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Using a phenological network to assess weather influences on first appearance of butterflies in the Netherlands

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ABSTRACT

Phenological responses of butterflies to temperature have been demonstrated in several European countries by using data from standardized butterfly monitoring schemes. Recently, phenological networks have enabled volunteers to record phenological observations at project websites. In this study, the quality of the first appearance data of butterflies from the Dutch phenological network 'De Natuurkalender' was examined and these data were then used to analyze trends in butterfly appearance between 2001 and 2013, the effects of climatic factors on appearance of butterflies as well as the phenological interaction of one butterfly species, *Anthocharis cardamines*, and its two major host plants. Although phenological networks are relatively unstructured, this study shows that data from De Natuurkalender were highly comparable to more standardized data collected by the Dutch Butterfly Monitoring Scheme. No trend in first appearance of any butterfly species was found during the time period 2001–2013. The first appearance dates of most butterflies showed, however, a clear relationship with spring temperature. Higher temperatures, especially in March and April, advanced the first appearance of butterflies. Therefore, with climatic warming in the future, earlier appearance of butterflies is expected. Although climate warming is a potential threat for phenological mismatches between different trophic levels, this study shows a similar temperature response of *A. cardamines* and its main host plants in the Netherlands. However, as only few phenological interactions between species are examined, further research including rarer monophagous butterfly species and their host plants is needed.

1. Introduction

During the last decades, phenological changes in response to global warming have been observed in birds, plants and insects (Parmesan and Yohe, 2003). In butterflies, advancements in first appearance and extension of flight period have been demonstrated for many species in Europe (Brakefield, 1987; Pollard, 1991; Sparks and Yates, 1997; Roy and Sparks, 2000; Stefanescu et al., 2003; Karlsson, 2014) and America (Forister and Shapiro, 2003; Westwood and Blair, 2010). Earlier appearance of butterflies is linked to increasing spring temperature, reflecting climatic change (Roy and Sparks, 2000; Stefanescu et al., 2003). Data from standardized butterfly monitoring programmes have enabled analysing and predicting responses of single species to temperature (Sparks and Yates, 1997; Roy and Sparks, 2000). The magnitudes of these responses differ between butterfly species, leading to an advancing appearance between 1 and 10 days per degree Celsius increase in Britain (Roy and Sparks, 2000). As butterfly species are dependent on the availability of their host plants, both their phenologies should match under varying climatic conditions. Whether differences in responses to temperature among species cause phenological asynchrony in interactions at different trophic levels remains unclear, as both examples of matching and mismatching phenology in insect species have been observed (Visser and Both, 2005).

Up till now, population trends and phenological responses of butterflies with regard to environmental and climatic factors have mainly been studied by using data from old databases and, especially, from butterfly monitoring schemes (Pollard et al., 1995; Sparks and Carey, 1995; Roy and Sparks, 2000; Roy et al., 2001; Stefanescu et al., 2003; van Swaay et al., 2008). These standardized monitoring schemes were first set up in Britain in 1973 (Pollard, 1977). Since then, similar programmes have been introduced in other European countries, as the Dutch Butterfly Monitoring Scheme (DBMS) in the Netherlands from 1990 onward (van Swaay et al., 1997, 2008). More recently, projects have been set up which

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aim to collect phenological observations from a range of species groups, including birds, plants and butterflies. These phenological networks have enabled the citizen scientists to record single phenological observations at websites, such as Nature's Calendar in Great-Britain and 'De Natuurkalender' (Nature's calendar) in the Netherlands (Whitfield, 2001; van Vliet et al., 2003; Lawrence, 2009). Besides the production of a large volume of phenological observations, phenological networks have raised public awareness for climate change and its impact on shifting phenological events in nature (van Vliet et al., 2003). Since the start of De Natuurkalender in 2001, the large annual variation in timing of phenological events of butterflies, birds, amphibians, dragonflies and plants in response to extreme climate conditions have led to hundreds of interviews for newspapers, radio and television programmes (van Vliet et al., 2014). However, of De Natuurkalender observations, only the impact of weather on the timing of plant phenological events has been scientifically documented in the Netherlands (van Vliet et al., 2013). A full analysis of the butterfly phenological data in combination with climate data has been lacking so far. Furthermore, there is a need to better quantify the data quality of volunteer phenological networks like De Natuurkalender as the observation methodology is less structured than, for example, the Butterfly Monitoring Schemes. Data in phenological networks might be biased by differences in interpretation of phenological events between participants (Whitfield, 2001). Furthermore, the unstructured phenological networks potentially generate a larger spatial and temporal variation from year to year in the number of volunteers reporting observations. As only the first appearance is reported, no information is available on how frequently the volunteers made the observations.

