Molecular Entomology 2024, Vol.15, No.1, 1-7
http://emtoscipublisher.com/index.php/me

Review and Progress Open Access

Evolution of Butterfly Wing Patterns and Their Ecological Functions

Baohua Xu
Chengxi Elementary School in Zhuji City, Zhuji, 311800, China
Corresponding author email: 243626142@qq.com

Molecular Entomology, 2024, Vol.15, No.1 doi: 10.5376/me.2024.15.0001
Received: 03 Nov., 2023
Accepted: 12 Dec., 2023
Published: 01 Jan., 2024

Preferred citation for this article:
Xu B.H., 2024, Evolution of butterfly wing patterns and their ecological functions, 15(1): 1-7 (doi: 10.5376/me.2024.15.0001)

Abstract This study delves into the evolutionary mechanisms of butterfly wing patterns and their ecological functions. Through a comprehensive analysis of classical theories and new models in evolutionary biology concerning the evolution of butterfly wing patterns, the study reveals the relationship between diversity and evolution. Factors influencing evolution are examined, with a particular focus on the potential impact of survival advantages, reproductive success, and external environmental pressures on pattern formation. The study compares the diversity of butterfly wing patterns, including differences among different species and regions. Attention is given to the ecological functions of wing patterns, especially protective colors and evolutionary adaptability, with an in-depth exploration of their roles in ecosystems. Through an in-depth analysis of relevant theories, models, and empirical studies, the study provides valuable guidance for future research and ecological conservation efforts. This research expands our understanding of biological evolution and contributes scientific support to the protection and sustainable development of ecosystems.

Keywords Butterfly wings; Evolutionary mechanisms; Ecological functions; Diversity; Evolutionary adaptability

Butterflies, as unique creatures among insects, have attracted widespread interest with their beautiful wing patterns (Figure 1). The diversity of these patterns encompasses a rich array of colors, shapes, and patterns, ranging from brilliant colors to unique spots and textures, demonstrating nature's infinite creativity in biomorphic design, and providing a rich source of material for bioaesthetics (Li et al., 2023).

Figure 1 Butterfly

The diversity and aesthetic appeal of butterfly wings have made them the subject of much attention in the fields of biology and ecology. These patterns are not only a landscape in nature, but also an enigma in evolutionary and ecological processes (Wang et al., 2019). Ecologists and evolutionary biologists have long shown interest in

butterfly wing patterns in an attempt to unravel the evolutionary story behind them and their ecological function in the ecosystem.

By tracing changes in wing patterns in butterfly populations, researchers have endeavored to uncover evolutionary traces and decipher the effects of natural selection and genetic drift on pattern formation. Scientists have come to realize that wing patterns may be more than just aesthetic expressions, but may be the product of evolutionary adaptations. This has led to in-depth studies of the evolutionary mechanisms behind butterfly wing patterns.

The aim of this study is to thoroughly investigate the evolutionary mechanism of butterfly wing patterns, and to explore the variation of patterns among different species and individuals and the genetic basis behind them (Quan et al., 2023). Through comprehensive analysis of related theories, models and empirical studies, this study will reveal the evolutionary laws and driving forces behind butterfly wing patterns. In addition to aesthetic appeal, butterfly wing patterns may also play important functions in ecosystems. This study aims to promote a deeper understanding of the mysteries behind butterfly wing patterns and provide useful guidance for future research and ecological conservation.

1 The Evolution of Butterfly Wing Patterns

The evolution of butterfly wing patterns is an integrative process, subject to a combination of factors. The classical theory provides the basic framework of evolution, while the new model provides a more in-depth analysis at the molecular and population levels. Meanwhile, the relationship between survival advantages and external environmental pressures has enabled butterfly populations to maintain a dynamic balance in evolution.

1.1 Evolutionary theory and models

The evolution of butterfly wing patterns has been a topic of great interest in evolutionary biology. Classical theories include Darwin's theory of natural selection, which states that an individual's adaptive wing pattern may be passed on over a long evolutionary process. The theory of natural selection suggests that individuals with wing patterns that are more compatible with their environment are more likely to stand out in the struggle for survival and increase their reproductive success. In addition, sexual selection theory also proposes that certain wing patterns may be better able to attract the attention of the opposite sex, improving the chances of reproduction (Figure 2).

