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CLIMATIC EFFECTS ON LONG-TERM FLUCTUATIONS IN SPECIES RICHNESS AND ABUNDANCE LEVEL OF FOREST MACROLEPIDOPTERAN ASSEMBLAGES IN A HUNGARIAN MOUNTAINOUS REGION

Ferenc SZENTKIRÁLYI[1*], Katalin LESKÓ[2] & Ferenc KÁDÁR[3]
[1]*Department of Zoology, Plant Protection Institute of H.A.S., H-1525 Budapest, P.O.Box 102., Hungary, [*]author for correspondence (E-mail: h2404sze@ella.hu)*
[2]*Department of Forest Protection, Forest Research Institute, H-1023 Budapest, Frankel Leó út 42-44. (E-mail: leskokatalin@invitel.hu)*
[3]*Department of Zoology, Plant Protection Institute of H.A.S., H-1525 Budapest, P.O.Box 102., Hungary*

Abstract. Hungarian forest protection service has operated a light-trap network since 1962 produced time series of catches of Macrolepidoptera. This study analysed how long-term fluctuation patterns of total annual species richness and abundance level of macro-moth assemblages and their humidity preferential subgroups were influenced by some climatic characteristics, i.e. aridity level, number of heat days, and amount of spring precipitation. By the 43-year trends in annual proportion of species number and abundance the macro-moth assemblages showed more or less stable structure in oak-hornbeam and beech forest zone. Euryoecic, hygrophilous, mesophilous, and xerophilous moths responded by increasing species number and abundance in their fluctuation patterns to the rising of aridity level and annual frequency of heat days. The growing amount of spring precipitation reduced both species richness and abundance of macro-moths by raising larval mortality.

Keywords: Macro-moth assemblage, light-trapping, forest, fluctuation pattern, trend, species richness, annual abundance, climatic effects, drought.

1. INTRODUCTION

Moths have a significant role in the material and energy flow of forest ecosystems by their great abundance/biomass levels and number of species. Occasional outbreaks are characteristic for a group of tree foliage consuming species, when their larvae completely defoliate trees over 3-4 years. Suppression of these harmful moth species as defoliators often requires insecticide treatments in forest protection. However, due to their large number of individuals moths provide essential trophic basis for numerous entomophagous insects (e.g. parasitoids), predatory spiders, and insectivorous vertebrates (e.g. bird nestlings, amphibians, reptiles, bats and other small mammals) in the forested habitats. Because of their diverse ecological requirements moth assemblages represented with high number of species (usually hundreds of species at a given locality!) are good bioindicators of many transformations in ecological conditions, like changes of habitats or climate.

Current scenarios of climatic changes for the 21st century predict the strengthening of the actual main tendencies within Carpathian Basin (Szalai et al., 2005), namely drier and hotter summers associated with milder and wetter winters and springs (Bartholy et al., 2004, 2007; Mika, 2004). At the same time an increase in the frequency of extreme meteorological and climatic events (e.g. heavy rainfalls, heat waves, and strong droughts) is expected. These climatic changes will greatly influence the condition of forests (e.g. water deficit stress, extensive forest burning) and area-borders of various trees species as well as the population dynamics of moths. An example of the potential future consequences may be the increasing frequency of outbreaks of certain moth pests, on the other hand the direct and indirect detrimental effects of stronger droughty summers and mild winters will increase the mortality and thus the population size and biodiversity level of moths will decline considerably. An evidence for the latter negative phenomenon is already documented on the British Islands (Conrad et al., 2004).

