



Climate-induced changes in the microlepidoptera fauna of the Netherlands and the implications for nature conservation

Johan H. Kuchlein and Willem N. Ellis

Tinea Foundation, c/o Institute for Systematics and Population Biology (Zoological Museum), Department of Entomology, Plantage Middenlaan 64, 1018 DH Amsterdam, the Netherlands

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We summarize the results of our studies of the changing patterns in phenology and distribution of microlepidoptera in the Netherlands. There is a strong dynamic effect, related to changing climate. In a sample of 104 common microlepidoptera species the date of the flight peak has receded by 11.6 days in the period 1975–1994. We also found changes in the species composition of the local fauna, although not necessarily in the number of species. Our findings imply that the number of rare (Red List) species may be an inappropriate parameter for the conservation value of a site.

Keywords: climatic change; faunal dynamism; Netherlands; Red Lists.

Introduction

It has long been recognized that climate and weather can have a considerable effect on animal populations. Climatological factors influence animal abundance, distribution and phenology. They are sometimes held responsible for insect outbreaks as well as for the control of insect numbers. Weather conditions change continuously, but climate is also subject to oscillations and trends. Of the many influences to which the Lepidoptera fauna is currently exposed, climatic change is certainly the most pervasive. Even the few pockets of landscape that have remained more or less free from human disturbance cannot escape from this phenomenon. Whether the recent changes in climate are a result of man-made alteration of the composition of the atmosphere has been a moot point for some years, but is now more generally accepted (Woiwod, 1997). In the present paper we will focus, first, on the magnitude and generality of phenological and distributional changes of microlepidoptera; secondly, on the relationship between these shifts and climate change; and finally, on the implications of these findings for the conservation management of microlepidoptera in particular, and terrestrial invertebrates in general.

Our study will be directed towards the microlepidoptera of the Netherlands. The Tinea Foundation maintains an extensive database containing faunistic and phenological data of all moth species throughout the country. The database, which is actively kept up to date, comprises approximately 340 000 records, cover-

ing a time span from about 1850 to the present day, and a total of nearly 1400 microlepidoptera species. This data bank enables us to deal with a great variety of ecological problems.

Phenological changes

Many organisms, including insects, respond to a rise in temperature by acceleration of the rate of development as long as temperature remains below lethal values. They may live for shorter periods, and are more active. One of the possible effects of warmer seasons is the production of extra generations, for instance three instead of two per year. In a recent analysis, we examined whether the timing of the peak of the first generation for 104 common species has tended to occur earlier (Ellis *et al.*, in press a) (Table 1). For each species, the yearly flight peak (Julian) dates were calculated (excluding years when the number of observed specimens was below 30). For each species, peak dates were standardized to a value D by subtracting from the observed peak dates the average peak date over all years. The results show that, during the period 1976 to 1994, the flight peak shifted to a date that is on average 11.6 days earlier (Fig. 1). This shift seems to be primarily associated with a rise in spring temperatures (April–June; Fig. 2); the effect of summer temperature appears to be much more limited. There can be little doubt that this shift in phenology of the smaller moths is related to the recent warming of the climate.



Table 1. List of the species used as the basis of our calculations, with the number of usable observation years and the mean Julian peak date (nomenclature follows Kuchlein and Donner, 1993)