Figure 2 Butterfly wing pattern

In recent years, with advances in molecular biology and genetics techniques, new models have played an important role in resolving the evolution of butterfly wing patterns. Factors at the molecular level, including gene mutation, gene flow and gene recombination, play a crucial role in evolution. In addition, new models of population genetics emphasize selection and evolution at the population level.

1.2 Factors affecting evolution

There is a close correlation between the evolution of butterfly wing patterns and survival advantage and reproductive success. Through long-term field observations and experimental studies, ecologists and geneticists have attempted to investigate the relationship between different wing patterns and an individual's survivability and reproductive success in the natural environment. Certain wing patterns may provide better protective coloration, making it more difficult for butterflies to be detected by predators and thus improving their survivability (Zhang et al., 2022). At the same time, some wing patterns may be associated with reproductive behavior as a signal of opposite-sex attraction.

External environmental pressures are another key factor influencing the evolution of butterfly wing patterns. Changes in the environment may lead to changes in survival pressures, thus driving the evolution of butterfly populations towards adaptation to new environments. Global climate change and anthropogenic disturbances may have far-reaching impacts on butterfly ecosystems, thus giving rise to new wing patterns (Han et al., 2023).

2 Diversity of Butterfly Wing Patterns

The diversity of butterfly wing patterns is a rich phenomenon at both the species and geographic levels. Variation in wing patterns across species and geographic regions is constrained by both a genetic basis and shaped by environmental factors.

2.1 Species differences

The diversity of butterfly wing patterns shows striking contrasts between species. By observing and studying butterfly species globally, researchers have found significant differences in their wing patterns in terms of color, shape and texture. These differences may be caused by species-specific evolutionary paths, ecological environments, and genetic variation (Duan et al., 2023).

The wing patterns of different species reflect their roles and adaptive strategies in the ecosystem. Some species may display more cryptic and protective color wing patterns to avoid the attention of natural enemies. Conversely, other species may employ more vibrant colors and distinctive spots to attract the opposite sex during the breeding season or as a sign of territory.

Differences in wing patterns between individuals within the same species are also an important aspect to study. Even if they belong to the same species, individuals may exhibit certain differences in wing patterns. These differences may be caused by a variety of factors such as genetic inheritance, environmental factors, or special experiences during individual development. Studying differences in wing patterns of individuals within the same species not only provides insights into genetic variation and phenotypic shaping, but also helps to reveal the role of the environment in shaping individual differences within the same species (Maheshwari et al., 2021). Such differences may play a key role in natural selection, sexual selection and population dynamics, influencing individual survival and reproductive success.

2.2 Regional differences

The regional differences in butterfly wing patterns are another noteworthy research direction. In different geographical regions, the same or similar butterfly species may exhibit completely different wing patterns. This regional difference may be due to limited gene flow caused by geographical isolation, or it may be the result of adapting to specific local environments. The study of regional differences helps to understand the adaptive evolution of butterfly populations in different ecosystems. The climate, vegetation, and other ecological factors in different geographical regions may shape the unique characteristics of butterfly wing patterns, making them better adapted to the local environment.

Climate and environment are one of the main factors leading to regional differences. The climate differences in different geographical regions can affect vegetation types, temperature ranges, and seasonal changes, thereby having a profound impact on the ecological environment of butterflies. This influence may be shaped by the

power of natural selection, shaping butterfly wing patterns to better adapt to the local environment.

3 Ecological Functions and Adaptability

The ecological functions and adaptations of butterfly wing patterns are key factors for their survival and reproduction in nature (Hao et al., 2019). The development of protective colors makes butterflies more hidden in the ecological environment and reduces the risk of predation (Figure 3). At the same time, evolutionary adaptive wing patterning has allowed butterflies to better adapt to different ecological pressures and maintain balance in the ecosystem.