In the face of both these opportunities and potential shortcomings, the main objective of this study is to quantify the quality of first appearance observations of butterflies in the Dutch phenological network and to increase our understanding of how climatic factors influence the first appearance of butterflies and their synchrony with the development of host plants. Thus, we addressed the following research questions:

1. Do the phenological observations of the Dutch phenological network correlate with the timing of observations made in the Dutch Butterfly Monitoring Scheme?
2. Are there significant trends in butterfly first appearance during the years 2001–2013?
3. How can the annual variation in timing of the first appearance of butterflies be explained by weather variables?
4. How does the variation in the first appearance of butterflies correlate with the timing of the first flowering of their host plants?

2. Materials and methods

2.1. Butterfly data

2.1.1. De Natuurkalender

Since 2001, over 8000 participants have recorded the timing of phenological events of butterflies, birds, plants and other species groups in De Natuurkalender project. From the start, the project has been promoted in the media, especially in the national radio programme VARA's Vroege Vogels (Early Birds), by which many recorders have signed up to participate in the project. The participants were instructed to record their annual first observations preferably on a location which they visited daily. The phenological observations were submitted via the internet (www.natuurkalender.nl), via telephone or via sending in paper forms. Although a total of 27 butterfly species were included in De Natuurkalender programme, seven species were excluded in this study for several reasons: not enough observations (less than 10 years with more than 15 observations), hard to recognize or their first appearance observations were reported year-round. In multivoltine species, only observations comprising the first generation were used. Years for which a species had less than 15 observations were excluded from the analysis. In total, the De Natuurkalender data analyzed included more than 22,500 first appearance observations of butterflies from 2001 till 2013. The number of observations per species ranged from 228 in *Callophrys rubi* to almost 3500 in *Gonepteryx rhamni*. As a measure of first appearance the median date of the observations was determined for every year for every species. The median date of first appearance observations has been commonly used as phenological measure and is not likely to be influenced by annual variations in number of observations (van Strien et al., 2008). The median data series of all butterfly species followed a normal distribution, which was tested by using the Shapiro–Wilk test ($p > 0.05$ for all species) (Shapiro and Wilk, 1965) and evaluating Quantile–Quantile plots on sight.

2.1.2. Dutch butterfly monitoring scheme

Data from the DBMS were used to examine whether the data from De Natuurkalender was comparable with data from a more standardized butterfly monitoring scheme. In the DBMS, butterflies were counted about weekly on fixed walking transects of maximally one kilometre long during the butterfly flight season. Butterfly counts were only performed under favourable weather conditions and only between 1 April and 30 September. During transect walks, butterflies were only counted within a limited range from the observer. In the Netherlands, about 700 of these transects were annually counted in the period of study (van Swaay et al., 2008). The same transects were monitored during multiple years, resulting in highly standardized data series. A detailed description of the outline and procedures of the DBMS is described elsewhere (van Swaay et al., 2002, 2011). In this study, three different phenological measures from the DBMS data were used to compare the first appearance of 16 butterfly species with the De Natuurkalender data between 2001 and 2013. The first phenological measure comprised the median date of first appearance observations on the DBMS transects of a species in a year, taking only first generation butterflies into account. The second and third measure confined the dates at which the first 2.5% and first 10% of butterfly individuals were observed, taking into account all observations of first generation butterflies on all monitoring routes. The latter two phenological measures were included as they are not affected by annual differences in butterfly population abundance (van Strien et al., 2008).

2.2. Weather data

Both temperature and precipitation data were provided by the Royal Netherlands Meteorological Institute (www.knmi.nl). For temperature, the Central Netherlands Temperature was used. The Central Netherlands Temperature is an average temperature based on measurements of several weather stations located centrally in the Netherlands, and therefore representative to a larger area when compared to temperature data from a single weather station (van der Schrier et al., 2011). As no such measure exists for rainfall, precipitation data were provided by weather station De Bilt, located in the centre of the Netherlands.

2.3. Analysis

2.3.1. Comparison of De Natuurkalender and DBMS

The median first appearance date from De Natuurkalender was compared with all three phenological measures of the DBMS. As the DBMS transects are only monitored between 1 April and