Based on monthly monitoring, 330 Lepidoptera species were observed in an urban district (Tuindorp, Utrecht, The Netherlands) between 1976 and 2001, many of these new with respect to current inventories. Seasonal variation of number of species, number of individuals and Shannon diversity of samples show sharp maxima at the end of July, while evenness shows a minimum. Trend analysis of the maxima shows decreases of 20-28% for the pertinent period, whereas the minimum and the days at which the extreme values occur do not change substantially. Temperature and precipitation can partly explain these trends.

Keywords: Lepidoptera, seasonal, annual, diversity, climate, urban district

Systematic and long-term monitoring of Lepidoptera in an urban district in The Netherlands has not been reported before in the literature, to my knowledge. However, his type of study can provide information on the fauna suited to survive in an environment of ever growing urbanization (Settele et al. 2009). Due to practical limitations my long-term monitoring had to apply relatively simple sampling methods such as visual inspection of consumer light sources, illuminated shop windows, beating of vegetation, short walking routes close to the place of living, and macrophotography. Fortunately, the past decades have provided a wealth of means for improved determination, recording and data interpretation enabling studies beyond the mere recording of species.

Here I report methods and results of a 26-year study in the district of Tuindorp in the city of Utrecht, The Netherlands. The study has three main objectives: determination of the local fauna at the level of separate species including all stages, and seasonal variation and long-term annual trends at the level of the total assemblage of adults only. The latter will include the possibilities for explanation based on climatic factors.
MATERIALS AND METHODS

Sampling, determination and recording

During 26 years (1976-2001) Lepidoptera (macrolepidoptera, diurnal butterflies and macromoths) were monitored in the garden of a private house (coordinates 52°06’26.25’N, 5°07’33.38’O) and in the surrounding district of Tuindorp (built in 1930-1937, area 0.464 km², around 6000 inhabitants). The district is located in the north-eastern part of the city of Utrecht, in 5 × 5 km gridcell 31-48 (Staatsbosbeheer 1981), The Netherlands. The district is relatively green. A few wasteland spots were built on during the monitoring period and another one in the north-western corner of the area was managed in an environmentally friendly way after 1993. The district is included by railways and, beyond 1 km distance, by highways, in the north-eastern direction bordering to a relatively open area, partly aiming at the development of nature.

On each of the 163 complete sampling days, focusing on adults, Lepidoptera were observed at daytime and evening-night (until 4-5 h after twilight) both in the garden and on fixed walking routes of 1-2 km length through the district. In the garden in the daytime beating of vegetation took place and in the evening-night visual inspection of a light source (consumer light bulb of 150 W at 2.5 m height shining to the south-west into the garden). On the walking routes butterfly and moth attracting vegetations in gardens were inspected and in the evening/night illuminated shop windows. In addition to these complete sampling days a large number of accidental and incomplete observations took place of all stages.

When necessary for determination the insects were photographed (diapositives up to 1.4× magnification). 74.8% of the species recorded were photographed. No killing or preparation took place. Individuals were identified by comparing with images and descriptions in the literature with an estimated certainty of 94.2%. Recently in some cases redetermination was carried out by comparison with data on websites on microlepidoptera (Microlepidoptera 2006) and macrolepidoptera (De Vlinderstichting & Werkgroep Vlinderfaunistiek 2008). Species were included in records of an Excel database. The total number of records is 12180, 2693 records of these are for complete sampling days.

Faunistics

Species of the total number of records were tabulated by series number and name (Werkgroep Vlinderfaunistiek & De Vlinderstichting 2010), number of years the species was observed, the first and last year of observation and its presence in gridcell 31-48 according to website data mentioned above. It was indicated whether alternative identification could be excluded, whether additional species could be present under the same identification and whether the species is considered to be rare for The Netherlands.
**Seasonal variation**

Complete samples were characterized (Magurran 2007) by: the number of species (S), the total number of individuals (N), Shannon diversity (H) and evenness (E = H/S). The latter is a measure of the equality of the partitioning of individuals over the species. The Shannon diversity is calculated from $H = \exp \left(-\sum_{i=1}^{S} \ln \frac{n_i}{N} \right)$ with $n_i$ = number of individuals of species $i$. Plotting characteristics of the samples vs. ranknumber of days in a year suggested that $S$, $N$ and $H$ for a year could be fitted to a Weibull model and $E$ to a parabola:

$$G = F \cdot \frac{K}{L} \cdot \left(\frac{D}{L}\right)^{K-1} \cdot \exp\left[-\left(\frac{D}{L}\right)^K\right]$$

with $G = S$, $N$ of $H$  \hspace{1cm} (1)

$$E = B_0 + B_1 \cdot (D-B_2)^2$$

$D$ = rank number of a sampling day

$F$, $K$, $L$, $B_0$, $B_1$ and $B_2$ = parameters to fit.