This study was a part of a larger research project that focused on how can be the negative effects of climatic changes (e.g. soil desiccation, decrease of biodiversity) minimise with the optimal management of forest ecosystem. Our investigations were carried out in the climatically endangered oak-hornbeam and beech forest stands in one of northern parts of the Hungarian middle-mountain region. Long-term, multi-year monitoring is required to study the expected reactions of insect assemblages to climatic changes (Szentkirályi et al., 2001, 2002). Future changes can be predicted from the detected past effects by comparing the time series of yearly abundance and species richness with climatic variables recorded in the same period. In the present study data sets from long-term (more than four decades) light trapping of forest macrolepidopteran assemblages were used. According to our earlier findings (e.g. Leskó et al., 1994, 1995, 1997, 2007; Szentkirályi et al., 1998), aridity characteristics have stronger effects on population fluctuation pattern of moths at species level, consequently these were selected for analyses from climatic variables.

Our analyses were aimed to detect and quantitatively characterise the possible responses to climatic fluctuations of species groups preferring different habitat climates within moth assemblages. The objectives of this study were as follows:

- to detect and characterise long-term trends in the studied climatic and biotic time series,
- to detect the extent of effect of annual climatic variations (e.g. droughty season) on fluctuation patterns of species richness and abundance level of total assemblages and various climatic preference groups of moths,
- to analyse the effect of the amount of spring precipitation on the species richness and abundance of climatic groups of moths.

2. MATERIAL AND METHODS

2.1. Sites and the sampling method

Data series of macro-moth assemblages selected for analyses were provided by collections of forestry light traps operating near Felsőtárkány and Répáshuta within an oak-hornbeam and beech forest region (Bükk-mountain, 600-900 m a.s.l.). The location of light traps set up in forest habitats has been unchanged since 1962 up to the present. Jermy-type traps (without baffles, light source: 125 W mercury vapour bulb at 2 meter above the ground) collected moths in each night from March to the first frosts in late autumn. Thus samples represented the total annual moth assemblages. Some years were excluded from the analyses, when the light trap did not operate throughout the season or the complete assemblages could not be identified.

2.2. Biotic and climatic time series used for analyses

Long-term catching data of macrolepidopteran assemblages covered the period 1962-2004. Time series of the total annual number of species (species richness) and individuals from both light trap stations were entered as dependent variables in the statistical analyses. Within assemblages the species were categorised into the following ecological groups according to their humidity requirement along a preference scale related to their habitats: hygrophilous, mesophilous, xerophilous, and euryoecic (generalist for humidity) moths. The total annual number of species and individuals of these climatic preference groups were also determined at both trapping sites yielding further time series for the analyses.

Climatic characteristics as independent variables in the analyses were as follows: (a) the annual values of the Pálfai aridity-index (PAI) as a measurement of the drought (Pálfai, 2004). By this index if annual value of PAI >6, then the given season is droughty; (b) the number of heat days ($T_{max} > 30°C$); (c) amount of spring (May-June) precipitation. Time series of climatic variables for the period 1962-2004 were calculated according to data measured at the meteorological stations (Eger and Miskolc) closest to the light-trapping sites in Bükk-mountain.

2.3. Statistical analyses

Various methods of time-series analysis were applied to study long-term data sets using the latest version of STATISTICA software package (Statsoft Inc., 2006).

Temporal tendency and orientation of changes in the data series were determined with trend analysis. In our analyses the linear trend equations were produced for the time series of total four decades, their slopes characterising the measure of potential changes at $P < 0.05$ probability level.

Within time series analytical methods cross-correlation functions (CCF) were used to detect the increasing or decreasing effects of climatic changes in long-term fluctuations patterns of species richness and abundance level of macro-moth assemblages. CCF was calculated from a series of correlation between different time series, which indicated the degree of synchrony between the fluctuation patterns of two variables. During the calculation one of the time series is fixed, while the other is lagged at a given time unit (year) with respect to the previous one. This process gave a correlation value in each year lagged through the investigated time period, and in this way produced a correlation series as a CCF between the two variables. Having calculated the CCF this way for each lag provides a positive or negative correlation at 95% confidence interval. The absolute value of the correlation at a given lag related to the strength of the relationship, while the sign showed the increasing or decreasing direction of the relationship. For CCF evaluation only no-lag (r_0) or 1-year lag (r_1) correlation values were considered. The rationale for this was that the stochastic fluctuation of climate elements was attributed to have a relevant effect in the given year or in the next season on the population dynamics of moths and thus indirectly on the level of whole assemblage. For CCF calculation the moth time series were fixed and climatic time series were lagged. Consequently, if for example at one-year lag of PAI a significant r_1 ($P < 0.05$) meant that the effect of droughty climate expressed in the subsequent season.

