# Drivers of change of butterfly populations

Butterflies are excellent indicators of environmental change due to their rapid and sensitive responses to subtle habitat or climatic changes, and as representatives for broader biodiversity.

## Weather

Short term changes in butterfly populations are often driven by the weather. Butterflies, like other insects, are ectothermic – often referred to as ‘cold-blooded’ – and need the sun’s energy to raise their body temperature to a level that enables them to function. Weather can have a multitude of direct and indirect effects and can affect different species in different ways (Roy et al 2001). The impact of weather is influenced by factors such as the timing of the species flight period, how many generations are produced in a year, and in what life stage the butterfly overwinters (i.e. as adult, egg, caterpillar (larva) or pupa). Consequently, what could be considered to be good conditions for one species can be less favourable or even detrimental for another. Adverse weather conditions can result in a large drop in butterfly numbers. While butterflies can bounce back from the impacts of unsuitable weather, they can take a long time to recover from a run of adverse weather years.

Winter temperatures and rain levels can have an important influence on survival rates. A mild and wet winter typically has negative consequences for butterflies, for example, overwintering eggs or caterpillars may become flooded and die, unseasonal plant growth may impact the microclimate of overwintering caterpillars (Klop et al 2015, WallisDeVries & van Swaay 2006), and their pathogens and predators may be a greater threat as they experience better survival or become more active. Weather can impact on the flight periods, for instance advancing or delaying the season of spring-emerging species, sometimes significantly. However, if the weather gets too warm too early in the year overwintering adults may wake up and die as they waste their energy at a time of the year when no nectar is available to sustain them.

During spring and summer, the sun’s energy enables butterfly lifecycle development to continue; overwintering adults wake up, eggs hatch, caterpillars develop and pupate, and new adults emerge. Cold and wet weather tends to reduce butterfly activity and can affect caterpillar growth and survival (Kamata & Igarashi 1994). Warm but damp weather in the spring can also negatively impact the development of caterpillars, because the resulting abundant plant growth leads to microclimate cooling, particularly in nitrogen rich areas (WallisDeVries & van Swaay 2006). Spring developing species that overwinter as eggs or larvae have been shown to be significantly affected by this phenomenon, while pupa or adult wintering species are not (Fischer & Fiedler 2000). Temperature and the amount of rain and sunshine also affects the availability of butterfly food sources – both larval food plants and nectar sources for adults. Studies have shown that nectar production in many flowers is significantly higher in sunny and in dry weather (Lack 1982, Benedek et al 2000, Pleasants 1983). However, while butterflies generally benefit from warm and dry spring/summers, drought conditions can cause early plant senescence, which can reduce caterpillar food availability by reducing plant growth or shorten the flowering season and hence nectar availability for adults.

## Climate change

The predicted longer-term changes in weather patterns as a result of climate change (e.g. an increase in extreme events such as very hot, dry summers) will undoubtedly impact butterfly populations, and indeed some indications of change are already being observed (Pearce-Higgins et al 2015, McDermot Long et al 2016, Oliver et al 2015). As different butterfly species respond to weather-effects in different ways, climate change impacts will also be species dependent, with some impacts being positive, and some negative. Climate change can impact where species are found, their population sizes, and the timing of their lifecycles.

The date of emergence of spring-flying species has been getting progressively earlier in recent decades, strongly linked to increased winter and spring temperatures. It is estimated that adults emerge, on average, 6.4 days earlier per 1°C increase in spring temperatures (Roy et al 2015). As a result, a number of single-brooded species are now able to produce a second brood in warm years, and this is increasingly observed at monitored sites. For example, Wood White now regularly produces a second brood at most sites where it is monitored, whereas when the monitoring started in 1979, this was a much rarer occurrence. There is a lot of between-species variation, with those species with narrow larval diet breadths, more advanced overwintering stages and smaller ranges tending to show the greatest advancement in their date of first appearance (Diamond et al 2011). A longer flight period is generally good news for butterflies, but there may be complications; meta-analyses have shown that butterflies may be advancing their seasons at different rates to both their food plants and their predators (Thackeray et al 2010). There may be negative impacts if butterfly species become active before their food sources are ready. The potential mismatch in timings between different trophic levels can also cause issues higher up the food chain, as caterpillars are an important food source for many small birds. Any benefits of an earlier season may also be negated if the climate also results in plants and flowers dying earlier than they used to, bringing a corresponding earlier end to the flight season.

In recent years we have being seeing that species traditionally found in the UK’s warmer southerly climes, for example Orange-tip and Peacock, have become more abundant in Scotland. Also, species that migrate to the UK from more southerly regions, such as red admiral and clouded yellow, now regularly successfully overwinter in the UK to produce a resident population. However, the potential for northward range expansion for butterfly species is likely to have more limited scope than generally thought because of interplay between a number of factors that affect butterfly survival and dispersal (Pelini et al 2009). A recent study indicated that climate envelope models overestimate the positive effects of climate change on north-west European butterflies. It is no use to butterflies if areas further north become hospitable to them if they can’t get there due to a lack of suitable habitat stepping stones (Heikkinen et al 2010). Roy et al (2015) showed that adaptation on local and regional scale is likely to be determined by multiple mechanisms, making butterfly populations more sensitive to future climate changes than currently thought. Overall, habitat specialist species are likely to be more vulnerable to climate change (especially in drought-susceptible habitats), and well less equipped to colonise new suitable regions, than widespread habitat generalist species (WallisDeVries et al 2011).

## Habitat related drivers

Habitat loss and degradation, and changes in habitat management, continue to be major drivers of change in UK butterfly populations, often resulting in population decline and/or range contraction.

