numbers, posing a threat to agriculture by consuming crops and causing widespread devastation. Ultimately, the remarkable reproductive abilities of insects contribute to their status as the most diverse and abundant group of animals on Earth, playing a crucial role in maintaining the health and balance of ecosystems worldwide. This output ensures genetic diversity

Fig.6: *Ephydra hians,* commonly known as the alkali fly
(https://en.wikipedia.org/wiki/Ephydra_hians)

within populations and allows for rapid evolution and adaptation to changing conditions.

Intricate ecological interactions further define the significance of insects in the natural world. They act as vital pollinators for countless flowering plants, ensuring their reproduction and maintaining the diversity of plant life (Klein et al., 2007). Additionally, as decomposers, insects play a crucial role in breaking down organic matter and returning nutrients to the soil, contributing to overall ecosystem health (Bardgett and van der Putten, 2014). Occupying diverse positions in food webs as both predators and

prey, insects contribute to the complex balance and dynamics of ecosystems (Price, 2012).

Beyond their ecological roles, insects offer a plethora of potential applications. They serve as biocontrol agents, playing a valuable role in controlling agricultural pests and offering a sustainable alternative to chemical pesticides (Van Lenteren et al., 2003). Moreover, insects present a promising food source, with potential implications for providing sustainable and environmentally friendly options for the future (Van Huis et al., 2013). In the realm of medicine, insect-derived compounds are being explored for their potential use, showing promising results for various diseases (Lee et al., 2010). This exploration underscores the profound importance of insects in the natural world and highlights the pressing need for their conservation.

Exploring the Richness: Where to find Insect Biodiversity:

Now that we have delved into the unique aspects of insect biodiversity, it's time to embark on a journey to explore the richness of these fascinating creatures. Insects can be found in a wide range of habitats, each offering a unique array of species and ecological niche. The tropical rainforest is one of the richest and most diverse habitats for insect biodiversity and it harbor a staggering number of insect species. Estimates suggest that there could be 10 million or more insect species in these forests, although only a fraction of them have been described (Mora et al., 2011). Insects are ectothermic, meaning they rely on external heat sources to regulate their body temperature. The consistently warm temperatures in tropical rainforests provide an ideal environment for them to thrive. These lush and dense environments are home to an incredible variety of insects, from colorful butterflies to camouflaged stick insects. The diverse vegetation provides abundant food sources and diverse microhabitats for insects to thrive and evolve (Erwin, 1982).

However, the wonders of insect biodiversity are not limited to the rainforest. Insects, with their astonishing ability to adapt and thrive in diverse and often extreme environments, have a global presence, spanning from the scorching deserts of the Sahara to the frigid tundras of the Arctic (Capinera, 2011). This adaptability is exemplified by remarkable species such as the Ephydra fly, which thrives in the seemingly uninhabitable environment of petroleum wells, showcasing the incredible limits of insect resilience (Horodyski et al., 2014). Noteworthy adaptations include the production of cryoprotectants by some insects, like the Alaskan beetle, preventing their body fluids from freezing in subzero temperatures (Zachariassen, 2002).

Additionally, certain insects, such as the desert locust, exhibit desiccation tolerance, surviving long periods of dehydration by entering a state of diapause where their metabolic processes significantly slow down (Chown and Nicolson, 2004). Furthermore, some insects, like the Pompeii worm, demonstrate extreme heat resistance, withstanding temperatures exceeding 100°C, enabling them to thrive in volcanic environments (Cui et al., 2017). Even in our backyards, a world of insect diversity is waiting to be discovered. Observing and documenting insects in our local environments can contribute to citizen science initiatives (kosamala et al., 2016)

Fig. 7: Butterflies of India website (https://www.ifoundbutterflies.org/)

and help build a better understanding of insect distributions and population trends, with platforms like iFoundButterflies.org (Kunte et al., 2023) providing valuable opportunities for individuals to contribute to the collection of information. This data

significantly aids in the broader effort to enhance our understanding of insect distributions and population trends, ultimately supporting initiatives for their conservation.

