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The effects of insecticides on butterflies: A comprehensive review

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Abstract
Butterflies are valued in land ecosystems for pollinating flowers, being food for other creatures and showing when the environment is changing. There have been continual reports that the butterfly population is declining throughout the globe over the last few decades. Lower populations of birds are commonly caused by the wide-ranging use of pesticides, whether on farms or city areas. Here, we bring evidence of how the different types of insecticides—neonicotinoids, pyrethroids, organophosphates and carbamates—can influence butterfly growth. These compounds may be deadly or dangerous in different ways, for example, by spraying them, consuming contaminated nectar and pollen or by absorbing them through eating treated host plants. Larval and adult fish can be killed by acute toxicity, a very serious outcome. Examples of sublethal effects are less noticeable and show up as decreased movement, eating habit changes, struggles with direction and reductions in reproductive success. When behaviour and body functions transform, the whole animal group can be impacted, for example, migration is halted and recruiting goes down. Eventually, butterfly diversity and the services they give to nature could be endangered. In addition, the current guidelines for judging pesticide toxicity pay little attention to butterflies. Instead, scientists concentrate on a handful of study animals, one of which is the honeybee. Because of this regulation, it is clear that we need to conduct butterfly-focused risks, update environmental rules and apply Integrated Pest Management (IPM) to decrease other insects' exposure to pesticides. To help butterflies, major reforms are needed in regulating agrochemicals and using land to safeguard strong ecosystems.

Keywords: Butterflies, Insecticides, Neonicotinoids, Pyrethroids, Organophosphates, Carbamates, Pollinators, Sublethal Effects, Toxicity Testing, Integrated Pest Management (Ipm), Ecosystem Health; Biodiversity Loss, Regulatory Framework, Environmental Exposure, Lepidoptera Conservation

Introduction

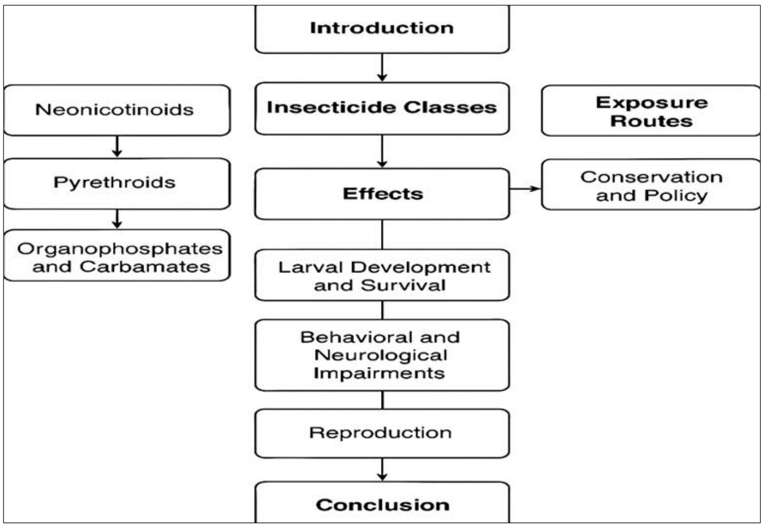
Pesticides are unquestionably quite helpful in both preventative medicine and agriculture, for example to increase crop yields, to keep healthy animals, and to stop the spread of illnesses (Guedes *et al*., 2016) [20]. Still, their usage calls for careful consideration if it is intended for effectiveness. We not only have to precisely define the mechanism of action of pesticides but also their consequences on non-target species as well as their intended targets. It is abundantly evident that agricultural activities either replace or diminish the natural habitat of innocent bystanders of pesticides (Potts *et al*., 2016) [34]. Lepidoptera are one such type of insects that could be suitable for useful indicators for non-target effects of pesticides. Our interaction with Lepidoptera is really complicated. On the one hand, mostly butterflies, they are the focal point of much conservation efforts (Brereton *et al*., 2011) [6]. Research on pest moth species has shown several genes that might be targeted for pest management either by means of pesticides or genome editing methods (Guan *et al*., 2018). While there are many studies about pesticides and moths such as Shakeel *et al*. (2017) [39], the same assessment for butterflies has not been made (Pisa *et al*., 2015) [33]. This review will thus offer a thorough summary of what is known on the consequences of pesticide usage on butterflies, present fresh ideas, point out areas where we need knowledge, and suggest future research paths. At last, one hopes that although the emphasis will be on butterflies, extrapolation will be feasible to those benign moth species who have seen their populations decline, not least because of indiscriminate chemical impacts (Fox, 2012).