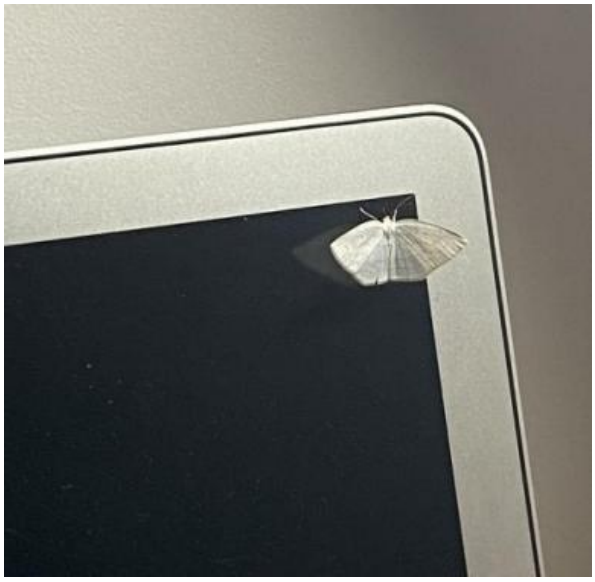

Figure 3 Protective colors of butterflies

3.1 Protective colors that integrate with the environment

The protective coloration of butterfly wings is an important part of their survival strategy. By coloring in harmony with their surroundings, butterflies are better able to blend into their habitat and reduce the probability of detection by natural predators. The evolution of this protective coloration has made some butterflies almost imperceptible in leaves, flowers, or other natural backgrounds.

The study found that butterflies blend in with their environment in an extremely subtle and complex way by mimicking the texture and color of plant surfaces. This natural selection has resulted in some excellent protective coloration, making the butterflies more secretive in their habitats and reducing the risk of predation.

3.2 Mimicry with toxic plants and food

Some butterflies choose to mimic toxic plants or foods as a way to develop a mimetic protective coloration. This evolutionary strategy reduces the risk of predation by mimicking the color and texture of toxic substances, causing natural enemies to misidentify toxic organisms. Such mimicry not only gives butterflies a survival advantage in ecosystems, but also provides ecologists with a unique object of study to deepen their understanding of evolution and ecological adaptations.

3.3 Genetic diversity in relation to wing pattern

The evolutionary adaptability of butterfly wing patterns is closely related to genetic diversity. The existence of genetic diversity in butterfly populations provides a basis for the variation of wing patterns (She, 2022). Through the diversity of genetic mechanisms, butterflies can form different phenotypes in populations to adapt to different ecological environments and natural enemy pressures.

Studies have shown that there is a strong correlation between the presence of some specific genes and certain

wing pattern characteristics. This genetic relationship has driven the evolution of butterfly populations to exhibit a diversity of wing patterns, thereby enhancing their ability to survive in the ecosystem.

3.4 The evolutionary advantages of wing patterns in predation and predation

The evolution of butterfly wing patterns is not only related to genetic diversity, but also influenced by the dynamic balance between predation and prey. During the long evolutionary process, butterfly populations have gained the evolutionary advantage of finding a balance between predation and prey through the continuous adjustment of wing patterns (Figure 4).

Figure 4 Butterflies in predation

Some studies have shown that butterflies with more subtle wing patterns are more likely to avoid the attention of predators, thus improving survival rates. Conversely, some butterflies with striking colors and spots may be more likely to attract the opposite sex, improving their chances of reproductive success. This evolutionary advantage of predation and prey has enabled butterfly populations to achieve ecological balance in complex and changing ecosystems.

4 The Impact of Human Activities on Butterfly Wing Patterns

4.1 The impact of urbanization and agricultural activities

Butterfly habitat loss and destruction is a serious problem caused by human urbanization and agricultural activities (Xie et al., 2019). With the increase of urban expansion and agricultural land use, the native habitats of many butterflies have suffered serious threats. Urbanization has led to the covering of large areas of land, and natural environments originally used for butterfly reproduction and foraging have been gradually replaced by concrete.