3. RESULTS AND DISCUSSION

3.1. Trends in time series of climatic variables

Direction and degree of long-term (1961–2004) changes in climatic variables measured near the two light trapping localities were first studied in the analyses. Linear trend analyses of PAI time series revealed a low, non-significant rising in the degree of drought at region of both sampling sites in Bükk-mountain. Increase in the local averages of aridity-index during four decades was 1.5 (slope = 0.034) at Eger, and 1.1 °C/100mm (slope = 0.025) at Miskolc.

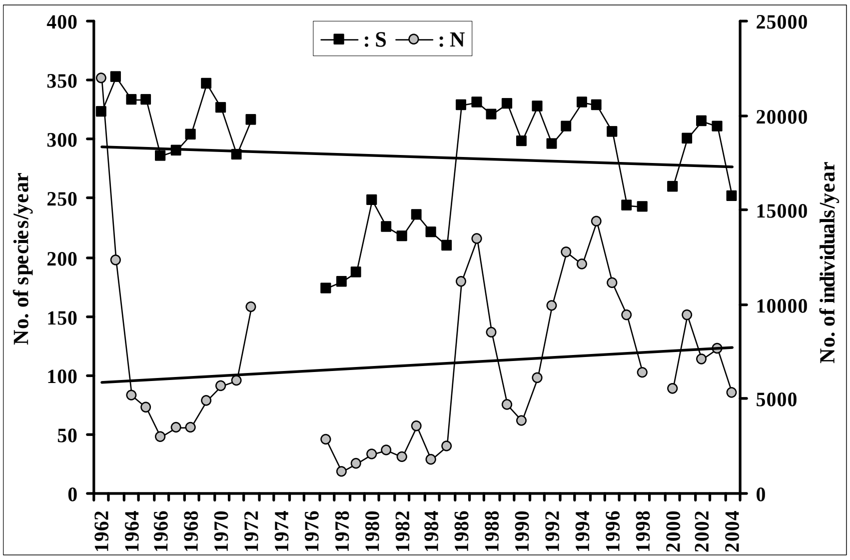

Fig. 1. Long-term fluctuation pattern and trend of species richness (S) and annual number of individuals (N) of forest macro-moth assemblage sampled by light trapping at Felsőtárkány, in Hungary

Number of heat days were also characterised with an increasing, non-significant tendency (1.1 day over four decades, slope = 0.026), but we had measured such data series only for one site, Miskolc in this case. These results suggest that within the studied areas of the Northern mountainous region, strong climatic trends (rising aridity level) associated with global warming have not yet been observed unlike in other regions of Hungary (Szalai et al., 2005). In some other areas the increase in number of heat days exceeded 20 in the studied period, and the value of PAI was also significantly higher with several degrees than four decades ago.

3.2. Trends in time series of annual abundance and species number

Despite quite stronger fluctuations were recorded in annual number of species and number of individuals during the four-decade temporal period (see Fig. 1 & 2), the trends did not show any significant long-term changes in the structure of assemblages. Among time series there was a slight decrease in number of species for the assemblages at Felsőtárkány (slope = -0.415, 18 species/4-decades), and a small increase at Répáshuta (slope = 0.294, 13 species/4-decades), while the number of individuals indicated a small, non-significant increasing trend in both cases (slope at Felsőtárkány: 43.6 ind./year and Répáshuta: 89.7 ind./year).

