Anthropological Climate Change: Affect on Hibernation of Pollinators in the Netherlands and its Cascading Effects

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Abstract

This paper focuses on the hibernation of insect pollinators in the Netherlands and examines the impact of climate change and increasing temperatures on their phenology. Through a systematic literature review, important aspects related to the behavior and survival of pollinators were analyzed comprehensively. The findings highlight significant alterations in pollinator activity, changes in flora and biomes, and transformations in agricultural practices. These disruptions have resulted in reduced fitness, impaired health, and a threat to natural phenology. Pollinators face challenges such as increased heat during summers and reduced food resources. These consequences have far-reaching implications for agriculture, including reduced crop productivity and imbalances in human diets. The disruptions caused by rising temperatures can potentially lead to a decline in pollinator populations in the future. Therefore, further in-depth and long-term studies are necessary to understand the significance of insect pollinator hibernation and to develop strategies for their conservation. Recognizing the crucial role of pollinators, these research efforts will inform conservation measures and help safeguard their importance in maintaining ecosystem balance.

Keywords: hibernation, climate change, pollinators, phenology, agriculture

Introduction

Pollination is a key ecosystem service (Klein et al., 2007). It contributes to sustaining ecosystems, provides humans globally with crops, and even generates an economic contribution (Southwick & Southwick, 1992). Pollination is the act where plants exchange pollen with one another to reproduce. This can through wind, water, and animals (Potts et al., 2016). In this paper the focus lies on animal pollination, called pollinators. They feed themselves on flowers and like so obtain pollen which they spread by the continuation of foraging (Potts et al., 2016). In Europe, 84% of the crops are being pollinated and most of them are consumed by humans every day (Allsop, De Lange & Veldtman, 2008). This makes pollination of high value for the diet of humankind. However, this pollination service is threatened. Rising temperatures disturb the ecological habitat, phenology, and pollinator behaviors(Burkle, Marlin & Knight, 2013). Phenology refers to the study of the timing and seasonal patterns of biological events in connection to climate and environmental conditions. It focuses on the synchronization of life cycles among different organisms, including the timing of flowering in plants and the emergence and activity of pollinators (Chmielewski & Rötzer, 2001). One important aspect that is disrupted in the cycle of pollinators is the hibernation. Hibernation is a seasonal activity whereby animals go into a deep long sleep to survive the colder winter months (McDowell, 2015). Nevertheless, the altered hibernation state caused by climate change and rising temperatures pose significant consequences for the overall well-being and adaptability of animals which hibernate. Pollinators that hibernate are similarly affected by the interruption of hibernation. This may decrease pollination efficiency. This not only affects the survival and reproductive success of pollinators but also threatens the overall pollination service and the biodiversity of plant communities which may lead to reduced crop production. This emphasizes the urgent need to address the effects of climate change on pollinator hibernation and put conservation measures in place to protect these crucial species and the ecosystems they sustain. The topic of pollinators and their interactions with flowering plants is of utmost relevance in today's world. The decline of pollinator populations, combined with the increasing recognition of their essential role in ecosystem functioning, is explored in this paper. The research question is: *How does climate change affect the hibernation of insect pollinators in the Netherlands and what are some of the cascading effects?* By addressing these questions, the research aims to enhance the understanding of the potential consequences of climate change on pollinator populations and their interactions with flowering plants and how hibernation plays a role in these processes. The approach to address these research questions involves conducting a comprehensive systematic literature review. The main topics that will be covered in the literature review are pollinators, the role of pollinators and the value they give to ecosystems and agriculture and the significance of hibernation for pollinators and its potential disruption due to climate change, , more threats that pollinators face, the effect of climate change, extreme weather events and their impact on the Netherlands. The method section will explain how the systematic literature review is conducted. In the discussion, the research question of this paper will be answered and finally, the paper will culminate with a summary and conclusion that encapsulates the key findings and implications discussed throughout.

Literature review

Pollinators

Aside from their small size, insects are one of the most diverse groups of organisms on earth and makeup 66% of all animal species (Jankielsohn, 2018; Yang & Gratton, 2014). Many ecological functions of insects are highly important for humans (Losey & Vaughan, 2006). A few vital ecological functions of insects are pollination, pest control, decomposition, and maintenance of wildlife species (Losey & Vaughan, 2006). Globally, 200,000 distinct animal species serve as pollinators for plants. The predominant pollinator species are insects both globally and in rangelands (Harmon, Ganguli, & Solga, 2011). The insects keep the natural systems in stand, without these services, human life could not persist (Garibaldi et al., 2013). Therefore, the life of these small organisms must be preserved (Losey & Vaughan, 2006). However, their conservation is of a lower priority since it is hard to determine their economic value. Which is for many funders an important factor in their choice of funding (Losey & Vaughan, 2006). Therefore, will the next part focus on the value of the activity of pollinators.

Pollination activity

One vital service that pollinators bring us is the pollination of crops. Pollination is a complicated, multi-layered relationship between a rich diversity of flora and fauna that is provided by large numbers of organisms in a particular range (Kremen et al., 2007). This relationship has been around for over 400 million years and has evolved into a highly important ecosystem service (Harmon, Ganguli & Solga, 2011). Pollination mostly relies on animal pollination (Potts et al., 2016). This relationship is based on mutualism; the species work together to both gain a mutual benefit (Harmon, Ganguli & Solga, 2011). This relationship usually starts with the plants that want to reproduce. Despite the fact that plants can generate offspring asexually, plants need sexual reproduction in order to mix their genes (Potts et al., 2016). Plants that are pollinated have the benefit of increasing genetic variety within a species by increasing the genetic diversity of their progeny (Kearns & Inouye, 1997). For this to happen, the male part needs to exchange its pollen with the female part of the plant from the same species (Harmon, Ganguli & Solga, 2011; Nowakowski & Pywell, 2016). Here pollinators play an important role since they are the transporters of the pollen. The majority of pollination is passive and generic, with insects collecting pollen on their bodies while searching for nectar or pollen (Harrison, Woods & Roberts, 2012). For example, bees must visit flowering plants to collect two essential food sources: protein-rich pollen, which females use to expand their ovaries and feed their larvae, and sugar-rich nectar, which gives them the energy to fly (Nowakowski & Pywell, 2016).