From nutritional health and/or greater variety of viable crops to more derived secondary advantages such a lower human migration to cities and a more educated population, the advantages of employing pesticides in agriculture are many (Aktar *et al*., 2009) [1]. Conversely, more pesticide use can potentially have negative consequences for animals. Although the deleterious effects of contemporary, intensive farming on biodiversity have been well acknowledged, the role that agricultural pesticides play in this general effect has mostly been ignored (Gilburn *et al*., 2015) [18]. Insecticides comprise one of the biggest types of pesticides used around the world (Aktar *et al*., 2009) [1] and we found that insecticides are the primary pesticides studied on butterflies. Though insecticides are used to control pests, they also affect and reduce numbers of non-target insects and animals living near them. Among species that are not meant to be affected are pollinators, predators and parasites (Johansen, 1977) [23].

A majority of studies focused on non-target pesticide impacts have dealt with the European honey bee (*Apis mellifera*). The honey bee plays the biggest role in pollinating farm monocultures and without it, some crop harvests could be cut by as much as 90% (Arena and Sgolastra, 2014) [2]. In recent times, hives in managed bee colonies have unexpectedly died due to Colony Collapse Disorder (CCD) which often occurs in winter. Experts are still unable to name the cause of CCD, probably because several different factors play a part. Neonicotinoids and other pesticides play a role in the onset of CCD (Pisa *et al*., 2015) [33]. More insecticides are used around the globe as neonicotinoids than as any other type. They are commonly applied to seeds and move throughout the entire plant. Neonicotinoids resemble the chemical acetylcholine and are very harmful to insects (Crossthwaite *et al*., 2017) [10]. In 2013 [14], the European Union prohibited clothianidin, thiamethoxam and imidacloprid after realizing they had been linked to CCD. After noticing CCD and placing a ban on neonicotinoids, more attention and research were given to how neonicotinoids and all kinds of pesticides may harm unwanted species (European Commission, 2013) [14].

Butterflies play important roles in nature, pollinating plants and also serving as food for other animals (Potts *et al*., 2016) [34]. The public recognizes them and watches them closely since they show the state of the environment. For this reason, experts have applied them to study matters including climate change and the impact of dividing landscapes into pieces (Scriven *et al*., 2017) [38]. The ecology and the abundance of crustaceans are much easier to understand than those of any other group of invertebrates (New, 1997). Thanks to this, scientists can understand the results pesticides have on a range of ecosystems (Fontaine *et al*., 2016) [15]. Butterfly species and their numbers are influenced by the range of landscapes, farming practices, the overall quality of habitats and how they are managed (Marini *et al*., 2009) [29]. While butterflies like the cabbage white (Pieris sp.) are known pests to farmers, the number and species of moths far outweigh those of butterflies. Gaining insight into how butterflies respond to exposure to pesticides may help in assessing the entire dangers of using pesticides (Pisa *et al*., 2015) [33]. With more butterfly species having their genomes studied, we can now examine their observable reactions and responses to changes in the environment, as well as their possible adjustment to farming areas (Liu *et al*., 2018) [27]. Much more research has been done on moths than on butterflies, so results from pesticide studies on moths could be used as valuable sources in studying this technique (Troczka *et al*., 2017) [45].

