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Climate Change and Its Impact on Butterflies

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Abstract. Climate change had been influencing the world since the industrial revolution when fossil fuels including coal and petroleum were greatly used for industrial and production purposes. Increasing output of greenhouse gases had blocked more heat in the atmosphere, increasing the global temperature. Butterflies, from the class Insecta, had been living for thousands of years. These insects sit in a unique niche, considering their special place as both pollinators and primary consumers. Studying the butterflies will be a good approach to figure out the impact of climate changes on the ecosystems, by studying how butterflies are affected by climate changes, since they adapted and lived for billions of years. The results had shown that while butterflies have a certain extent of phenotypic plasticity to combat climate change, overall, climate change is destroying their lifespan and behaviors, causing losses in populations of butterflies throughout the globe. Our paper gives a rough frame about how, or in what factors, butterflies are influenced by climatic changes. However, more studies are needed to further investigate all the influences climate change conducted on butterflies. Also, more acts need to happen to successfully stop climate change from making butterflies and the biospheres even worse.

Keywords: climate change, global warming, butterfly, rising temperature, ecological responses

1. Introduction

Climate change is affecting the ecosystem in different facets. Rising temperatures and increasingly extreme weather generate a series of problems like mismatches, shifts of distribution, and habitat destruction. Animals respond to climate change differently, some animals adapt to the changing condition, and they survive and even thrive in the new environment. However, animals that rely on specific conditions were affected badly by climate change and even went extinct.

Members of Class Insecta represent a dominant component of biodiversity in most terrestrial ecosystems and they play different roles like pollinating for plants, decomposing organic materials, acting as primary consumers (herbivore insects), etc. [1]. Because of those important roles they play, they are crucial to both the ecosystem and humanity. Many crops and trees we plant like apples are entomophilous, and predators need to consume lower consumers, all these need insects. If they go extinct, the ecosystem will collapse and agriculture will get damaged badly. Climate change advanced insect phenologies generate mismatches, many insects adapted to climate change might expand their

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distribution, affecting local species and causing problems in the ecosystem [2, 3]. Species that have not adapted to climate change have a decrease in their population, some have even gone locally extinct.

Lepidoptera, including moths and butterflies, has about 160000 species. Among them, butterflies distribute in every continent except Antarctica, they act as pollinators and primary consumers in the ecosystem [4]. Butterflies are Completely metamorphosed insects, they have many characteristics of flying insects like phototaxis, making them an excellent representative of how Completely metamorphosed insects and flying insects have been affected by climate change. Butterflies have their unique ability to control their body temperature, but that does not mean all of them can tolerate climate change because they are very sensitive to the changing in temperature which can affect their phenology, morphology, behaviors, population dynamics, and so forth [5]. Some researches and reviews about butterflies affected by climate change meanly focus on a specific zone, like Lee et al. research about butterflies affected in Korean Peninsula [6]. This research focuses on a variety of species, it reveals the information on butterflies' distributions shifting. The result shows that most species shift their distribution northward and southern species are more sensitive to climate change, they expand their distribution when the temperature rises. A review by Hill et al. is very comprehensive: it includes butterflies' physiology, behaviors, morphology, population dynamics, phenology, and species interactions [5]. The review shows the different impacts climate change brings to butterflies in these 6 aspects. Still, there are some factors many pieces of literature do not mention like alien species that bring by climate change, they can also affect local species.

The primary purpose of this essay is to analyze what climate change affects butterflies and show how severe this problem is. It reveals temperature, alien species, extreme weather, and humidity as factors related to climate change. About how and what climate change affect butterflies, this essay focuses on butterflies' population, distribution, life span, and reproduction.

2. Factors of climate change

2.1. Temperature

One of the most dramatic effects climate changes can bring is rising in temperature. Activities like burning fossil fuels and deforestation can generate greenhouse gases. When greenhouse gases are out of limit, the temperature starts to rise abnormally. In the last few decades, the temperature kept rising. Take Europe as an example, the trend of summer temperature anomalies is positive. The first positive anomaly temperature appeared in 1988 and from 1994 till 2019, all annual data of temperature anomalies were positive except in 1996 and 2003 (Figure 1).