For months (March-December) without sampling days the average was taken of months from years having observed data. After the fit of parameters to 10 monthly data the seasonal variation of each year was characterized by the extreme values (peaks and valleys) of the models and the day on which these extrema occur:

$$G_{\text{max}} = F \cdot \left(\frac{K}{L}\right) \cdot \left[\left(\frac{K-1}{K}\right)\frac{1}{K}\right] \cdot \exp\left[-\left(\frac{K-1}{K}\right)\right], \quad E_{\text{min}} = B_0  \hspace{1cm} (2)$$

$$D_{\text{max}} = L \cdot \left[\left(\frac{K-1}{K}\right)^{\frac{1}{K}}\right], \quad D_{\text{min}} = B_2.$$

**Annual trends and climatic factors**

Trends of the 4 extrema and 4 peak-/valley days $P(J)$ over years ($J$) and trends of climatic factors $K_i(J)$ were defined as the slopes $P_i$ and $K_{i,i}$ to be fitted in linear regression equations:

$$P(J) = P_0 + P_1J, \hspace{1cm} (3)$$

$$K_i(J) = K_{0i} + K_{1i}J. \hspace{1cm} (4)$$

Twelve climatic factors $i$ – based on KNMI (2010) data – were studied: the annual and seasonal temperatures and precipitation plus Weibull temperature peak ($T_{\text{max}}$) and peak-day ($D_{T_{\text{max}}}$) calculated from these. It was attempted to explain the trends of the characteristic quantities from trends of climatologic factors by first carrying out the multilinear regressions:
\[ P(J) = A_0 + \sum_{i=1}^{12} A_i \cdot K_i(J) \]  

(5)

followed by substitution of eqn. 4 in eqn. 5, resulting in

\[ P(J) = V_0 + V_1 \cdot J, \]  

(6)

with \( V_0 = A_0 + \sum_{i=1}^{12} K_{0i} \cdot A_i \) and \( V_1 = \sum_{i=1}^{12} K_{1i} \cdot A_i \). For a statistically perfect explanation \( V_1 \) should be equal to \( P_1 \).

All calculations were carried out in Excel or using S-PLUS software (S-PLUS 2000).

**RESULTS**

**Fauna**

The list of species (not shown here, but available on request) contains 330 species (155 microlepidoptera, 21 diurnal butterflies and 154 macromoths). Eighteen species, 10 identified unambiguously, are considered to be rare in The Netherlands. Only one of these, *Idaea rusticata* (Denis & Schiffermüller, 1775), was observed frequently (22 years) in the district. After division of the total period into 1976-1984 (9 years, 5766 records) and 1985-2001 (17 years, 6414 records) it turned out that the number of species not observed in the second period (76) was larger than the number not met in the first period (52). This decrease was strongest for microlepidoptera and macromoths (see Fig. 1). *Maniola jurtina* (L., 1758) and *Polyommatus icarus* (Rottemburg, 1775) were found because of improved nature management after 1993.

On websites (Microlepidoptera 2006, De Vlinderstichting & Werkgroep Vlinderfaunistiek 2008) 316 species (119 microlepidoptera, 26 diurnal butterflies and 171 macromoths) are found for the complete gridcell 31-48 and the period of 1980-2010 (see Fig. 2). In my district 187 species were also found, 129 only in the gridcell and 143 only in the district. The website Microlepidoptera 2006, recently founded, strongly underestimates the number of microlepidoptera. The website De Vlinderstichting & Werkgroep Vlinderfaunistiek 2008 is mentioning more diurnal butterflies because of the presence of a large open and nature area in the gridcell which is not present in the district.

**Seasonal variation**

For each year extreme values of \( S, N, H \) and \( E \) were found after fitting of eqn. 1. A typical example is given in Fig. 3 for the year of 1981. Sharp peaks were found around \( D = 203 \) (July 22) for \( S, N \) and \( H \). Evenness shows shallow minima with inaccurate valley-day values.
Trends of S, N, H, E extrema and their peak-/valley-days are pictured in Fig. 4, which contains the coefficients $P_1$ (change/year) of eqn. 3. $S_{\text{max}}$, $N_{\text{max}}$ and $H_{\text{max}}$ have statistically significant downward trends. Decreases of 20-28% of the mean values were found in a period of 26 years. $E_{\text{min}}$ does not show any trend, nor do the peak-/valley-days of S, H and E. Only the peak-day of N shows a weakly positive trend.