In addition to natural habitats, certain man-made environments also harbor significant insect biodiversity. Urban areas, often perceived as concrete jungles devoid of life, can surprisingly harbor a rich diversity of insects, with parks, gardens, and green spaces providing essential habitat for these tiny creatures, offering them food, shelter, and breeding opportunities (Beninde et al., 2015). These urban oases contribute significantly to maintaining insect populations and fostering a healthy ecosystem, even amidst the built environment. Studies have highlighted the importance of urban green spaces for insect biodiversity, showing that urban areas support a remarkable variety of insect species, as demonstrated in a 2019 review published in Biological Conservation (Wenzel et al., 2019). Additionally, urban green spaces can act as stepping stones, facilitating the movement of insects between fragmented habitats and promoting the exchange of genetic material (Gilbert-Norton et al., 2010). Furthermore, insects play a vital role in pollinating urban plants, contributing to the production of fruits, vegetables, and flowers, thereby enhancing the aesthetics of the urban environment (Frankie and Ehler, 1978). To actively promote insect biodiversity in urban environments, adopting sustainable gardening practices such as choosing native plants, avoiding pesticides, providing nesting sites, and minimizing water use can significantly enhance insect populations in urban gardens (Baldock et al., 2015). Creating insect-friendly habitats, such as establishing green roofs, meadows, and other features with diverse vegetation, can provide a range of habitats for different insect species (Frankie and Ehler, 1978). Additionally, educating and raising awareness about urban insects can foster community-based conservation efforts and encourage individuals to contribute to their protection (Crutzen, 2017). Thus, exploring insect biodiversity expands our knowledge and appreciation of the natural world and raises awareness of the importance of conservation efforts.

Preserving and Protecting: Giving insect biodiversity the platform it deserves:

Fig.8: Monarch Butterfly Biosphere Reserve, Mexico (https://whc.unesco.org/en/list/1290/)

Fig. 9: Waggle dance of Honey bee (https:/theconversation.com)

Now that we have explored the vast riches of insect biodiversity and discovered the incredible wonders that lie within, it is time to shift our focus towards preserving and protecting these extraordinary creatures. As we continue to uncover the secrets of their intricate ecosystems, ensuring their continued survival is becoming increasingly important. Insect biodiversity faces numerous threats primarily driven

by human activities, including habitat destruction, pollution, climate change, and pesticide use, all of which pose significant challenges to these delicate creatures on a daily basis. Without intervention, there is a considerable risk of losing countless species crucial to the natural world, as they provide invaluable ecosystem services such as pollination and decomposition. The alarming rate of land-use change, primarily for agriculture and urbanization, leads to the destruction and fragmentation of insect habitats, disrupting populations and diminishing their ability to disperse and find resources (Dirzo et al., 2014). The use of pesticides, herbicides, and other pollutants has a devastating impact on insect populations, either directly causing their death or harming their reproductive systems, ultimately resulting in population decline (Goulson, 2013). Furthermore, rising temperatures and changes in precipitation patterns disrupt insect life cycles, pushing them to their limits and causing range shifts, population declines, and even extinctions (Parmesan, 2006).

One of the most effective ways to conserve insect biodiversity is through the establishment of protected areas. These designated spaces provide a safe haven for insects and serve as important research sites for scientists to study these often-overlooked creatures. By advocating for creating and maintaining these protected areas, we can ensure that future generations can marvel at the beauty and importance of insect diversity.

Fig 10: Conservation of Insect Biodiversity (https://www.istockphoto.com)

Furthermore, individuals need to take action in their own lives to support insect conservation efforts. Small changes, such as reducing the use of pesticides, creating insect-friendly habitats in gardens, and practising sustainable agriculture, can significantly impact be promoting and protecting insect biodiversity. Addressing the multifaceted challenge of preserving insect biodiversity requires more than individual actions; governments and policymakers play a crucial role in creating a supportive framework and implementing effective conservation strategies that impact vast landscapes, agricultural practices, and public awareness. Policy-driven solutions include habitat protection through the designation of protected areas, restriction of harmful land-use practices, and implementation of restoration projects (Fischer et al., 2021). Governments can also address the issue by implementing stricter regulations on pesticide use, promoting alternatives, and supporting research on safer methods of pest control (IPBES, 2019). In addition, policymakers can incentivize sustainable agricultural practices, such as crop diversification, organic farming, and reduced tillage, to benefit insect populations (Garibaldi et al., 2020). Furthermore, governments can play a vital role in raising public awareness about the importance of insects and promoting actions for their conservation (Crutzen, 2017). For instance, in India, the government has launched initiatives like the National Mission for Sustainable Agriculture and the National Biodiversity Action Plan, which promote organic farming, biodiversity conservation, and research on pollinator-friendly practices. In the European Union, the Pollinators Initiative has been implemented, encompassing measures to improve habitat quality, promote sustainable agriculture, and support research on pollinator health.