Plants invest a lot of energy in their attractiveness, so they receive efficient visits to achieve adequate amount of levels of seed sets (Postel et al., 2012; Price 1997). To attract pollinators, plants use pollen as a transactional method for their services. The pollen has been specially designed as rich nutriment (with essential amino acids, proteins, lipids and much more) that pollinators need to survive (Dafni, 1992). Around 75% of flowering species interact with pollinators(Harmon, Ganguli & Solga, 2011). When a pollinator has visited several flowers of the same kind, it is considered a successful pollination (Brosi, 2016). Thus, pollination is highly important for plants, since it influences the dynamic of communities by the amount of pollination taking place (Dafni, 1992). Additionally, plant species that are pollinated by animals generate seeds and fruits that are food for wildlife.

The pollination services are performed by wild species or commercially held species (Kremen et al., 2007). Next to insects, there are birds, mammals and even bats who participate in this service. Out of all pollinators, bees are the most significant for the continuation of this process. The 25.000 different bee species are most responsible for pollinating the top 107 global crop types (Potts et al., 2016). Bees are active, constant foragers, and they are reliable pollinators because they must continually forage for their own nutritional needs and those of their progeny (McGregor, 1976). Furthermore, are they able to travel for miles in search of food, hereby the spread of pollen reaches a substantially larger area (Harmon, Ganguli, & Solga, 2011). Honeybees, one of the most well-known bee species, can live in colonies with enormous populations of up to 50,000 adult bees (Spivak, 2011). The number of hives has grown exponentially since 1950 by more than 45%, mainly because of farmers that keep them for commercial goods (Potts, 2016). Many wild plants and crops rely on pollination for sexual reproduction (McGregor. 1976). And thousands of wild plants depend on the services of bees for seed and fruit formation. Thus, reductions in bee abundance could have serious implications for both natural and agricultural ecosystems (Kearns & Inouye, 1997).

Pollination value

Pollination is considered a key ecosystem service (Klein et al., 2007). Animal pollinators contribute to about one-third of crop yield, while they are a necessity for 60 to 90% of plant species (Kremen et al., 2007). Humankind is intertwined with pollinators since they maintain the health and functioning of ecosystems, continues wild plant production as well as crop production and contribute to global food security (Potts et al., 2016). Humans consume tons of foods every day that are resulted from pollination (Losey & Vaughan, 2006). The production of enough food to feed the world's expanding population is becoming a major challenge. The predicted 46% rise in world population by 2050 will necessitate higher agricultural production to assure food security (Jankielsohn, 2018). Therefore, the human species relies heavily on animal pollination for the production of the majority of the world's food crops (Klein et al., 2007). Since 1950 the world population has increased from almost 3 billion to today 8 billion (Roser, Ritchie, Ortiz-Ospina & Rodés-Guirao, 2013; UN, 2022). Since there were more mouths to feed the supply of food needed to be increased. This has led to an exponential growth in the food industry. The agricultural field has seen a large expansion of 30% of cultivated crops in the last seven decades (Aizen, Garibaldi, Cunningham & Klein, 2008). The majority of these crops were pollinator-dependent, such as cocoa, coffee and soybeans. Because of this large increase, global agriculture is nowadays twice as dependent on these kinds of crops than in 1950. Animal pollination directly impacts 75% of globally significant crops in terms of production and/or quality (Potts et al., 2016).

Worldwide, there are around 220,000 plants that rely on pollination by animals (Postel et al., 2012). Global crop markets are significantly impacted by animal pollination. The global crop yield depends approximately 35% on pollinators (Allsop, De Lange & Veldtman; Klein et al., 2007; McGregor, 1976). In Europe, crops rely 84% on animal pollination (Allsop, De Lange & Veldtman, 2008; Klein et al., 2007). Annually, the value of animal pollination services to the world's agriculture is calculated to be about US$235-577 billion (Potts et al., 2016). Thus, the loss of global pollination could result in large losses economically. Millions of people rely on animal-pollinated crops for food, money and jobs. Especially in the global south, where 70% are reliant on agriculture as income (Stewart, 2021). Worldwide, 2 billion people in developing countries rely on smallholder agriculture. Therefore, if their harvest fails it directly impacts households and close-by communities. This can lead to detrimental consequences, such as malnutrition and starvation (Potts et al., 2016; Stewart, 2021). Worldwide, honeybees continue to be the most economically significant pollinators of monocultures of crops (Klein et al., 2007; McGregor, 1976). The honeybee visits approximately 100 flowers per flight (Wahengbam, Raut, Pal & Banu, 2019). Without honeybees, the crop yield can decrease by 90% worldwide (Southwick & Southwick, 1992). In the United States, approximately 15% to 30% of the diet comes from food that is pollinated (McGregor, 1976). The economic value of agricultural pollination services can be estimated by comparing the crop yield with and without pollination (Southwick & Southwick, 1992). In the United States, this value is almost $3.07 billion (Losey & Vaughan, 2006). Bumblebees pollinate over 25 very important crops that humans are likely to consume almost every day (e.g., tomatoes, zucchinis, sunflower oil, and strawberries) (Bonmatin et al., 2015).

Pollinator-dependent plants are besides food also used for pharmaceuticals, biofuels, fibers, building supplies, musical instruments, artistic creations, and leisure activities (Kremen et al., 2007; Reybroeck, van Veen & Gupta, 2014). In over 50 countries, bees can assist in ensuring livelihood security and reducing poverty among rural populations through honey-hunting and beekeeping techniques based on local and indigenous knowledge (Reybroeck, van Veen & Gupta, 2014). These small practices can sustain a lot of small businesses and people. Pollination can thus, directly and indirectly, increase the value of the marginal increase in production of commercial or subsistence crops, fiber, forage, timber, and non-timber forest products (Kremen et al., 2007).

Pollinator threats

Due to their sensitivity to the phenology, behavior, physiology, and relative abundances of various species, plant-pollinator interaction networks may be especially vulnerable to anthropogenic changes (Burkle, Marlin & Knight, 2013). Several threats can be defined that affect the existence of pollinators. Several threats can be defined that affect the existence of pollinators.

Destruction of ecosystems

One of the primary causes of bee reduction is thought to be anthropogenic land use change and intensification (Rader et al., 2016). Worldwide, pollinators are threatened. Many local groups of pollinators have a population decline and even a few that have gone extinct. IUCN has estimated that 16,5% of pollinator species are on the Red List and are facing extinction on a global scale (Zedan, 2004). In Europe, for example, are bees nationally threatened up to 50% (Nieto, 2014). This decline in bee and other insect species is most prevalent in regions with extensive industrialization (Wagner, 2020). The industrialization has led to fragmentation and decline in habitat and diminished their food supply. Large-scale land use changes can lead to the destruction, fragmentation, and degradation of pollinators (Wagner, 2020). Especially when the area is converted to intense mono-agriculture. This affects the nesting resources, and food supplies and discharges insects from their homes (Potts et al., 2010). Changes in the flora can cause colony stress and starvation in addition to making them more susceptible to chemicals and infections.