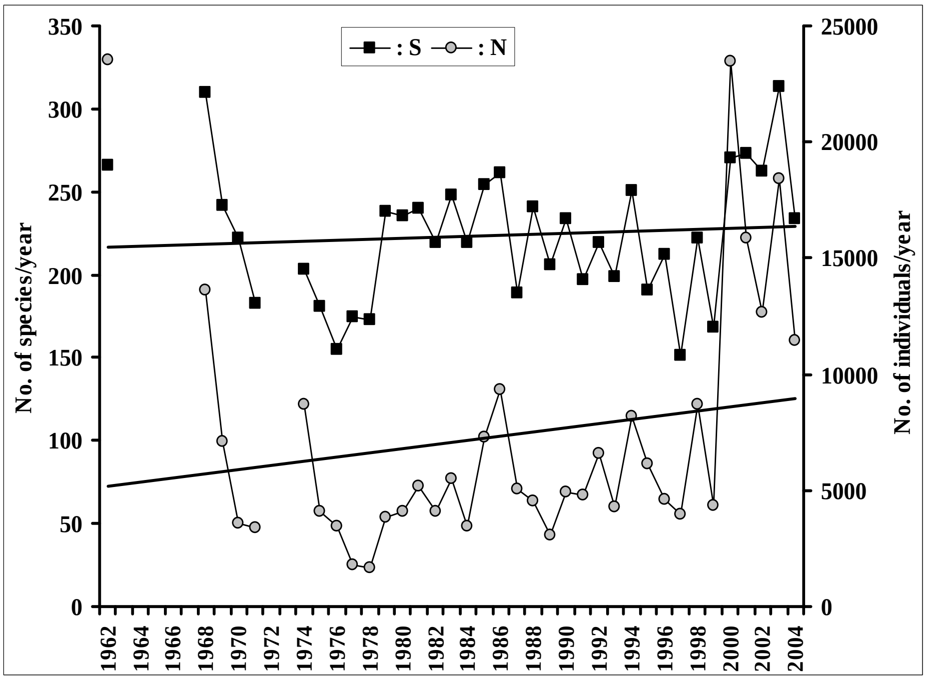

Fig. 2. Long-term fluctuation pattern and trend of species richness (S) and annual number of individuals (N) of forest macro-moth assemblage sampled by light trapping at Répáshuta, in Hungary

3.3. Trends in rates of climatic groups within macrolepidopteran assemblages

The long-term time series of the percent proportion of the number of species and individuals of different humidity requiring groups (hygrophilous, mesophilous, xerophilous, and euryoecic) inside the macro-moth assemblages were studied with linear trend analysis. The trend equations depending on the slope and its sign expressed the increase or decrease of the relative rates of climatic moth groups within their assemblages. At Felsőtárkány only the proportion of mesophilous species richness increased at a small degree of 6.7% (slope = 0.16, not significant) during the four-decade period, while other humidity moth groups remained at a stable level with low amplitudes of fluctuations. At Répáshuta the trend of proportion in species number of euryoecic moths significantly reduced with 9.7% (slope = -0.23, $P < 0.05$), the rate of hygrophilous and mesophilous species richness showed a non-significant, but slightly (5%) increasing (slope = 0.12) tendency. There were no detectable significant trends in the time series of the ratio of individual numbers at Felsőtárkány. At Répáshuta the proportion of abundance in euryoecic species group significantly declined by 5% (slope = -0.12) during the investigated period. Although the abundance rate of mesophilous species decreased by 10% (slope = -0.24) at this site, this was not a statistically significant change.

According to these results there have been only small structural changes in the assemblages on the long-term period, which can be attributed to mesophilous and euryoecic moth groups. The degree of proportional changes was small, only a few percents, suggesting that the two studied macrolepidopteran assemblages have a more or less stable species composition in response to climatic changes.