The UK has seen major changes in land use since the UKBMS started in the 1970s, and the preceding decades and centuries. For example, over the past few hundred years 85% of heathland covering the Tertiary soils in Southern England has been lost, in particular by conversion to conifer plantations, arable land or urban sprawl (Moore, 1962; Thomas and Webb, 1984).

Wide-scale agricultural intensification has had a big impact on wildlife, with bigger fields and hence less wildlife-friendly margin habitat, and a greater use of herbicides and fertilisers. This has resulted in much fewer wild flowers, meaning less nectar sources for butterflies and a decline in some larval food plants. There is a strong correlation between the decline of Lepidoptera species during recent decades and increasing intensification of agriculture in Western and Central Europe (Habel et al 2019). There is a long-established link between herbicide use and reduction in butterfly abundance (Rands & Sotherton 1986). Establishing conservation headlands and unsprayed field margins (Dover et al 1990, Longley & Sotherton 1997, Cole 2007) has been shown to help butterflies and other beneficial insects. Management methods to benefit butterflies and other pollinators remain a part of environmental and countryside stewardship schemes (e.g. Natural England 2009). Fertilisers have also been shown to have the potential of a negative impact on some butterfly species (Kurze et al 2018).

Many semi-natural habitats in the UK depend on regular management to maintain their distinctive features that their component species rely on. A decline in traditional management activity can impact habitat quality, or even cause loss of that habitat completely due to vegetation successional change. Lowland heathlands, the habitat of the Grayling butterfly (a declining species), has traditionally been managed by grazing, controlled burning and the collecting of bracken and gorse. In a review of Dorset heathlands, Moore (1962) reported steep declines in management practices, so that by 1959–1960, only 6% of the total area of heathland was grazed by stock, whilst 8% underwent controlled burns. These practices have now largely ceased and now if any management exists, it is likely to be at sites managed for conservation purposes.

Habitat connectivity is key to a species being able to disperse to new sites, their ability to recover after population crashes (e.g. caused by extreme events such as drought) and their ability to respond to conservation management (Oliver et al 2012, Oliver et al 2015). This means that loss of habitat can have a disproportionately negative effect, as it can also increase habitat fragmentation. Colonisation can take several years after an area of habitat has been restored, especially by species that are less mobile or are dependent on localised larval host plants (Woodcock et al 2012). This is particularly pronounced in fragmented habitat.

## Pesticides and pollution

Alongside the habitat mediated effects of agricultural intensification, the accompanying use of pesticides may have direct toxicity impacts on butterflies. Ongoing and future research into the effects of pesticides is an area of research where monitoring data is likely to help determine the extent to which butterflies are affected by farmland chemicals. While much of the research into the impact of pesticides on beneficial insects has concentrated on bees, recent studies in the UK and in Europe have shown a correlation between butterfly declines and application of neonicotinoids (Gilburn et al 2015, Forister et al 2016, Basley & Goulson 2018).

Very little research exists on direct effects of pollution on lepidoptera, but there are recent studies on indirect effects mediated by changes to habitat, such as availability and quality of caterpillar food plants. Nitrogen deposition is often considered a major threat to biodiversity and ecosystem functioning. This nutrification can come from both airborne pollution and from application of fertilisers. Nitrogen deposition from air pollution causes nutrification that can result in significant changes in species composition and other habitat characteristics in low-nutrient ecosystems (Weiss 2001) such as species-rich low-nutrient grasslands. Such nutrification can cause rapid invasion by annual grasses that crowd out larval foodplants, resulting in population decline of butterfly species that depend on those plants. Nutrient mediated changes to plant growth can also result in microclimate cooling in the spring. This is thought to have contributed to recent declines of species such as the wall brown whose caterpillars depend on warmer microclimates as they develop in the spring (Klop et al 2015). In terms of the direct impact of nutrient levels within caterpillar foodplants, the picture is complicated and seems to be species dependent. Some species, often habitat generalists, seem to benefit and can be considered to be pre-adapted to higher nitrogen content in their food plants (Kurze et al 2017). Studies have found that caterpillars of such species feeding on fertilised plants have higher survival rates, shorter larval periods and heavier pupae. However, for other species there seems to be a mixed or negative impact. In one continental study involving the sooty copper, the benefit of a higher caterpillar growth rate at high nitrogen levels was more than cancelled out by high pupal mortality and reduced adult size (Fischer & Fiedler 2000). Further studies would be needed to establish how widespread this response is among declining UK butterfly species.

Doubling of CO2 levels from ambient levels has been found to reduce the amount of nectar produced per flower in some plant species and increase in others (Erhardt et al 2005), and to alter the amino acid composition in many plant species (Rusterholtz et al 1998) that have been tested. This has the potential to impact food availability for adult butterflies.

Exposure to toxins from haze smoke generated by forest fires has been shown by Tan et al (2018) to increase caterpillar mortality with negative effects on growth evident from direct and indirect exposure, emphasising the need to examine whether other forms of air pollution widespread in the UK have similar effects.

## Conservation action

Landscape scale conservation efforts can play an important role in improving the fortunes of declining butterfly species. As our understanding of butterfly ecology increases, conservationists have been able to restore suitable habitat to help many declining species. This is especially the case for species with very specific habitat requirements or poor powers of dispersal, and where the appropriate conditions may often rely on active habitat management. Such species can respond well to targeted conservation habitat management. Woodland coppicing to create more open areas that can support butterfly food plants has been successfully carried out for the Heath Fritillary, and establishing a sympathetic grazing regime has helped the Adonis blue and silver-spotted skipper. Management of unimproved grassland has enabled the re-introduction and subsequent establishment and spread of the endangered Large Blue.

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