Use of pesticides

Pesticide usage for crop protection in agroecosystems is a pertinent additional issue that has been cited as posing a serious threat to pollinators (Fauser, Sandrock, Neumann & Sadd, 2017; Wahengbam, Raut, Pal & Banu, 2019). This threat differs from species, between different chemicals, the scale and type of land management, landscape, the ecological infrastructure of the landscape and interactions with other factors (Potts, 2016). There are several ways for non-target creatures to become exposed, but pollinators are especially susceptible to exposure when foraging on crops and other adjacent flowering plants where pesticide trace residues can be discovered (Wahengbam, Raut, Pal & Banu, 2019). Herbicides, which eliminate weeds, do not directly target pollinators, however, it decreases the variety and number of flowering plants that provide pollinators with pollen and nectar. Another threat is insecticides, mainly neonicotinoids (Klein et al., 2007). This is used against herbivorous insects. However, when sprayed, the neonicotinoids are to be found throughout the whole plant and thus also in the nectar and pollen. The use of these insecticides has led to honeybee colony collapse disorder (CCD) and bumblebee decline (Klein et al., 2007; Wahengbam, Raut, Pal & Banu, 2019; Wood & Goulson, 2017). Honeybee CCD is a phenomenon where honeybee colonies experience a sudden and significant decline, potentially caused by various factors such as pesticides, habitat loss, parasites, pathogens, and environmental stressors. In short, neonicotinoids have diminished the survival and reproduction rate of pollinators. There are still significant knowledge gaps about how pesticides affect pollinators.

Parasites

Parasites pose another threat to pollinators. There have been seen humongous population losses of honeybees, bumblebees and other pollinating insects (Fauser, Sandrock, Neumann & Sadd, 2017). However, parasites are mostly dangerous in combination with other environmental stressors. Particularly during times of predicted increased vulnerability to mortality or decline in condition (such as hibernation) (Goulson et al., 2015). It is anticipated that climate change would have an impact on host-parasite interactions and that for some hosts, parasite infection will become more prevalent as temperatures rise (Goulson et al., 2015). Important pollinator population losses have previously been linked to parasitism and climate change on a global scale (Manlik et al., 2023).

Invasive species

Invasive species are another threat that local pollinators face (Vanbergen & Initiative, 2013). The predators can affect ecosystems by devouring native pollinators, and invasive alien predators can change ecosystems, leading to a shift to a pollination system dominated by invasive species (Potts et al., 2016). Although the degree of impact depends on the overlap in features or niches, foreign plant or alien pollinator species alternative plant-pollinator networks, and at high abundances invasive alien pollinators can outcompete native pollinators (Vanbergen & Initiative, 2013; Potts et al., 2016). One notable instance is how the spread of the managed European bumblebee species caused the Patagonian gigantic bumblebee to go locally extinct in much of its habitat. To stop fresh invasions, surveillance and regulation are the most effective policy responses, followed by quick action once an invasion is discovered to stop establishment (Potts et al., 2016).

Climate change

Climate change is the increasing or decreasing of the mean global temperature (Conway, 2008). Currently, there is an ongoing transformation in global temperatures, indicating a present changing climate, this current increase in temperature is called anthropogenic climate change, meaning that the change in the climate is driven by human interactions and influence (Malhi et al., 2020). The IPCC (Intergovernmental Panel on Climate Change) defines climate change as “any change in climate over time whether due to natural variability or as a result of human activity.” (Pielke, 2004; Shukla et al., 2019). The change of natural variability has a constant but small influence on the global temperature. However, the modifications made by human activities to the natural processes of the planet are a strong cause of the recent global warming (Houghton, 2002). Since the preindustrial period (1850-1900) humans have been burning fossil fuels and making large-scale deforestation possible (Houghton, 2005). These ongoing activities release annually billions of tons of carbon dioxide, methane, nitrous oxide, and chlorofluorocarbons into the earth’s atmosphere. These gasses are known as greenhouse gasses, and they absorb the thermal radiation that is emitted by the Earth's surface which leads to an increase in the Earth's surface temperature (Houghton, 2005).

Since 1850, the mean land surface air temperature has risen by 1.53°C (Shukla et al., 2019). Multiple climate models have predicted that by the beginning of the next century, the global mean temperature will be around 2°C degrees higher than before 1850. However, there are calculations that the temperature can even be up to 3°C (Kemp, 2022). This is increasing the risk of adverse effects of climate change on ecosystems and people. A number of the Earth system's possible climate tipping points, like the melting of the west Antarctic ice sheet, have already begun to activate (Shepherd, Wingham & Rignot, 2004; Malhi et al., 2020). As a result, the IPCC Special Report on 1.5°C cautions that permitting the earth to warm beyond 1.5°C will already have negative effects on humans and biodiversity, including drought, floods, heat waves, and sea level rise (Malhi et al., 2020; Shukla et al., 2019). Furthermore, at 1.5°C of global warming, it is predicted that there will be significant dangers from permafrost degradation, wildfire damage, dryland water scarcity, and food supply instability (Shukla et al., 2019). At 2°C, the risk of permafrost degradation and food supply instability is expected to be quite severe. And if the global temperature approaches 3°C, it is predicted that the risks of vegetation loss, wildfire damage, and dryland water scarcity will all increase significantly (Shukla et al., 2019). The world has roughly until 2030 to cut global net carbon emissions in half to avert the most catastrophic effects, according to a 1.5°C goal for warming, but even if this target is met, possible warming effects are likely to last for decades or even centuries (Malhi et al., 2020).

In this era, anthropogenic climate change is one of the most pressing environmental issues. Ecosystems are being affected by climate change through changes in mean conditions and climate variability, along with other related phenomena such as accelerated ocean acidification and elevated atmospheric carbon dioxide levels (Malhi et al., 2020). Additionally, it interacts with other stressors on ecosystems, such as deterioration, defaunation, and fragmentation (Field & Barros, 2014; Malhi et al., 2020). These impacts can lead to a wide range of environmental and societal consequences. Because of warmer temperatures, the melting of land ice is causing a global sea level rise. The world's biomes and ecosystems are also shifting because of the temperature rise (Gonzalez, 2010). The arid areas are expanding, and the global tree line is moving more to the north. The shifting of biomes and the infestation done by humans can lead to a worldwide decrease in biodiversity (Field & Barros, 2014). Many plant and animal species have consequently seen changes to their ranges, abundances, and seasonal activities (Tougeron, Brodeur, Le Lann & van Baaren, 2020). Furthermore, there will be an increase in droughts and heat waves. Together with the rising sea level, extreme weather and shifting rainfalls.