3.4. Drought effect on species richness and abundance level of moths

Time series of annual abundances and species richness of moth assemblages showed positive significant cross-correlations with the Pálfai aridity-index (PAI) at both sampling sites. Significant ($P < 0.05$) CCF values were found as follows without lag or at 1-year lag: in case of Felsőtárkány for number of individuals: $r_1 = 0.35$, and number of species: $r_0 = 0.45$; in Répáshuta for number of individuals: $r_0 = 0.46$, and number of species: $r_0 = 0.35$. From this correlation values we concluded that drought fluctuations influence the structural characteristics of total moth assemblages in a way that warmer-drier seasons increase both species number and the level of abundance. Further CCFs were calculated in order to decide if the influence of droughty (dry and warm) seasonal climate was similar or differing on the moth groups characterized with various humidity preferences. CCF values found at no-lag (r_0) and 1-year lag (r_1) between the time series of climatic moth groups and PAI are shown on Table 1 (see the first four rows). The table shows only correlation values exceeding 0.2 regardless of their sign.

Fluctuations of species numbers of climatic groups were only slightly modified by the degree of drought (PAI), correlations were weak ($r < 0.3$) or moderate (r: 0.30 – 0.45). The Table 1 also reveals that positive significant cross-correlations (r: 0.30 –

0.43, P < 0.05) were found between species numbers of euryoecic, hygrophilous, mesophilous, xerophilous moths and PAI in the droughty years at Répáshuta and in the year following the droughty seasons at Felsőtárkány.

Data in Table 1 also suggest that abundance levels of climatic moth groups were somewhat more influenced by aridity then their species richness. Each group responded with growing number of individuals to an increase in PAI values at both locations, and the number of significant correlations was also greater than for number of species. The cross-correlations values were in medium category (r: 0.30 – 0.50, P < 0.05) in most cases, and the increases of abundance level occurred already in the droughty seasons. The positive sign effect of dry-warm climate on hygrophilous species is a non-expected result. In our opinion the explanation for this phenomenon could be that in the mountainous forests associated with humid climate the summer droughts were not so manifested during the long-term period rather even beneficial on moth reproduction, instead of leading to higher mortality as it was recorded in lowland region in Hungary.

Table 1. Cross-correlation functions (CCF) between climatic characteristics and annual time series of macro-moth groups with various habitat-humidity preferences within the local assemblages monitored by forestry light traps between 1962 and 2004 in the Bükk-mountain

Light trap station and variables of CCF	Humidity requirement of moths							
	euryoecic		hygrophilous		mesophilous		xerophilous	
	r_0	r_1	r_0	r_1	r_0	r_1	r_0	r_1
Felsőtárkány: S-PAI		+0.30*		+0.33*		+0.35*		+0.28
Répáshuta: S-PAI	+0.38*				+0.35*		+0.43*	
Felsőtárkány: N-PAI	+0.40*	+0.44*	+0.42*	+0.46*	+0.30*	+0.36*		+0.32*
Répáshuta: N-PAI	+0.38*		+0.50*		+0.26		+0.26	
Felsőtárkány: S-H	+0.36*	+0.49*	+0.33*	+0.45*	+0.57*	+0.56*	+0.30*	+0.51*
Répáshuta: S-H	+0.32*				+0.40*		+0.42*	+0.26
Felsőtárkány: N-H	+0.28	+0.28	+0.32*		+0.39*	+0.25	+0.33*	+0.30*
Répáshuta: N-H	+0.46*	+0.22	+0.49*		+0.58*	+0.25	+0.42*	
Felsőtárkány: S-P_{MJ}		-0.32*	-0.20	-0.26	-0.29	-0.35*		-0.31*
Répáshuta: S-P_{MJ}	-0.39*				-0.39*		-0.31*	-0.26
Felsőtárkány: N-P_{MJ}	-0.33*	-0.35*		-0.21	-0.31*	-0.26	-0.24	-0.27
Répáshuta: N-P_{MJ}	-0.49*		-0.40*		-0.33*		-0.23	-0.24

