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# The Ecological Adaptability of Completely Metamorphosed Insects and the Interaction between Environmental Factors

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**Abstract** This review describes the life cycle and ecological adaptations of fully metamorphosed insects, and explores the effects of environmental factors on the ecological adaptations of fully metamorphosed insects, including climate change, food resources, natural enemies and other factors. By understanding the interactions between the ecological adaptations of fully transformed insects and environmental factors, some effective conservation measures are provided, such as adopting non-chemical methods such as biological control to manage pests and reduce the negative impacts on insect populations and ecosystems; and promoting production methods such as sustainable agriculture to reduce the damage to the environment caused by human activities. By strengthening the research on fully transformed insects, this review aims to better understand their importance and ecological roles in ecosystems, and to develop more comprehensive and effective conservation and management programs to ensure the sustainable development of ecosystems with fully transformed insects.
**Keywords** Complete metamorphosis insects; Ecological adaptations; Environmental factors; Conservation measures

Complete metamorphosis insects are an important group of insects that undergo complete metamorphosis, including four stages: egg, larva, pupa and adult. Totally metamorphosed insects play an important role in ecosystems and contribute to their stability and functioning. However, with the influence of climate change, human activities and other environmental factors, the survival and reproduction of fully metamorphosed insects are facing challenges. Therefore, studying the interactions between ecological adaptations and environmental factors of fully-metamorphic insects is of great scientific significance and practical value for understanding the stability and function of ecosystems, and conserving biodiversity and ecosystem services.

The adaptability and response mechanisms of fully metamorphosed insects to different environmental factors are of great significance in understanding the adaptation mechanisms of organisms to environmental changes. Studying the roles and functions of fully-metamorphic insects in ecosystems and their roles in food chains, inter-species relationships, ecosystem functions and ecosystem services can help to protect the stability of ecosystems and the fulfillment of ecosystem services. Meanwhile, the interactions between ecological adaptations of fully metamorphosed insects and environmental factors are of great significance for biodiversity conservation and management.

The objective of this review is to investigate the interactions between ecological adaptations and environmental factors of fully-metamorphic insects as a basis for a deeper understanding of their adaptive mechanisms, reproductive and survival strategies, and roles in ecosystem stability and function. At the same time, the study of the interactions between ecological adaptations and environmental factors of fully-metamorphic insects will provide a scientific basis and management strategies for the conservation of biodiversity and ecosystem services. This review will use a variety of methods, including field investigations and experiments, laboratory studies, data analysis and modeling, and simulation experiments, in order to deeply investigate the interactions between the ecological adaptations of fully-metamorphic insects and environmental factors, and to provide a scientific basis

for the conservation of biodiversity and the management of ecosystem services.

## 1 Ecological Adaptations of Fully Metamorphosed Insects

### 1.1 Food and nutritional requirements

The dietary and nutritional requirements of fully-metamorphosed insects are important aspects of their ecological adaptations, and they need to consume different types and sufficient amounts of nutrients to sustain their growth, development, and reproduction. The larval and adult stages of fully-metamorphic insects differ in their nutritional requirements and feeding habits.

Larval stages of fully metamorphosed insects usually feed on plants, such as the larvae of butterflies eat leaves and the larvae of mayflies eat the eggs or larvae of other insects (Folguera et al., 2010). In contrast, fully metamorphosed insects in the adult stage usually feed on pollen, plant sap, or other small insects. For example, butterflies and bees feed mainly on pollen in the adult stage, while cicadas feed on plant sap.

In terms of nutritional requirements, fully metamorphosed insects need to consume sufficient protein, carbohydrates, and fat to sustain their growth and development (Gibson et al., 2010). In the larval stage, they need more protein and energy to support their rapid growth and metamorphosis. While in the adult stage, fully metamorphosed insects need enough protein and energy to support their activities such as reproduction and flight.

### 1.2 Reproductive behavior and strategies

Different fully metamorphosed insects differ in reproductive behavior and reproductive strategies (Moreira and Hermes-Lima, 2022). For example, some fully metamorphosed insects, such as bees and wasps, live and reproduce together in a single nest. While some other fully metamorphosed insects such as butterflies and mayflies are solitary insects that search for food and breeding partners alone. These solitary insects usually choose a suitable site for reproduction, such as a suitable plant or soil, and use chemical or visual signals to attract the opposite sex for mating.