Extremes of Climate change

Weather extremes are becoming increasingly severe due to climate change. An extreme weather event is defined as uncommon weather or climatic phenomenon at a particular time and place of the year (NASA & Medince, 2016). Extreme weather events have been proven to be strongly correlated with rising global temperatures (Stott, 2016). Because of the disruption of the usual weather pattern caused by rising temperatures and an increase in greenhouse gases in the atmosphere, extreme weather events are occurring more often and more intensely (Planton, Déqué, Chavin & Terray, 2008; Stott, 2016). Events such as heatwaves, droughts, hurricanes and floods are tending to get more frequent and severe. The ability of damaged ecosystems to defend against the social and physical effects of these events is weakened. Global warming predominantly leads to an increase in the frequency, severity, and duration of heat-related events, especially heatwaves, across the majority of land areas (Shukla et al., 2019). Based on the resulting estimations, there has been a five-fold increase in global monthly temperature extremes that establish local records due to long-term warming (Stott et al., 2016). This is concerning for vulnerable human and animal populations. Therefore, these extremes have the potential to severely impact both civilization and wildlife (Mahecha et al., 2022).

During the summer of 2003, Europe experienced a historic heatwave characterized by temperatures exceeding 3°C above the average level of 1961-1990. This extreme heat event had far-reaching consequences, including widespread droughts, significant crop losses, and tragically, over 22,000 heat-related fatalities across Europe. (Schär & Jendritzky, 2004; Levinson & Waple, 2004). Heatwaves can make droughts more severe; this can lead to water and food shortages and conflicts over resources (Allouche, 2011). This will primarily occur in arid regions, where anthropogenic climate change will result in warmer, drier days with little to no precipitation (Planton, Déqué, Chavin

& Terray, 2008). It is predicted that by 2070, 2 billion people live in extremely hot areas (Kemp, 2022). Furthermore, intense heat waves and droughts can lead to wildfires. This, in turn, will exacerbate the destruction of habitats and result in mortality among humans, plants, and animals and thus pollinators.(Swain, Singh, Touma & Diffenbaugh, 2020).

Climate change in The Netherlands

The effects of anthropogenic climate change are also felt in the Netherlands. While the global temperature has increased by 1°C worldwide, the Netherlands has experienced an increase of 1,7°C (WWF.nl, 2022). A major effect the Netherlands has felt due to climate change is seasonal changes (Bradshaw & Holzapfel, 2008). Summers tend to get longer and warmer, while winters are getting shorter and warmer (Bron & van Vliet, 2007). For the winter season, most models indicate that the local temperature in the Netherlands will vary between 0.9 and 1.1 °C per °C increase in global temperature. However, during the summer, the local temperature is projected to have a wider range, varying between 0.9 and 1.4 °C per °C global temperature rise (Van den Hurk et al., 2007). In 2019, the temperature in the Netherlands surpassed 40°C for the first time (Blunden & Arndt, 2020). Several effects result from the temperature and changes in the lengths of the seasons. The most significant effect on wildlife is the extension of the growing seasons of plants (Bron & van Vliet, 2007). Plant and animal species have already felt the consequences of global warming (e.g., every year, apple trees start to blossom earlier) (WWF.nl, 2022). This can have both beneficial and harmful effects. On the plus side, this might result in improved crop yields for farmers and more food for animals. However, it could also indicate the emergence of non-native plant species, possibly displacing native ones and upsetting the ecosystems (Bron & van Vliet, 2007). If the temperature will rise to 3°C by 2080, 40 percent of the plant species in the Netherlands will not be able to survive the heat (WWF.nl, 2022). The phenology of animals is also significantly impacted by the changing seasons. The timing of many animal behaviors, such as migration, mating, hibernation, and feeding, depends on the seasons (Bron & van Vliet, 2007). As the seasons change, these natural cycles may be disturbed, potentially causing animal population declines, behavioral changes, or even the displacement of wildlife.

Water poses another big threat to the Netherlands. One danger that water is likely to bring is the rising sea level since 26% of the land is below sea level (Kron, Löw, & Kundzewicz, 2019). The sea level has increased from 12 to 20 centimeters between 1902 and 2010 (Mulder & Tonnon, 2010 B). The sea level has risen two times as quickly in the last few years as it did in the 20th century, at a rate of 4 to 5 millimeters every year (Le Bars & KNMI, 2019). The Netherlands has a large and dense population of more than 4 million people living along the coast, which puts them at serious risk if the sea level rises significantly (Kron, Löw, & Kundzewicz, 2019). If the sea level rises by 1 meter 6,57 million people will live under sea level (Hut, 2016). The increase in precipitation is another threat the Netherlands faces (Minnen et al., 2012). In winter, the local precipitation changes range from an increase of +3% to +7% per degree Celsius. However, in summer, there is even variation in the direction of the precipitation change, with some models showing an increase of +3% per degree Celsius, while others indicate a decrease of -10% per degree Celsius (Van den Hurk et al., 2007). Because of the location and position of the rivers, the rivers have the potential to overflow. In the winter, the river discharges will increase, and in the summer the water discharge will decrease (Klijn, Baan, De Bruijn & Kwadijk, 2007). Due to its location downstream of several major rivers, the Netherlands relies to some extent on the actions and measures taken by countries located upstream (Thaler & Hartmann, 2016). However, it is almost certain that the rivers in the winter will have more frequent highwaters and discharge which can result in floods and harm to human and animal populations because the Netherlands receives the most water from the rivers (Klijn, Baan, De Bruijn & Kwadijk, 2007).