Abbreviations: S: yearly number of species; N: yearly number of individuals; PAI: aridity-index; H: number of hot days; P_{MJ}: amount of precipitation in period of May-June; r_0 and r_1: values of CCF at 0- and 1-year lag, respectively; only r_0 and $r_1 \geq 0.2$ are given; ***:** P < 0.05

3.5. Effect of heat days on species richness and abundance level of moths

The effect of annual number of heat days on species numbers (Table 1, see in the central four rows) had a similar sign and degree as that of PAI: positive moderate and significant CCF values were dominant (r: 0.30 – 0.57, P < 0.05), without having any case with negative correlations. As expected, the species richness of xerophilous moths at both locations significantly increased simultaneously with the greater frequency of heat days in the given year and at Felsőtárkány even in the next season as well. Number of mesophilous and euryoecic species also increased with the number of heat days in the given year or also in the following year of all cases. At Répáshuta there was no detectable significant change of the number of hygrophilous species in their response to annual frequency of heat days.

All the four climatic preferential moth groups reacted with a significantly rising abundance level to the increasing number of heat days at both locations. Moderate CCF values with positive sign (r_0: 0.32 – 0.58, $P < 0.05$) were detected in seasons characterized with heat waves. An increase in the number of heat days had a weak, non-significant positive effect ($r_1 < 0.3$) on number of individuals within euryoecic and mesophilous (and xerophilous at Felsőtárkány) species groups in the subsequent season. Besides indirect population dynamic effects, warm nights associated with heat days were also likely contributing to the positive correlations, when a stronger flight activity could result in higher catching level in the traps.

3.6. Effect of spring precipitation on species richness and abundance of moths

The amount of late-spring (May-June) precipitation had weak or significant moderate correlation with species number in a few cases and with abundance level in more cases within each climatic preference group of moths (Table 1, see in the last four rows). As it was expected, CCF values had negative sign in the given (r_0) and also in the subsequent seasons (r_1), i.e. rising in amounts of rainfalls during the period of May-June reduced the annual species richness and abundance levels of moth groups. The detrimental effects of elevated precipitation manifested even during the following year, especially for xerophilous species. The reason behind this inverse relationship is probably that juvenile larvae of most moth species generally develop during this period and being sensitive to frequency and intensity of precipitation and cool weather, these unfavourable climatic conditions may have led to substantial mortality (e.g. starvation, infections). Although increasing trends are expected in species richness and abundances of macro-moths by the rising in the summer aridity level in future, however this favourable effect will decrease via increasing frequency and amount of spring precipitation predicted, too.

4. CONCLUSIONS

The degree of drought and number of heat days increased slightly and non-significantly during the last four decades in mountainous beech forest area investigated contrary to other Hungarian regions. As a consequence no long-term rising or declining trend of change could be detected in the time series of annual species richness and abundance of macro-moths, indicating a structural stability of assemblages.

The degree of long-term changes in the annual proportion of four humidity preference moth groups was small, only a few percents. It suggests that macro-moths assemblages at both studied light trapping sites today still have a rather stable composition with respect to climatic changes.

Rising aridity significantly increased the annual number of species and number of individuals of macrolepidopteran assemblages at Felsőtárkány and Répáshuta. The degree of drought showed less influence on the fluctuations in the species richness than on the abundance level of four climatic moth groups. Number of individuals and species number of euryoecic, hygrophilous, mesophilous and xerophilous moths were increased by droughty climate in the studied oak-hornbeam and beech forest zone. By further increasing level of drought as a consequence of climate warming in Carpathian Basin decreasing species richness and abundances are expected in each moth groups.

The effect of changes in the number heat days on the number of species and abundance level was manifested in a similar degree and direction than aridity: each climatic moth group responded with rising species number and abundance level in their fluctuation patterns to the increasing annual frequency of heat days.

According to the expectations, growing amount of spring (May-June) precipitation reduced both species richness and abundances of macro-moth groups by raising larval mortality.

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