species	n	peak date	species	n	peak date
Adelidae			Pyralidae		
<i>Adela reaumurella</i>	17	132	<i>Agriphila inquinatella</i>	25	219
<i>Nemophora degeerella</i>	15	162	<i>Agriphila straminella</i>	44	204
Bucculatricidae			<i>Agriphila tristella</i>	36	218
<i>Bucculatrix ulmella</i>	7	133	<i>Anerastia lotella</i>	11	183
Choreutidae			<i>Aphomia sociella</i>	14	160
<i>Anthophila fabriciana</i>	12	168	<i>Cataclysta lemnata</i>	16	173
Coleophoridae			<i>Catoptria margaritella</i>	12	192
<i>Coleophora laricella</i>	13	157	<i>Chilo phragmitella</i>	24	179
<i>Coleophora serratella</i>	14	182	<i>Chrysoteuchia culmella</i>	44	179
Elachistidae			<i>Crambus ericella</i>	7	201
<i>Elachista apicipunctella</i>	3	127	<i>Crambus lathoniellus</i>	35	166
<i>Elachista cerusella</i>	13	154	<i>Crambus pascuella</i>	21	181
Gelechiidae			<i>Crambus perlella</i>	36	187
<i>Aristotelia ericinella</i>	7	200	<i>Elophila nymphaeata</i>	21	177
<i>Exoteleia dodecella</i>	10	184	<i>Endotricha flammealis</i>	19	204
<i>Neofaculta ericetella</i>	10	144	<i>Eurrhyncha hortulata</i>	25	153
<i>Teleiodes proximella</i>	8	162	<i>Evergestis forficalis</i>	23	155
<i>Teleiodes vulgella</i>	1	185	<i>Hypsopygia costalis</i>	21	176
Gracillariidae			<i>Metriostola betulae</i>	10	175
<i>Caloptilia alchimiella</i>	18	145	<i>Numonia advenella</i>	16	216
<i>Phyllonorycter harrisella</i>	10	143	<i>Ostrinia nubilalis</i>	14	188
<i>Phyllonorycter quercifoliella</i>	9	133	<i>Phycita roborella</i>	22	211
Incurvariidae			<i>Pleuroptya ruralis</i>	28	210
<i>Incurvaria masculella</i>	10	135	<i>Pyrausta aurata</i>	16	146
Nepticulidae			<i>Schoenobius forficella</i>	19	191
<i>Ectoedemia albifasciella</i>	8	157	<i>Scoparia ambigualis</i>	24	172
Oecophoridae			<i>Synaphe punctalis</i>	17	201
<i>Batia lunaris</i>	6	175	Tischeriidae		
<i>Batia unitella</i>	6	198	<i>Tischeria ekebladella</i>	9	162
<i>Carcina quercana</i>	21	214	Tortricidae		
<i>Denisia stipella</i>	1	146	<i>Agapeta hamana</i>	81	190
<i>Diurnea fagella</i>	19	100	<i>Aleimma loeflingiana</i>	17	181
<i>Diurnea phryganella</i>	3	307	<i>Ancylis achatana</i>	8	178
<i>Ethmia funerella</i>	6	174	<i>Ancylis mitterbacheriana</i>	10	154
<i>Pleurota bicostella</i>	8	164	<i>Apotomis betuletana</i>	20	219
<i>Stathmopoda pedella</i>	5	193	<i>Archips podana</i>	27	186
Plutellidae			<i>Archips xylosteanana</i>	26	191
<i>Plutella xylostella</i>	31	144	<i>Bactra lancealana</i>	12	161
Pterophoridae			<i>Capua vulgana</i>	14	146
<i>Platyptilia gonodactyla</i>	0	-	<i>Celypha striana</i>	15	188
<i>Pterophorus pentadactyla</i>	9	182	<i>Choristoneura hebenstreitella</i>	5	164