Hibernation

When an environment changes, organisms are driven to adapt in order to survive. This is a form of natural selection and organisms survive by taking on different types of adaptations (Sheikh, Rehman & Kumar, 2017). Those who are best adapted to their surrounding environment have a better chance of surviving offspring (Sheikh, Rehman & Kumar, 2017). Different types of adaptations include physiological, behavioral and morphological adaptations (Ramløy, 2000). Hibernation is one behavioral adaptation that is important for many species to survive the winter months (Sheikh, Rehman & Kumar, 2017). Hibernation is a phenomenon where animals during the winter months are in a deep long sleep (Walker et al., 1977). Throughout the winter, food is more difficult to come by and the weather is harsher. To survive this, some animals go into hibernation (Bouma, Carey & Kroese, 2010). By doing this, they may conserve energy and continue for extended periods without feeding. These periods can last a few days up to 8 months (Rice et al., 2020). During the winter sleep, the metabolism is reduced to a very low level. This ability is achieved by slowing down their breathing, and heart rate, and reducing their body temperature. In the months prior, the animals eat a lot of food and save the energy they gain in fat reserves, this is what helps them survive during the torpor state (Bouma, Carey & Kroese, 2010; Geiser, 2013). During hibernation animals are going into a state of torpor, this serves several vital purposes, including energy conservation under harsher conditions, but it is also used to enable energy-intensive processes like growth and reproduction, particularly when food is scarce (Geiser, 2013). Animals who are going into a state of torpor are mainly found in cold-climate zones, such as The Netherlands. However, different species all over the world, even in the tropic regions, are also able to get into this state (Geiser, 2013). In the past, hibernation was mostly thought of as a cold-weather adaptation because it frequently occurs from late summer/autumn to late winter/spring and is strongly seasonal. Since hibernation is now known to occur in a wide range of habitats, from the Arctic to the tropics, it seems that the primary motivation for its use is a lack of food, which occurs for a portion of the year in both dry tropical areas and cold temperate and arctic areas (Allen & Meyer. 1998). Some species can go into a state of torpor daily. These are more often found in the desert and tropics. Torpor is important for them to regulate their body temperature while they are non-active (Geiser, 2013). To conclude, hibernation is an intricate method used by species throughout the world to survive harsher environmental circumstances.

Hibernation of pollinators

During the winter months, the pollinators disappear (Lee Jr, 2009). There is no food to sustain them during these months and the temperatures are too cold. In this period pollinators take on different strategies to survive the winter. The most common adaptation is hibernation (Lee Jr, 2009). The form of hibernation differs per pollinator species (Miller, 2022). For example, in a bumblebee colony, only a queen goes into hibernation and the rest dies off. In the spring she will start a new colony (Pryes-Jones & Corbet, 2015). Honeybees survive by nestling together and vibrating their bodies, so they create heat. Together with a supply of honey, the hive can survive the winter months (Miller, 2022). Other species of bees hibernate in the ground or tiny hollow spaces. Another example of a pollinator species is the butterfly. Some butterfly species migrate to the south to survive the winter; however, this is more common in the tropic areas (Miller, 2022). Another adaptation butterflies take on is entering a diapause. This is a period of suspended development, here they stay in one of their four life stages throughout the winter (Miller, 2022; Sheikh, Rehman & Kumar, 2017). Unlike mammals and birds, which are endothermic and generate their own body heat internally, insects are ectothermic creatures. They rely on external sources, such as the environment and sunlight, to regulate their body temperature (Beck, 1983).

Pollinators during hibernation can be divided into two groups: freeze-avoiding and freeze-tolerant (Hengherr et al., 2009; Sheikh, Rehman & Kumar, 2017). These adaptations are paired with complex interaction processes, the same and different adaptations we see in other hibernating species (Marchand, 2014). For example, diminishing their transpiration rate, antifreeze proteins, and cryoprotectants are among other things that allow the insects to survive under different extreme temperatures.

The freeze avoidance species chose a completely dry hibernation site. These insects cannot tolerate ice formation within their bodily fluids and therefore need to be isolated from any water bodies nearby (Marchand, 2014). Additionally, certain insects may have a physical defense against external ice, such as coating themselves in a wax layer (Sheikh, Rehman & Kumar, 2017). The most important process they use is supercooling, in this instance, the liquid in their body cools below its freezing point without solidifying (Sheikh, Rehman & Kumar, 2017).

The freeze-tolerate species have adapted in such a way that they have gained the ability to survive ice formation within their tissues (Ramløy, 2000). By regulating where, when, and how much ice accumulates, insects that have developed freeze-tolerance techniques can prevent tissue damage (Ramløy, 2000). Unlike the supercooling technique, freeze-tolerant species allow the freezing of their fluids at higher temperatures (Lee Jr & Costanzo, 1998). This is preferable since the pace of the ice formation is slower, giving the insects more time to adapt to the internal changes brought on by the ice formation (Lee Jr & Costanzo, 1998). In the Northern Hemisphere, 29% of the insect species take on the freeze tolerance adaptation (Sinclair, Addo-Bediako & Chown, 2003).

The effect of climate change on pollination

Several effects result from the climate change the temperature and changes in the lengths of the seasons. The most significant effect on wildlife is the extension of the growing seasons of plants (Bron & van Vliet, 2007). The beginning of spring season can have an impact on pollinator hibernation because pollinators play a crucial function as pollen transporters and because of their seasonal hibernation.

Plant and animal species have already felt the consequences of global warming (e.g., every year, apple trees start to blossom earlier) (WWF.nl, 2022). This can have both beneficial and harmful effects. On the plus side, this might result in improved crop yields for farmers and more food for animals. However, it could also indicate the emergence of non-native plant species, possibly displacing native ones and upsetting the ecosystems (Bron & van Vliet, 2007). If the temperature will rise to 3°C by 2080, 40% of the plant species in the Netherlands will not be able to survive the heat (WWF.nl, 2022). The phenology of animals is also significantly impacted by the changing seasons. The timing of many animal behaviors, such as migration, mating, hibernation, and feeding, depends on the seasons (Bron & van Vliet, 2007). As the seasons change, these natural cycles may be disturbed, potentially causing animal population declines, behavioral changes, or even the displacement of wildlife.

Without global pollination, the diet of humankind will have to go through a major shift. It is estimated that 15-30% of the global crop production will disappear (Jones & Snyder, 2018). Mostly fruits and vegetables are impacted and thus humans will have a less balanced diet. These crops are rich in vitamins A and C, calcium, fluoride and folic acid. Without a sufficient supply of fresh produce, humans can suffer from malnutrition of these nutrients (Marshman, Blay-Palmer & Landman, 2019). For example, the loss of pollinators could significantly increase the prevalence of avoidable diseases such as ischemic heart disease, potentially resulting in an additional 1.4 million deaths annually (Smith, Singh, Mozaffarian & Myers, 2015).

Methodology

The search method was created to find literature on the hibernation of pollinators and how climate change influenced this. Given the nature of this review, this research did not seek to undertake a meta-analysis pooling result. In April and May of 2023, systematic research was carried out. In the initial stage, a merger of several terms and synonyms related to climate change, hibernation, pollinators, Netherlands and phenology was used to find useful and relevant literature. This was searched on multiple platforms and the main ones are Google Scholar, SmartCat and Scopus. Google Scholar and SmartCat were mainly used for the literature review and primarily in the first stage. The final search engine was used for specific papers that are mainly used for the discussion. With a specific search on Scopus, the second phase started. Here there following terms were searched: TITLE-ABS-KEY ("climate change" OR "global warming" OR "heatwaves" OR "climate extreme") AND TITLE-ABS-KEY ("hibernation") AND TITLE-ABS-KEY ("arthropods" OR "insects" OR "pollinators" OR "pests" OR "pollination") OR TITLE-ABS-KEY ("phenology"). This resulted in 16 papers. Of these papers, the abstracts were reviewed and only used if they included 1) Hibernation of pollinators and consequences 2) Climate change affecting phonology 3) Repercussions of climate change on biomes, flora and agriculture. After the final selection, the papers were reviewed, and the needed information was extracted. In the third phase, extra literature was searched for gaps and additional information that fell out of the terms searched in Scopus. This search method eventually was a perfect system for this systematic literature review and worked efficiently.