The reproductive behavior of fully metamorphosed insects also differs with respect to mating. For example, some fully metamorphosed insects such as butterflies require specific plants for their larval growth process, so their adult stages need to mate on a suitable plant and lay their eggs on that plant. In contrast, some other fully metamorphosed insects such as bees and wasps do not need to search for a specific plant; their queens can lay their eggs at any time and mating usually occurs within the nest (Figure 1).

Figure 1 Honeycomb morphology

### 1.3 Group behavior and sociality

Group behavior and sociality are another important aspect of completely abnormal insects, and they are the most social among insects. Completely metamorphosed insects usually exhibit group behavior and sociality during their larval stage, which is usually aimed at better survival and reproduction.

For example, bees and wasps are among the most social of fully metamorphosed insects. They usually live in a nest where the queen is responsible for laying eggs while the worker bees collect food and care for the larvae. This social behavior allows bees and wasps to effectively divide up the workload for better survival and reproduction. In addition, some fully metamorphosed insects such as butterflies and dragonflies also exhibit some degree of group behavior. For example, butterflies will lay their eggs collectively at the same location, while dragonflies will rest collectively at the same location. This group behavior improves their survival rate and helps protect their offspring.

In terms of group behavior and sociality, the behavior of fully metamorphosed insects is also influenced by environmental factors. For example, the abundance of resources in the environment and the intensity of competition may affect the group behavior and sociality of fully-morphic insects. Overall, group behavior and sociality are important characteristics of holobionts, which are better adapted to their environment by increasing survival and reproductive success through division of labor and mutual care.

### 1.4 Survival and adaptability

Completely metamorphosed insects have diverse survival and adaptation strategies to adapt to different environments and ecological conditions. These adaptation strategies include relying on one's own physiological mechanisms and behavior to adapt to the environment, utilizing flight and perception abilities to adapt to the environment, and entering a dormant state and adjusting reproductive behavior to adapt to different ecological conditions.

Complete metamorphic insects have different adaptive strategies at different stages of their life cycle (Villarreal et al., 2015). For example, fully metamorphosed insects in the larval stage usually rely on their own physiological mechanisms and behaviors to adapt to their environment. Some larvae select suitable plants or soil for growth and development, while others select suitable host insects to parasitize.

Fully metamorphosed insects in the adult stage, on the other hand, often rely on their flight and sensory abilities to adapt to their environment (Raś et al., 2018). For example, butterflies and dragonflies can use their flight ability to quickly escape from natural enemies, while nectar moths can use their sensory ability to find suitable flowers. Complete metamorphic insects also show different adaptive strategies when faced with different ecological conditions. For example, some fully metamorphic insects can go dormant under drought or cold conditions to adapt to the harsh environment. In contrast, under abundant ecological conditions, some holotropic insects increase their reproductive behavior and reproductive success.

## 2 The Impact of Environmental Factors on Completely Metamorphosed Insects

### 2.1 Climate and temperature

Climate and temperature have important effects on the survival and reproduction of fully metamorphosed insects. Fully metamorphosed insects can usually adapt to different climatic and temperature conditions, but their adaptive strategies and ecological behavior may change as a result.

Climate and temperature can affect the rate of growth and development of fully metamorphosed insects. Some fully metamorphosed insects require specific climatic and temperature conditions for rapid growth and metamorphosis (Itsukushima, 2021). For example, some butterflies and dragonflies require warm climates and high temperatures to complete metamorphosis. In cold climates, some fully metamorphosed insects need to enter a state of dormancy to retard growth and development.

Climate and temperature can also influence the feeding and reproductive behavior of fully-morphing insects. For example, some holothurian insects require specific temperature and humidity conditions to find suitable food and reproductive partners. In dry and cold climates, some holothurian insects may reduce their reproductive behavior or seek out suitable food sources.

Climate and temperature also affect the distribution and migration of holotype insects. Some holotropic insects require specific climatic and temperature conditions to survive and reproduce, so their ranges and seasonal migrations are limited by climate and temperature. For example, some butterflies and dragonflies migrate in the spring to more favorable temperatures and climates to breed.

### 2.2 Water resources and humidity

Water resources and humidity are important environmental factors for the survival and reproduction of fully metamorphosed insects. They usually affect the behavior and physiological functions of fully-morphing insects, including feeding habits, growth and development, reproductive behavior, and behavioral and physiological functions of fully-morphing insects. Totally transformed insects usually adapt their behaviors and physiological functions to different water resources and humidity environments in order to maintain their survival and reproduction.