Table 1. Continued

species	n	peak date	species	n	peak date
<i>Clepsis consimilana</i>	12	185	<i>Olethreutes arcuella</i>	3	162
<i>Clepsis spectrana</i>	19	166	<i>Olethreutes bifasciana</i>	8	187
<i>Cydia pomonella</i>	23	171	<i>Olethreutes lacunana</i>	24	173
<i>Cydia splendana</i>	18	200	<i>Olethreutes schulziana</i>	12	157
<i>Epiblema cynosbatella</i>	3	175	<i>Pandemis cerasana</i>	26	179
<i>Epiblema rosaecolana</i>	11	179	<i>Rhopobota naevana</i>	13	207
<i>Epiblema uddmanniana</i>	13	181	<i>Tortricodes alternella</i>	14	82
<i>Epinotia bilunana</i>	4	169	<i>Tortrix viridana</i>	30	176
<i>Epinotia immundana</i>	11	135	<i>Zeiraphera isertana</i>	17	195
<i>Epinotia nisella</i>	1	236	Yponomeutidae		
<i>Epinotia solandriana</i>	6	206	<i>Argyresthia bonnetella</i>	4	196
<i>Epinotia tedella</i>	6	152	<i>Argyresthia brockeella</i>	11	180
<i>Epinotia tetraquetra</i>	5	139	<i>Argyresthia conjugella</i>	10	160
<i>Eucosma cana</i>	13	188	<i>Argyresthia goedartella</i>	19	211
<i>Eupoecilia angustana</i>	5	180	<i>Argyresthia pruniella</i>	7	189
<i>Gypsonoma dealbana</i>	14	190	<i>Argyresthia retinella</i>	13	180
<i>Hedya dimidioalba</i>	25	178	<i>Yponomeuta evonymella</i>	23	200
<i>Lathronympha strigana</i>	11	171	<i>Yponomeuta sedella</i>	3	127

Distribution and abundance

Distribution limits

Lack of correlation with plant distribution. The great majority of microlepidoptera are herbivores, and cannot maintain populations outside the range of their host-plants. Nevertheless, the ranges of micros and their foodplants rarely coincide completely because generally the micros do not occur in large parts of their host-plant's range. Evidently the factors limiting plant distributions often differ from those limiting distributions of the moths. This non-coincidence of the distributions of microlepidoptera and their foodplants can be illustrated from the Netherlands which is divided by botanists into ten phytogeographical districts (Van Soest, 1929). Only in a small minority of cases do distributions coincide with one or more of these phytogeographical districts (Kuchlein and Donner, 1993).

Determination by climate factors. For 439 species of microlepidoptera (31% of the fauna), there is a geographical limit which crosses the Netherlands (Kuchlein and Donner, 1993). These limits generally show a NE-SW trend. Similar trends that run more or less parallel to the coastline are apparent in most climatological isolines (e.g. isotherms) in the Netherlands (Westhoff *et al.*, 1970; Anonymous, 1972). The

similarity between range borders and climatic isolines suggest that climatological factors often limit the distribution of these species.

The role of climatic factors in the control of insect abundance: the 'density-dependent' versus 'density-independent' debate, has been a controversial subject for more than 70 years (Antonovics and Levin, 1980; McIntosh, 1987). However, the opponents in this debate agree that the range of animals is generally determined through the operation of climatic factors. This does not necessarily mean that these factors affect the animals directly: they may also operate through the foodplant or through a differential influence on competitors.

Populations at the edges of their range. For butterflies it has been found that species tend to occupy relatively narrow, transient and more isolated niches close to the border of the species' range; populations here are also inherently less stable (Thomas, *et al.*, 1994). This agrees with theoretical predictions made by Zeegers (1991). From several other investigations into insect populations at the edges of their range, it is known that abundances are determined nearly exclusively by climatic factors, which explains the unstable character of these populations (Birch, 1957; Randall, 1982; Inkinen, 1994). Even species that throughout most of their range are K-selected and regulated by density-