Discussion

In the Netherlands, there is a rich variety of pollinators foraging the lands. There are 358 different bee species; more than 2000 butterfly and moth species, 4108 beetle species, and hoverflies (Groenendijk, Koopman, et al., 2001; Peeters et al., 2012; Naturalis, N.B.). As highlighted before, bees are most important, however, other species are causing more diversity in flowers since they are not restricted to only a few flower species, together they form a rich and diverse landscape (Potts et al., 2016; Rader et al., 2016).

Insect pollinators are very valuable for more than only crop yield. They contribute to the world's health, economy and biodiversity (Pimental et al., 1997). Therefore, it is very important that they are conserved and studied. Temperature is the main abiotic element influencing insect growth, reproduction, feeding behavior, range of distribution, and timing of their activities (Tougeron, Brodeur, Le Lann & van Baaren, 2020). Thus, it is essential to know what role climate change will play in the changing temperatures. The temperature increase is already known for affecting insect communities (Harvey et al., 2020). In recent years, there have been more action plans against the decline of insect populations, especially bee populations. However, the research of Biesmijer et al., (2006) showed that there was a decline of 29% of bee species and 36% of Dutch hoverflies compared to 1980. This is until today still the only data available about pollinator density in the Netherlands. However, it is still proof of a decline in insect hibernation species in the Netherlands. In some local places, the decline was over 60% of bee species (Biesmijer et al., 2006). Butterflies have experienced locally a decline of 50%. In the Netherlands, on average there has been a decline in butterflies of 30% (Warren et al., 2021). For beetles and moths, there has been a decline, respectively of 40% and 61% (Hallman et al., 2020).

Hibernation is an important part of the life survival of pollinators. The hibernation is timed according to the change of seasons. In recent years, researchers have seen changes in these patterns in connection to climate change (Tougeron, Brodeur, Le Lann & van Baaren, 2020). However, no paper or source lists all the consequences insect pollinators face due to climate change. Therefore, the discussion is divided into three main areas of focus:

1. Shift in the activity of pollinators
2. Shift in flora and biomes
3. A shift in agriculture.

These topics will be firstly discussed separately and end in a conclusion. Furthermore, the focus of the discussion lies in the Netherlands and thus different sources will be drawn on to concentrate on the hibernation of pollinators in the Netherlands. Also, for pollinators, this discussion will mainly focus on insect pollinators, since most mammals, birds and bats are to be found in the tropics and at lower altitudes thus not relevant to this paper's focus area (Fontúrbel et al., 2021). In addition, species of bees and butterflies are most mentioned since these are the most researched, this data gap is discussed in the limitations. Through a comprehensive exploration of these three aspects, the author aims to provide a coherent understanding of how rising temperatures impact the hibernation patterns of Dutch pollinators, ultimately creating a clear and vivid depiction.

The three main areas of focus are all influenced by climate change. Climate strongly affects the timing of many spring activities, including plant blossoming, starting new life cycles, and the emergence of insect pollinators. The timing of phenological events is extremely essential for the health of organisms because the life cycles must coincide with favorable environmental conditions and resources (Schenk, Mitesser, Hovestadt & Holzschuh, 2018). Pollinators must schedule their emergence so that their activity period corresponds to the phenology of the plants they forage on (and vice versa). Mean ambient temperature and the number of floral resources become more abundant as spring goes on, creating more and more favorable emergence conditions for spring-emerging insects (Schenk, Mitesser, Hovestadt & Holzschuh, 2018). This and other aspects will be touched upon. Understanding how different aspects of the climate influence species' life histories is essential for both the success of the individual and the resilience of the population (Wells et al., 2022).

1. Shift in the activity of pollinators

As a consequence of climate change, pollinators experience a shift in their activity. This is mainly caused by the changing of the seasons. In the Netherlands, the winters are warmer, shorter and wetter (Bron & van Vliet, 2007; Van den Hurk et al., 2007). Another notable finding is the transition from winter to spring, which is happening earlier every year (Koppel & Kerr, 2022). Since 1960, the start of spring has arrived 4.6 days earlier in the northern hemisphere for every degree of temperature increase (Menzel & Fabian, 1999). With no harsh and steady winter, the hibernation patterns of pollinators are alternating as well (Nürnberger, Härtel, Steffan-Dewenter, 2018). There are multiple repercussions to this. There are five main and they each will be discussed separately since they all play a large part in the way climate change is affecting the hibernation process of pollinators in the Netherlands. These impacts are as followed;

a) The duration of hibernation.
b) The life stage of insects.
c) The physiology of insects.
d) Foraging and the fat reserve for the winter.
e) Adaptations that insects are going through.

In the end, one can see that these repercussions are connected and may even enhance one another.

a) Duration of hibernation

The change in seasons brings multiple consequences before/during/after hibernation. Since the weather is declining later in the year, hibernation starts later as well (Nürnberger, Härtel, Steffan-Dewenter, 2018). In the Netherlands, there has been seen clear evidence of insects that are adapting their rhythm of seasons (Bron & van Vliet, 2007). For instance, the duration of hibernation has a big effect on the health and life stages of pollinating insects. An example of bumblebees, earlier discussed, considered one of the most important pollinators (in the Netherlands) the hibernation period is shortened from six up to 35 days (Koppel & Kerr, 2022). This change in their natural rhythm is concurrent with climate change and the increase in temperature. Butterflies are too spotted late in the beginning of November and even in December in 2006 (Bron & van Vliet, 2007). In 2006 the increase in the mean temperature was relatively lower than in 2022. Nowadays it should thus not be a surprise if there will be more sightings of insects throughout the winter season. Furthermore, warm winter temperatures may wake the insects up during the hibernation process, this is very energy-draining and could cause a depletion of fat stores before spring (Wells et al., 2022). Almost every single one of the solitary bees is also experiencing this interruption (Schenk, Mitesser, Hovestadt & Holzschuh, 2018). In addition to the late hibernation and interruption during is spring also arriving earlier. Thus, the circumstances for winter sleep are ended and insects emerge earlier (Tauber, Tauber & Masaki, 1986). The best hibernation conditions for insects tend to be uniformly cold winters with lots of snow. The second-best option is a very mild winter with little to no freezing (Sheikh, Rehman & Kumar, 2017). Many types of hibernating insects suffer greatly in cold winters with warmer days and warm winters interrupted by intense cold spells (Sheikh, Rehman & Kumar, 2017). Thus, due to climate change pollinators experience a shorter and more unsteady hibernation, with major consequences for their health, life stage and physiology.