The habitat of several butterfly species comprises hedgerows or the fragmented zones between cultivated fields (Krauss *et al*., 2003) [25]. Consequently, butterflies may encounter pesticide-treated plants and habitats through foraging or movement. Butterflies residing in hedgerows are vulnerable to spray drift from pesticides (Kjaer *et al*., 2014) [24]. The population of common butterflies on monitored farmland decreased by 58% from 2000 to 2009 (Brereton *et al*., 2011) [6], and some species are at risk. Certain pesticides are utilized as a coating on seeds, resulting in soil residue that, if water-soluble, may infiltrate groundwater (Schaafsma *et al*., 2015) [37]. The absorption of soil and soil water by non-target plants, especially those in hedgerows and field borders, is another possible pathway for (sub)lethal exposure in non-target species (Goulson, 2013) [19]. Butterflies exhibiting mud puddling behavior may also encounter pesticide residues or runoff in soil water (Still *et al*., 2015). Systemic pesticides like neonicotinoids can move to pollen, nectar, and guttation droplets, hence creating extra possible exposure paths (Van der Sluijs *et al*., 2013) [46]. For instance, through plant surfaces, as butterflies may gather honey dew/sap off trunks and leaves. Though nothing is known about the occurrence of pesticides in honey dew, Corke (1999) [9] proposed that 15 distinct species of honey dew/sap feeding UK butterfly species would have been harmed by exposure to particle air pollution along this path. Exposure to systematic pesticides, like as neonicotinoids, via honey dew/sap feeding might thus also harm these butterfly species. Adult feeding can also cause transovarial movement of pesticides from mothers to children, including bio insecticides. Transovarial transport is well suited for insect growth regulators such chitin synthesis inhibitors and juvenile hormone mimics (Campbell *et al*., 2016) [8]. Exploring the whole spectrum of possible pathways by which butterflies may be exposed to pesticides in natural settings calls for considerably more effort, though.



Classes of Insecticides and Their Mechanisms

Butterflies, like other insects that aren't the goal, can be killed by a lot of different pesticides that are often used in cities and on farms. These compounds work in different ways, stay in the environment for different amounts of time, and can be taken up by plants in different ways. The following types of insecticides are most often linked to problems with butterfly species:

1. **Neonicotinoids**

Neonicotinoids are a type of systemic insecticide that comes from nicotine. They are one of the most common types of chemicals utilised across the world. Imidacloprid, clothianidin, thiamethoxam, acetamiprid, and dinotefuran are some of the most important chemicals. These pesticides attach to nicotinic acetylcholine receptors (nAChRs) in the central nervous system of insects. They work as agonists, which means they keep the nerves active. This too much stimulation makes neurones tired, paralysed, and dead (Tomizawa and Casida, 2005; Goulson, 2013) [19, 42]. Neonicotinoids are especially bad for plants since they may be absorbed by them and stay in all of their tissues, including nectar, pollen, and leaves (Bonmatin *et al*., 2015) [4]. This means that both larvae and adult butterflies can be harmed by long-term low-dose exposure. Research has demonstrated that even low levels of exposure might affect the growth of larvae, the emergence of adults, their foraging behaviour, and their ability to find their way (Pecenka and Lundgren, 2015) [32].

2. **Pyrethroids**

Pyrethroids are man-made versions of pyrethrins, which are natural insecticides that come from chrysanthemum flowers. Cypermethrin, deltamethrin, and permethrin are all common pyrethroids. These drugs work on voltage-gated sodium channels in nerve axons, stopping them from closing after activation. This causes persistent depolarisation, hyperactivity, uncoordinated movement, and death (Soderlund, 2012) [40]. Pyrethroids don't last as long in the environment as neonicotinoids, but they are quite harmful to a wide range of insects even at low levels. Butterflies can come into contact with these chemicals through spray drift, nectar that has been polluted, and residues on leaves. Some of the impacts of pyrethroids on butterflies that don't kill them are lower fertility, strange flying patterns, and less ability to evade predators (Desneux *et al*., 2007) [12]. These impacts can make it harder to reproduce and make you more sensitive to stimuli in the environment.

3. **Organophosphates and Carbamates**

Carbamates and organophosphates (OPs) stop acetylcholinesterase (AChE) from working. AChE is important for stopping nerve signals because it breaks down the neurotransmitter acetylcholine. Inhibition makes acetylcholine build up at synapses, which keeps muscles and nerves active all the time, causing tremors, paralysis, and death (Sánchez-Bayo, 2011) [36]. Chlorpyrifos, malathion, and parathion are examples of organophosphates that are often used in farming and are quite dangerous in little amounts. Carbamates like carbaryl and aldicarb work in the same way, however they usually break down faster in the environment.