By implementing and enforcing regulations that

prioritize conservation, we can create a harmonious balance between human activities and the needs of insect populations. Education and awareness campaigns can also help shape public opinion and generate support for insect conservation efforts. In Insects, often overlooked and underestimated, play a crucial role as the cornerstone of healthy ecosystems, providing vital services such as pollination, decomposition, and pest control; however, these essential creatures face numerous threats, including habitat loss, climate change, and pesticide use. Nearly 41% of insect species are threatened with extinction, with some regions experiencing declines exceeding 75% (Dirzo et al., 2014), and the State of the World's Biodiversity for Food and Agriculture report in 2019 emphasizing the critical role of insects in food production and warning of potential food insecurity due to pollinator decline (FAO, 2019), underscores the urgency of taking action to conserve insects.

Fortunately, there are various ways individuals can get involved, such as supporting citizen science initiatives like iFoundButterflies (Kunte et al., 2023) and Bumble Bee Watch (Vanbergen et al., 2015), which provide valuable opportunities to contribute data vital for understanding insect populations and trends. Additionally, creating insect-friendly habitats by planting native flowers and avoiding pesticide use in gardens, balconies, or window boxes can offer crucial resources and shelter for diverse insect species. Advocating for policy change to support sustainable land management practices, reduce pesticide use, and protect critical habitats is another impactful step, as is educating others about the importance of insects and the threats they face. By raising awareness within your community and inspiring collective action, we can work together to create a future where insects are valued and protected, unlocking the mysteries and marvels of these incredible creatures for generations to come.

Success Stories in Insect Biodiversity Conservation in India and Beyond:

Insects, vital components of healthy ecosystems due to their crucial roles in pollination, decomposition, and pest control, are globally facing significant threats from habitat loss, pollution, and climate change. Fortunately, there is hope for the future as various successful regulatory programs have emerged to protect and strengthen insect biodiversity. In India, the National Mission for Sustainable Agriculture (NMSA), launched in 2014, actively promotes sustainable agricultural practices beneficial to pollinators and other insects. It encourages the adoption of organic farming techniques, provides financial assistance to farmers implementing pollinator-friendly practices, and raises awareness about the importance of insect conservation, resulting in increased pollinator populations and crop yields in participating regions. Beyond India, the European Union's Pollinator Initiative, initiated in 2018, addresses pollinator decline in Europe through measures like research, habitat restoration, and awareness campaigns, funding successful projects such as pollinator-friendly corridor creation and innovative pest control methods. Furthermore, the Monarch Butterfly Biosphere Reserve, established in 1980 as a UNESCO World Heritage Site in Mexico, protects the monarch butterfly's overwintering grounds and has successfully stabilized their population after a significant decline through strict regulations and conservation efforts.

Advocates of the Unseen: How Insect Biodiversity enhances our understanding of the Natural World

Insects, with their incredible diversity and abundance, are not only fascinating creatures in their own right but also serve as vital indicators of the health of ecosystems. Their intricate relationships with plants, animals, and other insects provide valuable insight into the functioning of the natural world. One of the key ways in which insect biodiversity enhances our understanding is through its role in pollination. Bees, butterflies, and other pollinators transfer pollen from one flower to another, enabling plant reproduction and the production of fruits and seeds. This process is

not only essential for the survival of numerous plant species but also for the production of a significant proportion of the world's food crops. By studying the interactions between insects and plants, scientists can gain insights into how to manage and protect these crucial pollinators.