b) Lifestage of insects

Pollinating insects' lifespans may be impacted by warmer temperatures brought on by climate change (Scaven & Rafferty, 2013). The window of time during which particular pollinators might obtain the right pollen intake is essentially smaller due to their shorter lifespans. For plants that are non-autogenous and rely on just a few species of pollinators during a brief flowering period, such an effect could be very harmful (Scaven & Rafferty, 2013). Aligning, the life cycle of pollinators with advantageous environmental factors and available resources is crucial. The temperature during the winter affects numerous bee species' emergence dates and body weights (Schenk, Mitesser, Hovestadt & Holzschuh, 2018). Shortened hibernation leads to multiple effects in the development of pollinator insects from larvae to adults (Bradshaw & Holzapfel, 2010). During the winter when the insects are in winter sleep or diapause, they are developing. They need a vast amount of time since spring begins sooner, and they have not achieved the required number of days for their development (Bradshaw & Holzapfel, 2010). For example, insects' vernal development began earlier than expected (Bradshaw & Holzapfel, 2010). Here, the winters were not cold enough to stimulate the process of vernalization. Warmer winter and summer temperatures can cause a shortening in the life span and disturbance the development of many insect pollinator species.

c) Physiology of insects

Climate change is causing external stress on pollinators. One result that originates from this is the disturbance of development during winter sleep. This can lead to alteration in the physiology of insect pollinators (Arce, 2023). One example is a high asymmetry in the wings of bumblebees (Arce, 2023). This asymmetry of the wings is caused by external stress, like weather, during development.

This abnormal development is traced back to 1925 and increased levels of asymmetry were seen alongside the increase in temperature over the decades. When years had more precipitation or had a higher mean temperature the wings were more uneven than in other circumstances (Arce, 2023). Animals need rapid adaptation to "match" their phenology to assure body mass gains and growth, which ultimately increases the likelihood that they will reproduce and survive (Wells et al., 2022). Persisting in healthy physiology is significant for a normal life span in which they can provide enough ecosystem services and maintain biodiversity.

d) Foraging and fat reserve for winter

Gaining enough fat reserve is crucial for animals to survive the winter (Clark & Worland, 2008). Climate change causes multiple hindrances beforehand and during hibernation for insects. Foraging efficiency may be impacted by rising temperatures. Extremely hot weather during the active season may impair a species' ability to regulate its body temperature and cause it to become less active, including when foraging (Kearney, Shine & Porter, 2009). As a result, the daily activity patterns and timing can change due to the thermal restrictions of insect pollinators. Long flights may become uncomfortable due to the heat, which could change the pollen movement (Scaven & Rafferty, 2013). This might prevent gaining sufficient reserve during the winter. Moreover, drying trends could lead to higher levels of individual water stress and/or lower food quality and/or quantity (Wells et al., 2022). Drought can lead to increased mortality of plants and a reduction in the production of nectar and pollen, further exacerbating the challenges faced by pollinators (Goulson et al., 2015). By reducing energy stores and jeopardizing reproduction and survival, these resource constraints have a severe impact on animal foraging opportunities (Fontúrbel, 2021). After winters with warm temperatures, the body weight of bees was dangerously low, because of waking up from hibernation multiple times (see Duration) (Schenk, Mitesser, Hovestadt & Holzschuh, 2018). Bumblebee colonies rely solely on the survival of the queen during hibernation to start a new nest (Fauser, Sandrock, Neumann & Sadd, 2017). Therefore, the queens need to have a peaceful winter sleep. However, they are facing environmental stressors that are forming a threat (Baron et al., 2017). During hibernation, they lose up to 80% of their fat reserve. Just before waking up, with low-fat reserves, they are very vulnerable. Hence, they must have enough fat reserves to make it through the winter and spring for initiating a new colony (Baron et al., 2017).

The morphology of flowers is changing as a result of global warming (Scaven & Rafferty, 2013). It has an impact on the production of floral fragrance, nectar, and pollen (Sagae, 2008). The temperature has been discovered to have an impact on nectar production, content, and concentration (Scaven & Rafferty, 2013). Finally, pollen performance and chemical composition might be impacted by temperature. According to Koti, Reddy, Reddy, Kakani, and Zhao (2005), soybean blooms produced 30–50% less pollen and pollen that was less likely to germinate. Since many bees may need to gather pollen from numerous plants to effectively raise their progeny, decreased pollen production is likely to have an impact on the reproductive success of many bees (Müller et al., 2006). The changes in floral scent and benefits may have an impact on both the likelihood that insects will visit particular flowers and the benefits they receive. In particular for pollinating insects like moths that depend on long-distance cues to locate floral resources, altered floral fragrance emission or volatilization at higher temperatures could affect the detectability of flowers (Yuan et al., 2009). Additionally, flowers can bloom at different times of the day, which might affect how well foragers perform (Scaven & Rafferty, 2013).

e) Adaptations of insects

Particularly during times of increased sensitivity, like the winter hibernation of temperate bumblebees, the detrimental effects of individual stresses or mixtures of different stresses may prevail (Fauser, Sandrock, Neumann & Sadd, 2017). To analyze the effects of the naturally relevant ecological stresses that these bees experience, it is important to look into stresses like pesticides and parasites during these times. Pollinator insects shall have to adapt to the warming climate for their survival. Research has observed three adaptations of insects to changes in the climate (Tougeron, Brodeur, Le Lann & van Baaren, 2020). They can change their phenology to adapt to new seasonal climatic patterns, change their geographic distribution to match their current thermal preferences or adjust their thermal tolerance capacities to match local temperature changes. Modifications in phenology, which are insects' adaptations to climate change, are the most frequently documented effects for insects from temperate and polar regions (Tougeron, Brodeur, Le Lann & van Baaren, 2020). According to studies, insects in these areas migrate and reproduce more frequently, generate more generations each year, and postpone, diminish, or completely forgo diapause expression.