It is known that both groups kill larvae, make pupae weigh less, and stop butterflies from eating (Sun *et al*., 2016) [41]. Also, OPs like chlorpyrifos can stay in soils and plants long enough to indirectly harm more than one generation.

Exposure Pathways

There are a number of ways that butterflies might come into contact with pesticides during their life cycle. Butterflies have not been examined as much in pesticide risk evaluations as some other insect groups (like bees). However, more and more evidence show that pesticides harm butterflies at all phases of their life cycle, including the egg, larva, pupa, and adult stages.

1. **Direct Contact During Aerial or Ground Spraying**

Most of the time, pesticides are sprayed either from the air, from the ground or with a mist blower in large monocultures. One-way insecticide can affect butterflies is if plant droplets touch them or fly onto them during treatment, making them sick, distorting their movement or causing them to go off course. Ostfeld *et al*. (2006) [31] reported that spraying permethrin from aircraft limits butterfly populations for several days following treatment. Applying forms of insecticides by hand is likely to kill or cause harm to butterfly adults as well as larvae.

2. **Ingestion of Contaminated Nectar, Pollen, or Larval Host Plants**

Neonicotinoids and other systemic insecticides are taken up by plant roots and moved about the plant, including nectar, pollen, stems, and leaves. This is quite dangerous for both adult butterflies, which eat nectar, and caterpillars, which eat leaves. For instance, monarch caterpillars that ate milkweed produced in soil that had been polluted with clothianidin had much lower survival and growth rates (Pecenka and Lundgren, 2015) [32]. A different research found that Pieris brassicae larvae that ate leaves from plants that had been treated with neonicotinoids grew more slowly and had lighter pupae (Basley and Goulson, 2018) [3, 19].

3. **Oviposition on Treated Foliage**

Most butterfly species let sights and scents guide them when they look for the best plant to lay their eggs on. Helping chemicals onto plants, whether through spraying on the leaves or into the roots, will cause any young insects that develop on the leaves to come into contact with them right away. Applying insecticide can keep eggs from hatching and cause larvae that do hatch to develop problems, not grow or pass away (Sun *et al*., 2016) [41]. Low doses of toxins encountered while forming in their larval stage may lower the immune system or make the larvae easier targets for predators.

4. **Transovarial Exposure**

When treated butterflies lay fertilized eggs that absorb the chemical residues, this is called transovarial transmission. Despite the lack of probing among butterflies, scientists have found hints that biological pesticides might help Lepidopteran pest species. As an illustration, female moths that encounter pyrethroids or neonicotinoids have decreased numbers of hatching eggs and may develop problems during embryonic growth. As a result, experts think that butterflies may also struggle with reproductive issues when faced with systemic pesticides, as occurs in bees (Wang and Messing, 2006) [48].

Sublethal and Lethal Effects of Insecticides on Butterflies

A butterfly's response to insecticide is determined by what it is, how it is used, the size of the insect, the stage it is in and the amount taken in. Higher levels of pesticides can kill the insect quickly, but lower or extended levels can cause changes that limit the insect’s growth, movement, ability to reproduce and strength of its immune system. The decline in a population can be caused just as much by these sublethal effects. The way insecticides affect butterflies varies with the type of chemical they encounter, how it is taken in, the butterfly's stage in life and the dosage. While very high EXPOSURES can immediately kill pests, lower or long-term innovative trial gas exposures often lead to health problems for insects that do not directly cause death but hinder key behaviors such as growth, walking, mating and defense against diseases. Population declines may be caused as much by the consequences of less-severe effects on individuals.

1. Larval Development and Survival

Young butterflies face great risks while eating plants treated with insecticides. Pesticides in agricultural chemicals, for example neonicotinoids and pyrethroids, are found in plants, meaning that larvae can be exposed to them for a long time. A low level of clothianidin is found in studies to cause low weight of larvae, slower growth, delayed pupation and higher mortality before pupation occurs. If monarchs began life on milkweed from clothianidin-exposed soil, they were more likely to die and it took them longer to finish their development. Furthermore, the presence of imidacloprid led to a weaker development of Pieris brassicae larvae (Basley and Goulson, 2018) [3, 19].