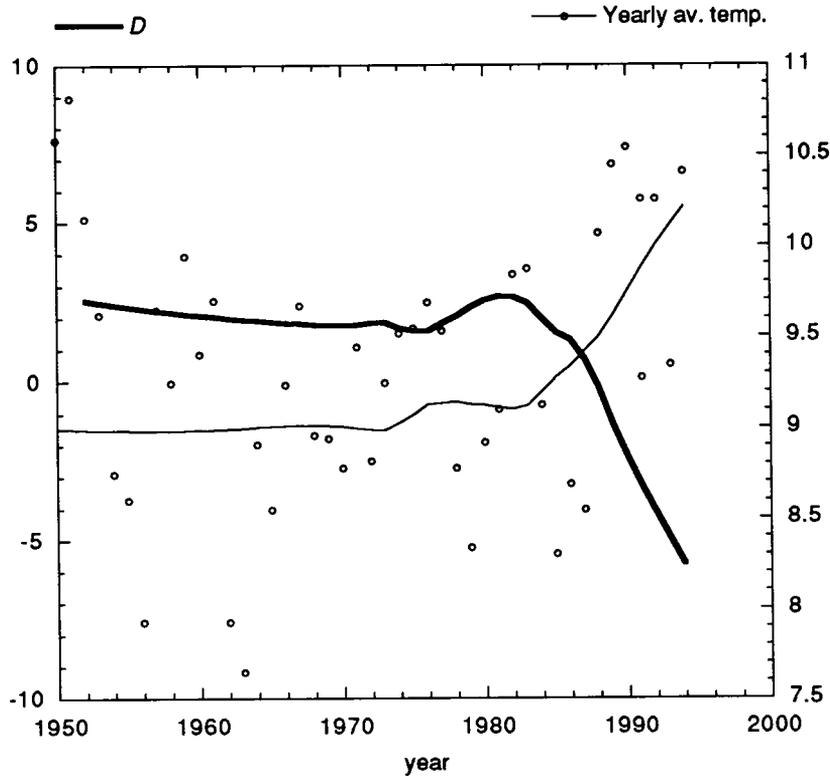


Figure 1. Trend lines of the values of D of all species (heavy line, left axis; the 1490 individual data points not shown), and of the yearly average temperatures in the Netherlands ($^{\circ}\text{C}$, thin line, right axis) in the period 1950–1994. (Trends are calculated using the locally weighted least square error method; smoothing factor 66%; reproduced from *Entomologische Berichten*, Amsterdam, with permission).

dependent factors, become r -species at the edges of their range (Klomp, 1962).

Species richness

To get an impression of any changes in species richness during the last 150 years, the data were divided into three periods, 1850–1899, 1900–1949, and 1950–1995. During these intervals, 1024, 1093, and 1297 species were recorded respectively (Kuchlein *et al.*, in press). A statistical comparison of these numbers would require an analysis of the number of records per species for each of these periods (Krebs, 1989), yet there is little point in such an exercise, because both the methodology of collecting and the philosophy of collectors and owners of collections has changed strongly in the course of this period. However, the data do not indicate a clear decrease in the number of species in the last 150 years. An alternative approach reached the same conclusion (Table 2). Nevertheless, the actual species composition of the fauna has changed considerably as a result of colonization and extinction and examination of the data suggests that the number of coloniza-

tions exceeds the number of extinctions (Kuchlein and Donner, 1993).

Distributional changes

In ecology, relatively little attention has been paid to changes in distribution. Now, after two centuries of collecting faunistic data, detailed information is available on the distributions of many species of various taxonomic groups. It appears that in many cases distribution limits are not fixed, but subject to both small and large shifts.

Changes in distributional range. Where a local fauna has been studied over an extended period, change rather than stability of the species composition seems to be the rule (Udvardy, 1969; Kuchlein and Munsters, 1988; Hengeveld, 1990; Bruun, 1992). In studies limited to a single locality it is difficult to distinguish the global effect of range changes from the effect of local changes in ecological conditions. However, the monumental study by Kaisila (1962) demonstrates for southern Fin-