Agricultural activities are also one of the important factors affecting butterfly habitats. Large-scale reclamation of agricultural land, the widespread use of chemical pesticides and the monoculture of agriculture pose a threat to the survival and breeding environment of butterflies. These activities have not only led to a reduction in plant diversity, but have also negatively affected gene flow and the evolution of wing patterns in butterfly populations.

4.2 Impact of deforestation on species diversity and wing patterns

Deforestation is another important factor affecting butterfly habitats. Large-scale logging activities have led to the destruction of many butterflies' natural habitats, depriving them of their ideal habitat. Deforestation has triggered a decline in species diversity, with far-reaching effects on the gene pools of butterfly populations and the formation of wing patterns.

The disappearance of forests poses new challenges to the genetic diversity and adaptability of butterfly

populations. The original lush forest environment not only provided sufficient food resources for butterflies, but also ideal breeding sites. Deforestation has gradually weakened these conditions, posing a threat to the survival of butterflies.

4.3 Possible effects of global warming on butterfly distribution and wing patterns

Global warming is an issue of great concern today, with potentially far-reaching effects on the distribution and wing patterns of butterfly populations. Warming has led to changes in temperature and humidity in many regions, which pose new challenges to butterfly habitats.

On the one hand, rising temperatures may lead to a reduction in the habitat of some butterfly species as they are unable to adapt to the new climatic conditions. On the other hand, climate change may prompt some butterfly species to expand their ranges in search of more suitable habitats. This will trigger competition between different species, creating new pressures on the evolution of wing patterns (Mortazavi and Moloodpoor, 2021)

4.4 Potential impacts of extreme weather events

Climate change is also accompanied by an increase in extreme weather events, such as droughts, floods and hurricanes. These extreme weather events may have a direct impact on the survival of butterfly populations and the formation of wing patterns. For example, droughts may cause herbaceous plants in butterfly habitats to die out, reducing the butterflies' food source and thus affecting their reproduction and survival. Meanwhile, floods may destroy butterfly eggs and larvae, reducing the birth rate of new generations. Overall, the impact of climate change on butterfly wing patterns is a comprehensive issue that requires a concerted effort by the global community to address in order to protect this unique and beautiful creature.

5 Summary and Outlook

The evolution of butterfly wing patterns is a complex and fascinating process involving the interaction of multiple ecological, evolutionary, and genetic factors (Zhang and Fang, 2019). This study delves into the diversity of butterfly wing patterns, evolutionary mechanisms, and associations with ecological functions. In terms of evolutionary theories and models, this study reviewed the classical theories on the evolution of butterfly wing patterns in evolutionary biology and introduced new models that have emerged in recent years. Among the factors affecting evolution, this study explored the association between survival advantage and reproductive success, as well as the potential effects of external environmental stress on the evolution of wing patterns. For the diversity of butterfly wing patterns, this study compares the differences between species and between individuals within the same species, and also investigates the territorial differences in butterfly wing patterns in different geographical regions.

Future butterfly wing pattern research can leverage advanced technological innovations and research methods to increase the depth and breadth of research. Among them, molecular biology techniques such as genomics and transcriptomics can help researchers gain a deeper understanding of the molecular mechanisms underlying the formation of butterfly wing patterns and reveal the association between genes and phenotypes. Meanwhile, the application of advanced imaging techniques and mathematical models will provide more detailed information on the three-dimensional structure and evolution of wing patterns.

In order to conserve butterfly diversity, one needs to adopt a comprehensive strategy. First of all, the protection of butterfly habitats should be strengthened, especially by formulating sustainable development policies with regard to urbanization and agricultural expansion. In this process, an ecological compensation mechanism can be adopted to compensate for habitat damage. Secondly, monitoring and response to climate change should be strengthened. A global cooperation mechanism should be established to promote the reduction of greenhouse gas emissions and slow down the rate of climate change. At the same time, corresponding protection strategies should be formulated for butterfly groups in different regions to ensure that they can adapt to the new climate environment. In addition, promote education and public participation to raise people's awareness of butterfly conservation. Through

popularization of science activities, establishment of protected areas and promotion of regulations, the whole society can form a synergy for the conservation of butterfly diversity (Alweshah et al., 2020).