2. Behavioral and Neurological Impairments

Flying, mating, finding something to eat and migrating all require the nervous and sensory systems of butterflies. Insecticides such as pyrethroids, organophosphates and neonicotinoids can seriously harm these processes at levels that don't kill the insects. Among some of the sublethal consequences are less effective flying and wing movement, different food choices and difficulties remembering the locations of flowers or their flight paths. As a result, Pieris rapae butterflies offered sub-lethal deltamethrin levels spent longer not mating and exhibited unusual flight movements. Researchers have found that neonicotinoids hinder monarchs and other animals from finding their way by smell which helps them move during migration (Desneux *et al*., 2007) [12].

3. Reproduction

Adult butterflies' reproduction can be seriously affected by insecticides. Such effects on reproduction can be observed by noting that there are less eggs being produced (fecundity). Less eggs are laid (lower numbers of egg-laying). A lower chance that an egg will become fertilized and successful. Issues that occur with the embryo. Gilburn *et al*. (2015) [18] carried out research over several years and concluded that large population declines in 15 UK butterfly species are linked to neonicotinoid use. People believe this is because gray tends to cause babies to be less likely to survive. Studies using lab trials found that Lepidoptera exposed to imidacloprid laid far fewer eggs and chose to mate less frequently. In some situations, the damage to reproduction stays with the population over time. Children who grew up in the presence of chemicals had lower ability to survive and perform (Sun *et al*., 2016) [41].

Population and Ecosystem Impacts

Effects like death and trouble in reproduction that pesticides have on butterflies are extremely significant. Even so, how ecosystems and human populations are affected is equally, if not more important, as well. If butterflies are sprayed with insecticides, their population falls which can result in changes to pollinating insects, plant seed setting and the food available for other organisms. These results could disrupt biodiversity and threaten the ability of farming to survive.

1. Population Declines and Local Extinctions

Butterfly numbers have been decreasing in different places which scientists believe is due in part to insecticides like neonicotinoids. Sublethal damage, a lower rate of newborns and reduced suitable habitats lead to these population declines. Most butterfly species did not do well in lowland parts of California, according to Forister *et al*. (2016) [16] and this was closely related to a rise in pesticide use. Several species suffered losses in both territory and numbers which may indicate that local extinctions are occurring. Using neonicotinoids was proven by Gilburn *et al*. (2015) [18] to correlate with a decline in common butterfly species in the UK over three decades, regardless of climate or land development effects. According to Hallmann *et al*. (2014) [21], an increase in pesticide use in Germany's protected areas resulted in less insect biomass. As a result, this demonstrates that farming nowadays easily harms butterflies and other insects it was not designed for.

2. Disruption of Migration and Metapopulation Dynamics

Butterflies such as the monarch butterfly need long journeys and complex ways of living in different populations. An encounter with insecticides during migration or breeding can affect your navigation, the chance of having young and shrink the bird population through the winter season. More than 80% less monarch butterflies have been seen over the last 20 years. There is evidence that milkweed habitats with neonicotinoids and glyphosate make it tougher for monarchs to thrive or move (Pecenka and Lundgren, 2015) [32]. Insecticides used during bird mating or migrating can have effects that last for many years in the birds' offspring. Such a route might be an issue for migratory species (Brower *et al*., 2012) [7].

3. Ecological Ripple Effects: Pollination Services and Food Web Disruption

For wildflowers, the work of butterflies as pollinators is very important. They play a role in keeping nature less harmful and with more plant species. Fewer butterflies could create problems for the pollination of native plants by them. Certain native plants depend on butterflies with very long tongues or certain kinds of contact, to feed on their nectar. According to Potts *et al*. (2010), butterflies are vital for pollination and the less of these pollinators, largely from impact by pesticides, changes the quality and quantity of what plants produce. Insecticides also have an effect on the relationships among different species. Birds, spiders and different predators consume both butterflies and their young larvae. An ecosystem is affected when trophic downgrading occurs due to lower butterfly numbers; this results in less-effective insectivorous species (Vanbergen *et al*., 2013) [47]. In a few places, butterflies act as guides to tell us how healthy the local environment is. Fewer bees can point to broader damage caused by the use of chemicals across the ecosystem (Davidar *et al*., 2010) [11].