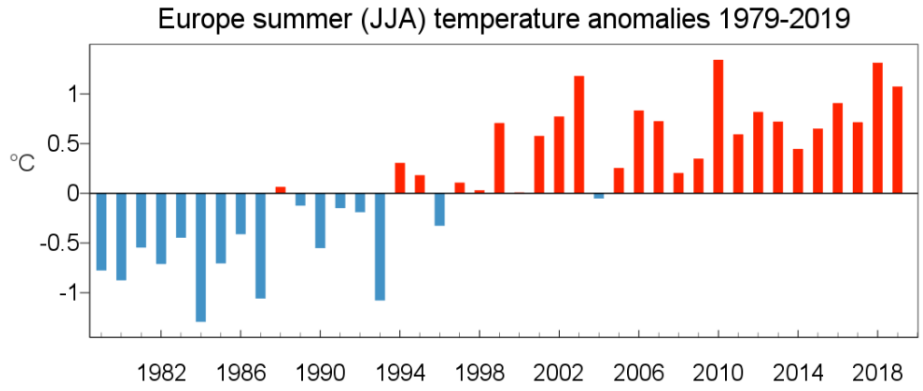


Figure 1. The annual average of European surface air temperature anomaly from 1979 to 2019 [7].

In the same period, the number of butterflies in Europe drops significantly. Besides temperature rising, habitat destruction and chemical pollution are also two reasons [8]. Butterflies still need a suitable

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temperature condition to grow, the change of temperature can disturb their physiology, behaviors, morphology, population dynamics phenology, and species interactions.

Butterflies are animal species that are widespread over the globe, the rising temperature does not mean there are nothing benefits for all of them. Some thermophile species might spread their distribution and some cold-adapted species were forced to hills and mountains, species that already live in mountains have no choice but to go locally extinct [8]. The increasing temperature can also advance butterflies' phenology, causing mismatches and other problems for both butterflies and other related organisms like plants [5].

2.2. Alien species

The impact of alien species has sometimes been ignored and seems no relation to climate change. When the temperature rises, the environment allows thermophiles butterfly species to expand their distribution northward. This also brings competitors to local species and even threatens susceptible species' survival [8]. Those butterfly species are from the south but not native in the north, so they are alien species. Alien species can bring diseases to the local environment and native species usually do not have resistance to those diseases [9]. Alien species can change biodiversity of pollinators and their services that support the ecosystem. They can modify the function and the structure of the pollination system they invaded, which often brings negative effects to native pollinators [10]. As pollinators, butterflies are parts of the pollination system, they can be affected by other invasive pollinators. From another angle, butterflies can affect other pollinators when they invade a new environment.

2.3. Drought is an extreme weather occurrence

Extreme weather events occur frequently all over the world and this is directly tied to climate change and global warming. There have been more extreme weather occurrences with higher intensity over the last few decades. Heat waves, cold waves, severe rains, droughts, hurricanes, storms, floods, and other extreme weather events occur more than before because of climate change. In particularly, due to the ongoing water scarcity, drought can cause a considerable adverse influence on natural stability and social environment. Climate change has caused droughts to worsen and last longer worldwide. The western and southern regions of the United States are experiencing far more severe droughts compared to other regions. Moreover, larger regions are likely to experience extreme droughts that are more intense and last longer (Figure 2).

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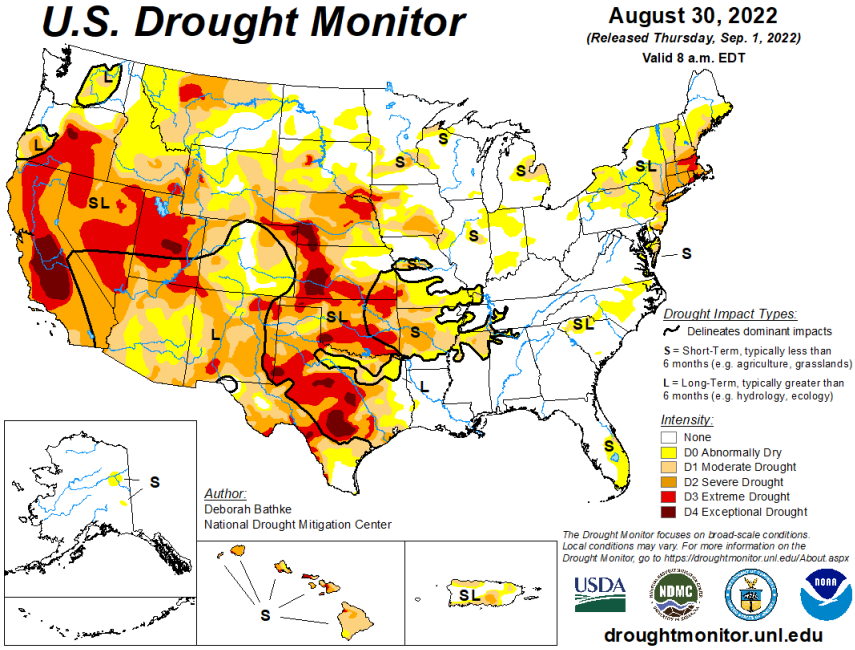


Figure 2. By using a variety of data sources, the U.S. Drought Monitor summarized the situation of drought occuring in the United States with intensity and impact types based on the data on August 30th, 2022 [11].