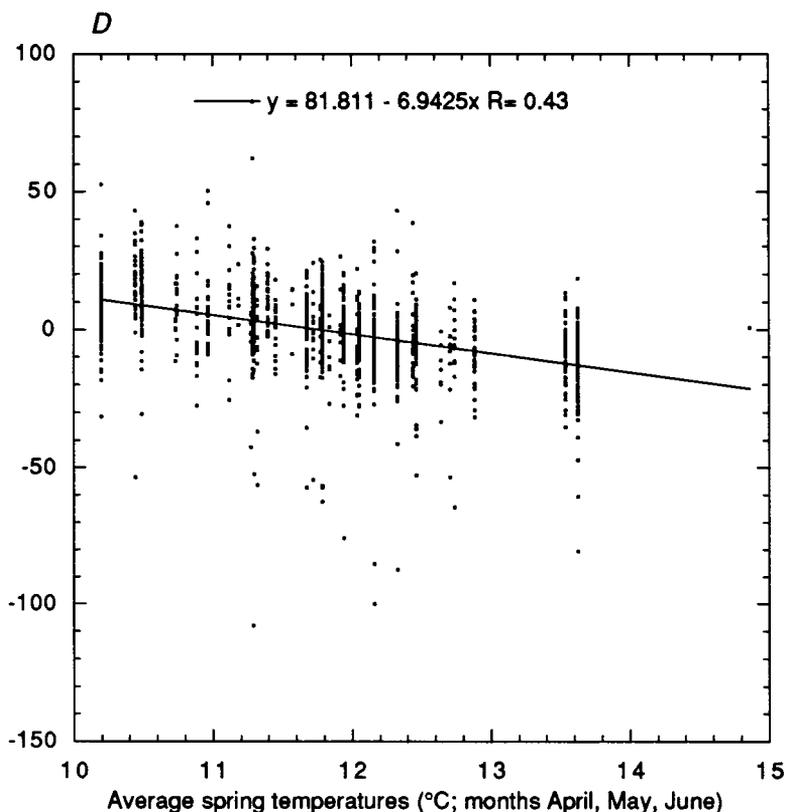


Figure 2. Linear regression of all species' values of *D* on yearly average spring temperatures (spring = April, May, June; °C; period 1955–1994).

Table 2. Situation of the Netherlands' microlepidoptera (1366 species) in the second half of this century (Kuchlein *et al.*, in press)

	1950–1979	1980–1989	1991–1995
Newly appeared	164	199	167
Numbers rising strongly	344	261	445
Numbers rising	31	33	38
Numbers stable	241	193	213
Numbers declining	72	76	78
Numbers declining strongly	416	518	322
Disappeared	98	86	103

land that at least in some cases a global, or at least regional, component must be involved.

It is interesting to illustrate this with a few examples from the Netherlands. Unfortunately but understandably, these cases mostly refer to range extensions. *Phyllonorycter platani* (Gracillariidae) was discovered in 1965, spread rapidly throughout the country and

now is one of the most abundant and widely distributed Lepidoptera (Kuchlein and Donner, 1993). *Phyllonorycter leucographella* was observed for the first time in 1984 and is spreading rapidly through the country (Stigter and Van Frankenhuyzen, 1991). Records of the noctuid *Omphaloscelis lunosa* before 1980 are all limited to the southern half of the Netherlands.



In the period 1981–1994 the species invaded the northern half of the country, including the relatively cool Frisian Islands. The number of records per year was < 10 in the period 1867 (first record) –1945, rose to 30–180 in the period 1946–1965, fell strongly during 1955–1975, then rose gradually again to over 260 in 1991–1993 (De Vos and Zumkehr, 1995). As one of the few examples of a contracting species we might cite the pyralid *Catoptria verellus*, that had its northwestern range limit over the centre of The Netherlands around 1900, but has gradually retreated to the south east, and does not occur in the country any more (map in Kuchlein and Donner, 1993).

The lability of the local species composition (Lawton, 1995) as a result of range changes as described here, makes it difficult to predict ecological processes. A recent example is the re-appearance, at high densities, of the notodontid *Thaumetopoea processionea* in the southern half of the Netherlands (Stigter and Romeijn, 1992). The phenomenon attracted much attention because of the medical importance of the larvae which cause severe irritations; but the appearance of this species also meant the addition of an important oak defoliator to the ecosystems in our country.

Changes in patterns of abundance. The studies mentioned above are of individual species in which a shift in distribution has been recorded. The question arises as to whether such changing distributions are restricted to a relatively small number of species or occur more generally. Moreover, species may not only change their abundance close to their distributional limits, but also nearer to the centre of their distribution. We studied this problem using a sample consisting of all records from 104 of the most common Dutch microlepidoptera mentioned earlier in this paper (Ellis *et al.*, in press a,b). For this, we divided the country into two halves, north and south, and three E–W zones, and compared the number of records per species in the six blocks before and after 1975. It appeared that more than half of the species have shown a significant change in their distribution across the areas since 1975.