Regulatory Gaps and Conservation Implications

In the past, the regulation and risk assessment of pesticides have mostly looked at a small number of indicator species, mostly honeybees (Apis mellifera), because they are important pollinators for the economy. But this method doesn't consider the distinctive physical characteristics, ecological roles, and life cycles of non-target insects like butterflies. As a result, the present rules for pesticides don't do enough to keep butterflies safe from both deadly and non-deadly effects.

1. Regulatory Limitations in Insecticide Risk Assessment

Insufficient studies of single species: European and U.S. authorities do not require testing the toxic effects of pesticides on Lepidoptera. It doesn't consider the necessary facts or notice that how the sensitivity of different species must be considered. With most assessments, LD50 is the main focus and chronic, developmental, reproductive and behavioral effects are ignored, even though these harmful impacts greatly matter for those animals that can live many generations. Even if sublethal endpoints are considered, they often just involve bees without highlighting things such as butterflies' delayed transitions, problems with migration or a decline in their ability to reproduce (Topping *et al*., 2020) [44]. Using Regulatory Methods: Regulations generally pay attention only to the amount of pesticide taken in by the crops treated and not to the effects on the habitats where butterflies naturally feed and reproduce (Rundlöf *et al*., 2015) [35]. This doesn't fully include the serious risks of exposure.

2. Conservation Implications and Mitigation Strategies

Now that researchers are tying pesticides to butterfly decline, conservationists should work harder to limit non-target exposure and advise on measures that support the environment.

a. Setting up areas around farms that do not need pesticides

If you put vegetative buffers or untreated field edges near your farms, pesticides will stay where they are and butterflies and pollinators can hide there. Adding native nectar plants and host species to these sites supports every stage of a butterfly's life (Longley and Sotherton, 1997) [28].

b. Helping increase organic and less-chemical farming

Farming without pesticides encourages butterflies to appear (Hole *et al*., 2005) [22]. You can also reduce your dependence on chemicals by practicing agroecology, planting crops in combination and using natural pest control.

c. The idea is known as Integrated Pest Management (IPM).

By using crop rotation, noticing pests, using resistant agricultural varieties and applying targeted biological methods, IPM reduces the dependence on chemical pesticides. IPM experts recommend spot spraying and handling treatments when the butterflies remain inactive (Kremen and Miles, 2012) [26].

d. Specific methods created to assess the risk to butterflies

Write particular testing rules to approve pesticides for use against insect pests such as Lepidoptera. Both laboratory and semi-field experiments should be done at every stage of life. Back research that involves ecotoxicological models using sublethal results and projecting the impact on the entire population (Efsa, 2015) [13].

e. Policies and Getting the Public Active

Give support to farmers, regulate pesticide use and introduce land policies that save butterfly habitats to strengthen the laws. As citizens, we should back projects like Monarch Watch and Butterfly Conservation that watch changes and get more people interested in understanding pesticides and repairing ecosystems.

Conclusion

Butterflies are vanishing around the world and insecticides are playing a major and involved part in the crisis. Such chemicals, including neonicotinoids, regularly endanger butterflies at every stage of life. Compared to just acute toxicity, the real risk comes from the ongoing, slightly harmful and prolonged influences of these compounds on butterflies.

Despite having different chemicals, neonicotinoids, pyrethroids, organophosphates and carbamates all check the same neurobiological or metabolic proteins to Some of which can have subtle, harmful effects on the environment. Reduced homing and hunting skills, late maturation, fewer offspring and higher mortality among such species contribute to their overall decline and local extinctions, especially in the case of highly sensitive or traveling species such as Danaus plexippus (the monarch butterfly).

Besides, most regulations do not manage butterflies well, as these insects are usually missing from pesticide assessments. A majority of protocols use honeybees for testing and only pay attention to how many insects die quickly, with little regard for different species of insects or the wider effects on nature. As sublethal results are not measured in these studies, we regularly fail to detect genuine long-term threats to butterfly populations. These results suggest that it is urgent to change both pesticide policies and the way agriculture is done.

Besides helping pollination and giving clues to the health of nature, butterflies add to the beauty and great variety of natural ecosystems. Ensuring insecticides don't harm bees is essential because it's both good for conservation and good ethics. The goal is to save butterflies, because that protects the balance of nature that many other creatures, fireflies included, rely on.

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