In terms of feeding and growth and development, some fully metamorphosed insects require large amounts of water for growth and development, e.g. mosquito larvae require water for growth (Figure 2). If water resources are insufficient or humidity is too low, these fully-morphic insects may face stunted growth and development. In terms of reproductive behavior, some fully metamorphosed insects need moist environment to reproduce, for example, some mosquitoes need moist environment to lay eggs, if water resources are insufficient or humidity is too low, these fully metamorphosed insects may face difficulties in reproduction. In terms of behavior and physiology, some holomorphic insects require moist environments to maintain the water balance of their bodies, while some insects require high humidity to protect their soft exoskeletons.

Figure 2 Mosquito larvae floating on the water surface

### 2.3 Vegetation and habitat

Different vegetation and habitat types can have different effects on the survival and reproduction of fully metamorphosed insects. Different vegetation types can provide different food sources and habitats. For example, some holothurian insects are phytophagous or parasitic and depend on different plants for food and habitat. Whereas some holotropic insects depend on specific habitat types to survive and reproduce, such as wetlands or forests.

It can also affect the growth and development of fully metamorphosed insects. For example, some fully metamorphosed insects require specific vegetation types and habitat types for growth and development. Under suitable vegetation and habitat conditions, these fully metamorphosed insects can grow rapidly and complete metamorphosis (Junk et al., 2020).

Different vegetation and habitat types can also affect the reproductive behavior and reproductive success of fully

metamorphosed insects. For example, some metamorphic insects require specific vegetation and habitat types to reproduce. Under suitable vegetation and habitat conditions, these holotropic insects can increase their reproductive behavior and reproductive success.

### 2.4 Habitat change and adaptability

Habitat change and adaptation are important influences on the survival and reproduction of fully metamorphosed insects. Fully-metamorphic insects need to adapt to new environmental conditions in order to maintain their survival and reproductive success. Through adaptive strategies and genetic mutations, fully-metamorphic insects can be better adapted to different habitat changes, thus improving survival and reproductive success.

Habitat changes can affect the range and population size of fully transformed insects. For example, climate change may lead to changes in the ranges of some holothurian insects, while habitat destruction may lead to a reduction in the populations of some holothurian insects. Habitat changes can also affect the feeding habits and growth and development of fully metamorphosed insects. For example, environmental pollution may affect the food sources of some TFIs, while climate change may affect the growth and development rates of some TFIs.

Acclimatization is an important strategy for fully metamorphosed insects to cope with habitat changes. Fully-metamorphic insects usually respond to different environmental conditions through adaptations, such as adjusting their food habits, growth and development rates, and reproductive behaviors. Some holomorphic insects also adapt to new environmental conditions through genetic mutations, thereby increasing their survival and reproductive success.

## 3 The Interaction between Completely Metamorphosed Insects and Environmental Factors

### 3.1 Adaptability to reproduction and survival

Reproductive adaptations in fully metamorphosed insects usually involve adaptations to environmental factors such as temperature, humidity, food and habitat. For example, grasshopper larvae require adequate food and water, as well as suitable temperature and humidity to complete their life cycle. Under arid conditions, grasshoppers may slow their growth and reproductive success, but under suitable environmental conditions, they can produce more offspring.

Habitat adaptation in fully metamorphosed insects usually involves adaptation to environmental factors such as vegetation, water sources, and habitat structure (Kang et al., 2016). For example, pygmy hunting bugs require specific types of vegetation and moist habitats to survive and reproduce. If their habitat is destroyed or the type of vegetation changes, they may experience difficulty surviving and poor reproduction.

Fully metamorphosed insects need to adapt to habitat changes to maintain their survival and reproduction. For example, in the context of global warming, some fully-morphing insects may need to adapt to new temperature and humidity conditions, as well as new vegetation and habitat types. Some fully metamorphosed insects may adapt to these changes through strategies such as altering their reproductive behavior, migration, or evolution. For example, some butterfly species will migrate to new areas in response to climate change to adapt to new ecological conditions.

Dietary source adaptation in fully metamorphosed insects usually involves adaptation to food sources such as plants, prey, or hosts. For example, some mango fruit fly species require specific mango species as their hosts to complete their life cycle. These mango fruit flies may have reduced survival success and reproductive success in the event of a change in host species or insufficient numbers.