Because of global warming, or climate change, water on the earth and in the soil evaporates more quickly, contributing to the occurrence of drought. Also, the schedule of water supplies is being modified by climate change. The concern is that warmer winters will lead to less snowfall and disarray in ecosystems and water management systems, which depend on melting snow, and make droughts more severe due to higher surface temperatures causing less snow cover (since snow can reflect surfaces). In general, some people and specific economic sectors can strongly sense the effects of drought. For instance, between June and July, the American Farm Bureau Federation polled farmers and ranchers in the western United States and 74% of them said the drought had lowered crop output [12]. A crucial aspect is that drought worsens ecosystem function by raising atmospheric carbon dioxide levels. Plants perish during a drought, and animal species' food sources diminish while their habitats may be harmed. This disruption of the food chain causes the ecological system to malfunction.

2.4. Humidity

Humidity is related to the hydrologic cycle, especially on land, because the amount of water available for evaporation is limited by precipitation, whereas the ocean surface is always moist, whether it rains or not. Compared to cool air, warmer air has the capacity to carry more water vapor because there is more energy in warm air to convert liquid water to a vapor state. Moreover, with temperatures increasing, humidity is becoming denser in high precipitation and high-temperature regions. Some researchers suggest that something happened in dry places as well. Dore (2005) observed and found that it has a propensity to get wetter in humid areas and vice versa [13]. According to Trenberth (2011), mild wind shifts can make subtropical, or dry areas drier and humid areas wetter, particularly in the mid-latitudes and high-latitudes [14]. So, scientists agree on the "dry places get dryer, wet places get wetter" idea based on previous research. Meanwhile, some reverse trends also exist, showing that earlier studies substantially overstated global moisture trends.

Since soil moisture is a sensitive factor to climate change and interacts with changing temperatures through energy transfer, it is an excellent predictor of humidity and precipitation. However, precipitation, evapotranspiration, subsurface water, and other factors are the final determinants of soil

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moisture. According to a German study, soils with less moisture limit the rate at which soil animals (such as earthworms, lice, and mites) and microorganisms (such as bacteria and fungi) break down dead plants [15]. This may have a huge impact on natural systems because the process of plant decaying does offer an advantage for nutrient cycling.

3. Impacts of climate change on butterflies

3.1. Butterflies' population groups

According to a study that appeared in science, the widespread butterfly decrease that is occurring in the western United States is being exacerbated by climate change. It is noticed that there is an adverse tendency in the majority of butterflies, which include once common species. The investigation concluded that climate change, specifically in areas that underwent warming during the fall months, is the best indicator of butterflies' mortality [16].

Autumn is becoming longer and warmer due to climate change. This peculiar set of circumstances was what affected the study's butterfly participants the most. The butterfly did not die immediately, but it was less likely to go from pupa to adult. Climate change has made butterflies less likely to survive winter and emerge in spring. Warm winters are worse for inactive creatures than cold ones, the researchers say, which implies that warmer autumnal days can possibly be more hazardous. In Sweden, green-veined white butterflies are usually minimal in spring due to the pressure of winter dormancy. Butterflies had a "bad year" in 2021, according to the annual British Butterfly Monitoring program, with the green-striped white butterfly (Pieris napi) having the fourth worst performance on record [17].

3.2. Butterflies' distribution

In addition to the change in butterfly populations, the distribution of butterflies is also altering. Because of climate change, many British butterfly species are migrating north. However, according to a biological study, the transition of going to the north can only occur if populations are either constant or growing. Based on butterfly distributions and abundance data gathered by the general public since the 1970s as part of a "citizen science" initiative, the study was conducted. The information showed that species that were only found in southern England are now settling in northern England and Scotland. Because of the increased hospitability of northern regions due to warmer climates for these temperature-restricted insects, butterflies have expanded their geographic range [18].