Cause of the changes: climate or other influences? We noted above that it is generally accepted that distribution limits are determined by climatological factors although there is no such consensus about the causes of any changes in distribution. The generality and magnitude of the phenological shift in microlepidoptera demonstrates the great sensitivity of insect populations in different habitats to relatively small climatic changes. Also, the distributions of the species, and the pattern of

their changes, indicate that the climate is primarily responsible for the phenomena we observed.

The other main factor that could be responsible for the changes in distribution is the alteration of the landscape by man. The fact that this has its own geographical pattern provides a tool to distinguish its effects from those of climate.

Our study of changes in abundance patterns indicates that the geographical changes in species' abundance are correlated in the north western half of the country (Ellis *et al.*, in press b). In the south east such a correlation could not be demonstrated. Nevertheless, this result suggests the presence of a more or less NE–SW directed separation line, parallel to most climatic isolines for the Netherlands (Anonymous, 1972). Moreover, it appeared that species for which the distribution limit crosses the Netherlands have undergone significantly stronger changes in abundance pattern than central species (Ellis *et al.*, in press b). These two elements in conjunction demonstrate that the climatic effect overrules that of landscape use, or at least that the speed of climate-induced pattern changes exceeds that of change due to human impact.

Conclusion and implications for nature conservation

Our results suggest that climatic effects have strongly affected the fauna of the smaller moths. Changes in landscape use will have had their effects as well, but these have been of a less uniform nature. It is unlikely that the shifts we found are confined to the microlepidoptera. More plausible is the assumption that, currently, drastic changes are going on in many communities in the Netherlands.

Climatic fluctuation does not make the task of nature conservation easier. Its direct and indirect effects on communities cannot be ignored, because it makes species come and go locally, especially in regions like the Netherlands, crossed by so many range edges. This applies generally, but the problem will be even greater if the global pattern of climatic change turns out to be man-made and as strong and unidirectional as is currently predicted (Gates, 1993; Graves and Reavey, 1996). In our view the data presented in this paper question the basic belief of many conservationists that species can be conserved at a given place for an indefinite time. Characteristically, the Butterfly Conservation Plan for the Netherlands (Anonymous, 1990) mentions five general causes for the decline in the number of species but makes no reference to range dynamism.



This static community concept may result in expensive and often futile efforts to conserve declining populations of butterflies at the edge of their distributions (Thomas *et al.*, 1994; Thomas, 1995).

Because the species composition of communities changes in time, there is little point in monitoring individual species for the sake of evaluating the 'ecological health' or 'conservation status' of ecosystems. It is also a bad policy to focus attention exclusively on rare and threatened species (Red Data Book taxa) as a yardstick of the quality of the ecosystem as a whole. Invertebrates, or rather (i.e. invertebrates plus many lower plants) share a number of biological traits (such as a generally small body size and a short life cycle) that cause their populations to fluctuate faster and wider than vertebrates and higher plants. This explains why the concept of Red Lists, originally developed for the latter groups, may be inappropriate when nature conservation is broadened to encompass 'lower life' as well. Moreover, many species are rare locally because they are living near their distribution limits, where dynamism is at its maximum. Expressing a similar view, Fernandez Galiano (in press) recently pointed out the inadequacy of the traditional conservation tools (such as compiling lists of rare species) for invertebrates in general.

The only viable alternative we see is to conserve the whole ecosystem instead of individual species. The most important parameters are the length of the species list (rather than its composition), probably some other index of diversity as well, and the number and diversity of ecological niches available. Of course, this approach can only be used to establish the relative value of morphologically similar ecosystems. When, as in practice will often be the case, there is insufficient expertise to identify the species complement of a site, an educated estimate of the niche richness will have to do.

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