Insects also play a crucial role in nutrient cycling and decomposition. They break down organic matter, such as dead plants and animals, and return nutrients to the soil. Without insects, these processes would significantly slow down, impacting the overall health and productivity of ecosystems. Understanding the intricate relationships between insects, microbes, and plants in these decomposition processes is key to maintaining healthy soil and sustainable agricultural practices. Furthermore, the study of insect behavior can offer valuable insights into complex ecological interactions. Communication and mating rituals to predator-prey relationships and territorial behavior, insects display a wide variety of fascinating behaviors. By observing and understanding these behaviors, scientists can further unravel the intricate web of life that underpins our ecosystems.

In addition to their ecological significance, insects offer remarkable promise for medical and technological advancements. These tiny creatures harbor a vast array of unexplored compounds with potential applications in various fields, waiting to be discovered and harnessed. In the realm of insect-derived pharmaceuticals, their constant exposure to pathogens has led to the development of potent antimicrobial defenses. Compounds such as defensins and cecropins isolated from insects exhibit promising activity against bacteria, fungi, and viruses, providing alternatives to conventional antibiotics (Zasloff, 2002). Moreover, research indicates that insect-derived compounds possess anticancer properties, with potential anti-cancer drugs identified in bee venom and firefly luciferase (Chassaing et al., 2018). Additionally, venom from various insects, including scorpions and wasps, contains peptides and proteins with analgesic effects, offering alternatives to traditional pain medications (Berenbaum, 2017).

Beyond the realm of pharmaceuticals, insects contribute to technological applications as well. Insect silk, known for its strength and elasticity, holds potential for bioengineering applications such as sutures and tissue scaffolds (Altman et al., 2012). Insects' highly sensitive olfactory and gustatory receptors can be harnessed for developing biosensors capable of detecting explosives, drugs, and environmental pollutants (Leal et al., 2013). Moreover, the remarkable agility and adaptability of insects inspire the development of biomimetic robots, with potential applications in search and rescue operations and environmental monitoring (Zhang et al., 2015). Furthermore, their unique adaptations, such as the ability to fly or walk on walls, have inspired innovations in engineering and robotics. By studying the vast array of insect species, researchers can unlock new possibilities for human well-being and technological development. In conclusion, the unseen world of insect biodiversity provides us with a wealth of knowledge about the natural world. By investing in the study and conservation of insect biodiversity, we protect these incredible creatures and pave the way for a deeper understanding of the ecosystems that sustain us all.

Concluding Thoughts: Embracing the wonder and importance of Insect Biodiversity:

As we conclude our exploration of the untold wonders of insect biodiversity, it becomes evident that these small creatures hold immense significance in our understanding of the natural world, from their pivotal role in pollination and nutrient cycling to their intricate behaviors and potential for medical and technological advancements. In recognizing their wonder and importance, it is essential to embrace the need for conservation and protection of these incredible creatures to ensure the continued functioning of ecosystems and the sustainability of our planet.

Participating in volunteer programs involving habitat

restoration, native plant planting, and invasive species removal offers hands-on support for insect habitats. Transforming your garden or balcony into an insect haven by planting native flowers, shrubs, and trees that provide food and shelter for various species is a practical approach to creating habitat spaces. Additionally, minimizing the use of harmful pesticides, opting for organic pest control methods, and creating a compost bin to recycle food scraps and yard waste contribute to a healthier environment, attracting decomposer insects like beetles and worms (Footit and Alder, 2009).

Educating others about the importance of insects and the threats they face is a crucial aspect of promoting conservation. This can be achieved through spreading awareness on social media, participating in community events, or giving talks at schools and local organizations. Inspiring the next generation of conservationists by engaging children in insect-related activities like butterfly watching or building bee hotels helps build a lasting commitment to environmental stewardship. So, our collective actions, no matter how small, can have a significant impact on the future of insect biodiversity, actively supporting conservation initiatives, fostering insect-friendly environments, and raising awareness all contribute to ensuring the continued survival of these vital creatures and to a healthier planet for all. By becoming advocates for the unseen world of insects, we can make a difference in supporting and protecting the wonders of insect life, appreciating and safeguarding their incredible diversity, and unlocking the secrets they hold for the benefit of our planet and future generations.

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