2. Shift in flora and biomes

The seasons are changing, and spring comes earlier every year. In 1999, Menzel and Fabian (1999) found that activities in the spring, like leaf unfolding, have advanced by 6 days, while activities in the fall, such as leaf coloring, have been put off by 4.8 days. This indicates that from the early 1960s, the length of the growing season has increased by 10.8 days on average per year (Menzel & Fabian, 1999). This data is up to 1999, new data including the hottest years have not appeared yet are not recorded (based on available information), these new events further enhance the shifting of the growing season. The physiology of flowering plants is known to be impacted by elevated temperatures, particularly in spring, in a variety of ways, leading to altered flower, nectar, and pollen production (Scaven & Rafferty, 2013). In terms of insect pollination, warming may have an impact on foraging behavior, mature body size, and lifespan. The relationships between plants and pollinators may be affected differently by these physiological reactions. Other effects of global climate change, such as increased carbon dioxide levels and modified precipitation patterns, may potentially have an indirect or direct impact on plant and insect physiology (Scaven & Rafferty, 2013). Which then again can alter the forage and reproduction activity.

Multiple species of flowers in Europe are going through a phenological shift. The paper of Jentsch et al., (2009) found that gradual warming for ten years has the same effect as severe droughts and heavy rain in one year. These extreme weather events are shifting the mid-flowering date by 4 days and the length of flowering was altered by 4 days (Jentsch et al., 2009). When heavy rainfall occurred, the flowers bloomed shorter. One must point out that for every species, droughts and extreme rainfall the altering in the blooming were different. The phenological mismatch is a significant limiting factor for spring ephemeral reproduction, according to relationships between flowering initiation time, phenological mismatch, and seed-set success (Kudo & Ida, 2013). The changes themselves are negative, however, the desynchronization with pollinators could be detrimental. According to Memmott et al. (2007), if plant phenology advances by as little as 1-3 weeks, between 17% and 50% of all pollinator species will experience a disruption in their ability to obtain food. Evidence from the Netherlands suggests that plant species that rely on insect pollination are seeing severe losses in both insect biomass and overall plant diversity (Biesmijer et al., 2006).

Because of climate change, the natural biomes are shifting to higher altitudes (Kerr et al., 2015). The average temperature is rising, and this provides a shift in natural landscapes. Flora and fauna are also following this pattern and migrating along this changing trend. Many species will be unable to track their climate niche as it shifts in a warming climate (Shukla et al., 2019). This is especially bad for species in large, flat landscapes like the Netherlands since they have limited ability to disperse (Shukla et al., 2019). The European bumblebees are expanding gradually along the northern shift and are therefore losing habitat in the south (Kerr et al., 2015). The maximum rate at which many pollinator groups can colonize new locations is predicted to be exceeded by the rate of temperature shift over the landscape (Vanbergen & Initiative, 2013). A consequence of this shift is that there is a lack of overlap in their usual habitat. This shift in seasonal activities changes the flora and fauna and could highly possibly cause food stress for pollinators. Food stress can cause diminished fat reserve for the winter and is thus forming a hazard to the hibernation of insect pollinators.

3. Shift in agriculture

Pollination is considered a key ecosystem service (Klein et al., 2007). In the literature review, it was made clear that pollination has economic-, health-, and environmental benefits. Agriculture is important for the economy and health. The total production of crops dependent on pollinators in the Netherlands is 31.9%, in 2019, and 5% of the agricultural GDP, in 2009 (no recenter numbers found) (Lautenbach et al., 2012; Porto et al., 2020). The value per hectare in $ in the Netherlands of agriculture ranges from 26-250$ (Lautenbach et al., 2012). Therefore, a loss of pollinators will cause an economic loss and result in job displacement for humans.

Moreover, there is enough evidence that connects pollinators, food security and climate change (Marshman, Blay-Palmer & Landman, 2019). Therefore, a decline in pollinator richness can cause distress for food among humans. Especially since they are important for pollinating over 25 very important crops (e.g., tomatoes, zucchinis, sunflower oil, and strawberries) (Bonmatin et al., 2015). In such a scenario, there is a risk of an unbalanced diet for humans, as they require a diverse range of crops to obtain an adequate intake of essential vitamins and nutrients (Bouis, Chassy & Ochanda, 2003). Furthermore, monocultures are vulnerable since they depend too much on a particular type of pollinator (Marshman, Blay-Palmer & Landman, 2019). The potential for disease or pest resistance, which could lead to the loss of the entire crop or colony, is enhanced when relying on any monoculture.

Limitations

During this research, multiple limitations were distinguished. The main import limitation was the niche of the scope that was taken on for this research. There has been a sufficient amount of research conducted on climate change and its effect on pollinators, but not in combination with their hibernation period. If so, the research conducted was short-lived and the suggestion for this is to extend the research on climate change effects on hibernation over a decade. Furthermore, this topic should be more explored since it is highly important for ecosystems and humankind. Another limitation is the scale of this research. The literature focused more on the hibernation of pollinators in general or in Europe and therefore more assumptions needed to be made during the discussion. This might again not be transferable to other countries. As mentioned in the discussion, there is a gap in research on beetle and moth pollinators. This resulted in a concentration on bee and butterfly species and how climate change affected them. An additional limitation is that within the scope of the current study, solely academic literature was reviewed. No empirical data was used in this research, which could be considered valuable for future research and more narrow information about the specific area. One more limitation that needs to be considered is the selection and exclusion of research articles. As a result, it is possible that crucial information was left out of the literature review.

Conclusion

In this paper the hibernation of insect pollinators in the Netherlands has been researched and how climate change and increasing temperatures affect this phenology. A systematic literature review was conducted to investigate this. Due to this, it became possible to address and analyze the crucial aspects comprehensively. The primary findings that were uncovered touched up on the shift of pollinators' activity, transition in flora and biomes and transformation in agricultural practices. The evidence was clear: several factors have induced alterations in the behavior of pollinators, exerting significant influence on their pre-hibernation and hibernation processes, which are crucial for their survival. As a result of this disturbance, the animals' experience reduced fitness and impaired health. Additionally, the modification of flora and the shifting of biomes pose a threat by disrupting their natural phenology. They will encounter more intense heat during summers and experience reduced availability of food resources. The consequences of pollinators underperforming in their natural habitats have profound implications for agriculture, resulting in reduced crop productivity and imbalanced human diets. Consequently, rising temperatures disrupt their entire physiological systems and natural behaviors, potentially leading to a decline in pollinator populations in the future. Hence, it is crucial to conduct further in-depth and long-term studies to explore the significance of insect pollinator hibernation and develop strategies to preserve this critical ecological practice. Recognizing the paramount importance of pollinators, these studies will help inform conservation efforts and safeguard their crucial role in ecosystems.

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