Butterfly behaviors can change not just in terms of location but also in terms of timing. Many butterflies adjust their flight times of the year to reflect changing temperatures, so as the world warms, their flight seasons will change. The researchers, from the University of British Columbia in Canada and other institutions, examined the flights of more than 200 butterfly species and examined more than 130 years of meteorological data [19]. Butterflies, it turns out, are very sensitive to changes in temperature. As temperature rises, butterflies are also appearing earlier in a year, and they are entering the active flight season earlier, researchers say, which can have detrimental effects on their survival -- they risk being hit by frost and dying, or showing up earlier than the plant food they depend on and starving. The shift in butterfly flight times also provides an early warning sign that the habits of other wildlife may also be influenced by climate change, the researchers said.

3.3. Butterflies' lifespan changes

As mentioned above, the increase in temperature is one major influence of the climatic changes over the globe. The increase in temperature is already enough to cause huge changes in butterflies' lifespan. It was already known that butterflies are sensitive to temperature increases, especially as elevation increases [20]. In detail, in a paper discovering temperature changes and how they affect butterfly phenology, the author observed a group of orange-tip butterflies for a long period in the wild and collected data from over 14 generations. What is significant as a result of the study is that higher temperatures accelerated subsequent emergence of butterflies, when larval stage almost ends and pupal stage had just begun, and when the pupal of butterflies are developing after diapause, but delayed it

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when the cooling phase began [21]. In detail, the increased temperature in some stages of pupal development will advance the lifespan, while temperature increases in other periods will delay the lifespan.

As another influence, butterfly lifespan will be also indirectly shortened, from other results of climate change, like droughts or alien species. Droughts can affect plant growth, which will further influence butterflies. Butterfly growth is especially dependent on plants, as when they're in the larvae stage they consume upon leaves on plants as caterpillars, and they drink in nectar as adult plants. As drought took place and killed lots of harvests, and plants in multiple areas mentioned above, butterflies' lifespan will be shortened. Larvae will shorten their growth time in response to higher larvae density and food stress, hypothesized as an adaptation.

3.4. Reproduction of butterflies

Usually, butterflies' eggs hatch in warm seasons. So, if eggs are laid in the winter, they will go through a diapause stage, or resting stage, and be hatched in spring. Some butterflies will lay eggs in spring and hatch in summer. As shown, the reproduction of butterflies is strongly correlated with temperature. Not only in the warm season, but the birth time of butterflies is also concentrated in wet seasons, too.

With that, it is clearly shown that the temperature change both directly and indirectly affects their reproductive success and details of reproduction. However, as unexpected, butterflies seem to have higher reproductive success as temperature increases. For a kind of tropical butterfly Bicyclus anynana, the eggs laid in lower temperatures are lower and fewer, but more, larger eggs are produced at higher temperatures. Meanwhile, total reproductive investment is also higher in higher temperatures, since more eggs were laid. Also, according to a different research, very slight temperature increases at chilly, alpine locales can have significant implications on the likelihood of reproduction and flight [20]. All the evidence points toward greater reproductive success as temperature increases, caused by climate change.

Drought is another issue that was brought about by climate changes, that also impacts the reproduction of the butterflies, since, it is favorable for butterflies to reproduce in wet climates. However, butterflies seem to also have plasticity in changing their laying dates. For a study of nymphalid butterflies, they spent time in the shelter through dry, cold seasons and instead reproduced in the warm, wet season. It seemed that they respond to changes in the climate with cues like photoperiod.

4. Conclusion

Climate changes are heavily influencing the biosphere, causing concerns including alien species, rise in temperature, drought, and humidity to take place. Many of them cause huge concerns to native environments, destroying plantations as well as other animals or lives. For butterflies, their population and distribution had changed drastically, and their populations had been migrating northward. Also, their lifespan changes and phenotypic plasticity in reproduction seem to be harmless and beneficial, but they contain hidden threats. The change in their lifespan and reproductive timing can cause severe harm. First, they are observed to migrate around, even in individual seasons but not the time to migrate; second, and the most, butterflies have the ability to change the formation or composition of a whole ecosystem, because of their complex relationship with plants, other animals, and bacteria. Overall, climate change are damaging butterflies. More research should be done in the future to discover climatic influences in detail. Most importantly, people should start working or work harder, on efforts to stop climate change and start to restore and protect organisms, not only butterflies. Our paper serves as an overall report indicating the influences of climate change, but more as a call to start reacting against these changes.

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