In conclusion, the in-depth study of butterfly wing patterns not only expands people's understanding of biological evolution, but also provides scientific support for ecological conservation. Through technological innovation and comprehensive conservation strategies, it is expected that this unique and beautiful creature can be conserved and contribute to the sustainable development of biodiversity.

References

Alweshah M., Khalaileh S.A., Gupta B.B., Almomani A., Hammouri A.I., and Azmi Al-Betar M., 2020, The monarch butterfly optimization algorithm for solving feature selection problems, Neural Computing and Applications, 27: 1-15.
https://doi.org/10.1007/s00521-020-05210-0

Duan M.Y., Zhu H., Qu Y.K., Wang W.H., Jiang S.Q. Yuan K., and Ren B.Z., 2023, Diversity of butterfly communities in different habitats in Songnen Plain and conservation suggestions, Shengtai Xuebao (Acta Ecologica Sinica), 43(18):7682-7692.

Han D., Han C.H., Wang C., She J.Y., Bian Q., Han W.J., and Yin L.Q., 2023, Butterfly diversity and dominant species niche in different urbanization zones of beijing, Zhongguo Chengshi Linye (Journal of Chinese Urban Forestry), 21(5): 74-81.

Hao S.L., Xue Q.Q., Feng D.D., Li X.F., Liu Y., Zhang Z.W., and Men L.N., 2019, Comparative study on butterfly diversity and niche difference in mountainous region of southern shanxi province, Shengtai yu Nongcun Huanjing Xuebao (Journal of Ecology and Rural Environment), 35(10): 1314-1321.

Li F., Zhao K.X., Yan C.Y., Yan J.W., Xing J.C., and Xie B.L., 2023, Identification of butterfly species in the natural environment based on residual network, Kunchong Xuebao (Acta Entomologica Sinica), 66(3): 409-418.

Maheshwari P., Sharma A.K., and Verma K., 2021, Energy efficient cluster based routing protocol for wsn using butterfly optimization algorithm and ant colony optimization, Ad Hoc Networks, 110: 102317.
https://doi.org/10.1016/j.adhoc.2020.102317

Mortazavi A., and Moloodpoor M., 2021, Enhanced butterfly optimization algorithm with a new fuzzy regulator strategy and virtual butterfly concept, Knowledge-Based Systems, 228: 107291.
https://doi.org/10.1016/j.knosys.2021.107291

Quan L.F., Yao Q., Dong Y.Z., Xu S., Chi Y.Y., and Chen B.X., 2023,Research progress and prospects of circadian clock in lepidoptera, Nongxue Xuebao (Journal of Agriculture), 13(9): 38-45.

She J.Y., Han D., Wang C., Yin L.Q., Sun Z.K., and Han C.H., 2022, Butterfly diversity in pocket parks at urban core of beijing, 20(3): 1-6.

Wang G.G., Deb S., and Cui Z., 2019, Monarch butterfly optimization, Neural computing and applications, 31: 1995-2014.
https://doi.org/10.1007/s00521-015-1923-y

Xie J.Y., Cao J.W., Ma L.B., Zhen W.Q., Chen Z.Y., Li X.D., Li H.H., and Xu S.Q., 2019, A dataset of butterfly ecological images for automatic species identification, Zhongguo Kexue Shuju Zhongyingwen Wangluoban (China Scientific Data), 4(3): 189-194.

Zhang Y.H., Huang F., Tan X.Y., Xia Z.Q., He X.Y., and Wu G., 2022, Resource survey and diversity analysis of butterflies in huangmei county,hubei province, Zhiwu Baohu Xuebao (Journal of Plant Protection), 49(4): 1277-1278.

Zhag Y.J., and Fang L.J., 2019, Evaluation on eco-environment in the danjiang river basin based on gis and butterfly diversity, Shijie Shengtaixue (International Journal of Ecology), 8(3): 223-232.
https://doi.org/10.12677/IJE.2019.83030