### 3.2 Biodiversity and ecosystem services

The contribution of fully metamorphosed insects to biodiversity is very important. They are one of the richest and most diverse groups of organisms in ecosystems and play a vital role in many of the planet's biological environments. For example, fully metamorphosed insect species such as butterflies, bees and ants (Figure 3) play

an important role in pollination and pollination of plants, which is essential for the health and stability of ecosystems. Fully metamorphosed insects are important components of many ecosystems and play an integral role in soil fertility, water circulation, climate regulation and natural control, for example, by improving soil structure and fertility, and thus crop yields and quality.

Figure 3 Ants and ant larvae on green leaves

Fully metamorphosed insects also play an important role in the stability of ecosystems. They are an important part of the food chain and play a key role in the stability of the food web and energy flow. For example, fully-metamorphic insect species such as ants and bees can control the populations of other insects, thus maintaining the balance and stability of the food chain. Fully-metamorphic insects are able to adapt to different environmental conditions and types of ecosystems, thus increasing the adaptability and resilience of ecosystems. For example, some fully-morphic insect species can adapt to different climate types and regions, thereby surviving and reproducing in different ecosystems.

### 3.3 Protection and management

The interactions between holotropic insects and their environment are very diverse. For example, certain species of holothurian insects may pose a threat to other species of life on Earth, a phenomenon known as "invasive species". Invasive species often have no natural predators in their new environment, so their populations can increase rapidly, adversely affecting local ecosystems. Insects can also play an important role in the environment, for example, some bees and other insects are important pollinators that promote plant reproduction and growth. If the populations of these insects were to decline, there would be negative impacts on the environment and on human food production.

In terms of conservation and management, we need to adopt a series of measures to maintain the balance of the ecosystem. For example, we can reduce the negative impact of human activities on the environment by protecting wildlife habitats and promoting organic farming. We can also formulate more effective conservation and management programs by monitoring the population size of insects and studying their ecological roles. In addition, for some fully metamorphosed insects, we need to adopt biological control methods or introduce natural enemies to solve the pest problem; for other fully metamorphosed insects, we need to protect their habitats and breeding environments in order to maintain their ecological roles. At the same time, we also need to be aware of the environmental impacts of human activities, such as the use of pesticides and deforestation, which may negatively affect insect populations and their ecological roles. In conclusion, we need to conserve and manage insect populations through multifaceted research and management in order to maintain the balance of the ecosystem.

## 4 Conclusion

The interactions between Totally Transformed Insects (TTIs) and the environment are very complex, and a variety of measures are needed to conserve and manage TTI populations. These measures include protection of wildlife

habitats, promotion of organic agriculture, adoption of biological control methods, introduction of natural enemies, etc. In addition, we also need to be aware of the impact of human activities on the environment to avoid negative impacts on the fully transformed insect populations and their ecological roles. Totally metamorphosed insects are an integral part of the ecosystem and play an important role in maintaining ecological balance and biodiversity, as well as in agriculture and food production, for example, some bees and other insects are important pollinators that promote plant reproduction and growth. The research results of this review can provide a scientific basis for the conservation and management of insect populations, which can help to develop more effective conservation and management programs to protect the balance of the ecosystem.

The findings of this review provide some knowledge and understanding of the interactions between fully-metamorphic insects and their environments, but there are some limitations that need to be further addressed. Firstly, due to the large number of species of completely metamorphosed insects, research work requires a great deal of time and effort, so this review only covers some insect populations, and further research on other populations is needed. Secondly, due to the complexity of environmental factors and the dynamic changes of insect populations, the research work requires long time observation and recording. Therefore, this review is only a study of the interactions between fully metamorphosed insects and environmental factors in a certain period of time, and longer-term observations are needed for future trends. In addition, the effects of human activities such as environmental pollution and climate change on TFIs and ecosystems are also very significant, which have not been addressed in this review and require further research.

To summarize, we need to strengthen the monitoring and research on holothurian insects to understand their ecological roles and importance in the ecosystem; we need to adopt non-chemical methods such as biological control to manage pests, and strengthen the promotion of sustainable agricultural production methods such as organic agriculture to reduce the damage to the environment caused by human activities; and we need to strengthen the research on the impacts of human activities on the environment and holothurian insects to formulate a more comprehensive and effective protection and management plan. and effective protection and management programs. Only in this way will we be able to conserve and manage the fully metamorphosed insects and the insect population as a whole, maintain the balance of the ecosystem and ensure the sustainable development of human beings and other living species.

## Author's contributions

XMY is responsible for reviewing, organizing, and writing relevant literature and materials for the first draft of this review; XYJ participated in discussions and paper revisions; HQK is the person in charge of this review, guiding the writing and revision of the paper. All authors have read and agreed to the final text.

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