Trends of yearly, seasonal and Weibull temperature descriptors ($T$ in °C × 10) and of yearly and seasonal precipitation ($R$ in mm) are given in Fig. 5, which contains the coefficients $K_{ii}$ (change/year) of eqn. 4. All temperature descriptors except for the autumn temperature show significant trends. All are positive,

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**Annual trends and climatic factors**

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Figure 3. Extreme values and peak-/valley-days of S, N, H and E in 1981.

Figure 4. Change/year of S, N, H, E extremes and their peak-/valley days.
except for the Weibull peak-day (D_{max},T) with its negative trend. The latter means that the temperature peak has shifted towards earlier days in the pertinent period. This is caused by the strong increase of winter and spring temperatures compared to the absence of a trend in the autumn temperature. Only yearly and summer precipitation show a significant trend, which is positive.

A complete analysis of the results of eqns. 5 and 6 is in preparation. As an example I present an explanation of the absence of a trend found in the peak-day of the number of species in a sample (D_{max},S of Fig. 4 and eqn. 3). Relevant data are given in Table 1.

The first and second column of the table mention the climatic factors explaining by 63% (r^2 = 0.63) the peak-day, the third column the changes/year of the climatic factors and the fourth column their contributions in eqn. 6. The estimated V_1 = P_1 = 0 within the errors. The temperature peak-day (together with the temperature height) contributes the expected shift to an earlier peaking of S, but this effect is neutralized by increased precipitation.

**Table 1.** Explanation of the absence of a trend in D_{max},S

<table>
<thead>
<tr>
<th>Ki</th>
<th>D_{max},S, eqn. 5</th>
<th>K_1,i in eqn. 4</th>
<th>K_1,A_i in eqn. 6</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>156.2±27.4 (A_0)</td>
<td>0.367±0.11 (A_1)</td>
<td>-0.373±0.185</td>
</tr>
<tr>
<td>D_{max},T</td>
<td>0.367±0.11 (A_1)</td>
<td>-0.373±0.185</td>
<td>-0.137</td>
</tr>
<tr>
<td>T_{max}</td>
<td>-2.49±0.83 (A_2)</td>
<td>0.029±0.024</td>
<td>-0.072</td>
</tr>
<tr>
<td>R_{year}</td>
<td>0.027±0.006 (A_3)</td>
<td>6.87±3.37</td>
<td>0.190</td>
</tr>
<tr>
<td>0.63 (r^2)</td>
<td>0.63 (r^2)</td>
<td>-0.018±0.145 (V_1)</td>
<td></td>
</tr>
<tr>
<td>0.000064 (p)</td>
<td>0.000064 (p)</td>
<td>0.143±0.153 (P_1 in eqn. 3)</td>
<td></td>
</tr>
<tr>
<td>3.82 (rse)</td>
<td>3.82 (rse)</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Figure 5.** Change/year of temperature and precipitation factors.
DISCUSSION

With respect to the fauna it has to be commented that my method will have underestimated especially leaf-mining microlepidoptera and other species not sensitive to visual inspection, beating of vegetation and light sources.

The (moderate) limitations to the certainty of identification of species will be of less importance in the study of seasonal variation and annual trends. Species in a sample should only be unique and different and not completely identified for this purpose.

I have found limited or no trends in peak-days of the number of species, the number of individuals and Shannon diversity of samples. I have explained that this will be caused by increased precipitation counteracting the shift caused by a decrease of the Weibull temperature peak-day. To the peaks will contribute an assemblage of species including migrating ones, species hibernating as adults and species of all generations. In addition, my temperature and precipitation factors are based on temperature and precipitation of the complete year. This may explain differences with studies of others (e.g., Ellis et al. 1997), who found peak shifts to earlier days for species selected in quite other ways.

Further analysis is required in order to find out to which degree the substantial decrease of peak-heigts of the number of species, number of individuals also found by others (e.g., Szentkiralyi 2002) and the Shannon diversity can be explained by climatic factors. Other factors both inside and outside the district studied could be much more important (Settele et al. 2009).

REFERENCES