Description of the nun moth temperature index

The 4C model incorporates the probability of endangerment due to Nun-moth (*Lymantria monacha* L.) infestation. This is marked NTIndex in the climate output file. The model for that is described in the following. Calculation is incorporated in sub-routine year_ini.f.

Zwölfer (1935) developed a thermal index based on experimental studies on the influence of hygrothermal conditions on the survivability of the nun moth (Lymantria monacha L.) and on her reproductive potential. To this end, the influence of temperature on the nun's individual stages of development was investigated and so-called values for the development zero point (t_a) were determined. The general formula for the development time is:

$$T = \frac{p}{t_m - t_a}$$

T – development time (days)

t_m – temperature (°C)

p – parameter

t_a – development zero point (°C)

Following parameterisations were determined.

For the first stage, egg (hatching period), Zwölfer calculated in a moisture saturated atmosphere:

$p = 65$

$t_a = 4.9$

For 70-80% relative humidity $p = 72$, $t_a = 5.4$

For 30-40% relative humidity $p = 90$, $t_a = 5.9$

For the stage larva I, Zwölfer assumed no deeper influence of humidity for the relative humidity range of 40 - 100%. Below 40%, an extension of the development period was found. The data of the other stages (larva II, III, IV, V) were collected at 70 - 80% relative humidity. For all stages the data are summarised in Table 1.

Table 1 Parameter of the nun stages, t(4),,,,t(9)- monthly mean temperature April - September, t_m – monthly mean temperature for the calculation o TS

Stage	Nr	p	t_a	T_p	month	t_m
Egg(hatching period)	1	65	4.9	30	IV	$t_m(1) = t(4)$
	2	65	4.9	3	V	$t_m(2)=t(5)$
Larva I	3	217	3.2	17	V	$t_m(3)= t(5)$

Larva II	4	84	5.7	8	V	$t_m(4)=t(5)$
Larva III	5	84	7.2	3	V	$t_m(5)= t(5)$
	6	84	7.2	6	VI	$t_m(6)=t(6)$
Larva IV	7	90	7.6	10	VI	$t_m(7)=t(6)$
LarvaV	8	132	7.8	14	VI	$t_m(8)=t(6)$
Larva VI	9	197	6.0	18	VII	$t_m(9)=t(7)$
Pupae	10	130	8.4	13	VII	$t_m(10)=t(7)$
	11	130	8.4	2	VIII	$t_m(11)=t(8)$
Egg (embryonic time)	12	240	6.8	29	VIII	$t_m(12)=t(8)$
	13	240	6.8	30	IX	$t_m(13)=t(9)$
Sum		**1239**				
life span moth m		195	-3.5			
life span moth f		91	-9.4			

A thermal constant was derived from the data, defined as the sum of the parameters p of the individual stages. The following value is set as the final value for the total temperature sum or thermal constant of the total development:

$T_{GS} = 1240 \pm 40$

From observations of the occurrence or the phenology of the phases of the nun (of 1931), see also Zwölfer (1935) p. 368, an average number of days T_p was defined for the individual phases. (see Table 1). Using the local, long-term monthly averages for the months April to September t(i), i = 4, .., 9, which are assigned to the 13 stages of development ($t_m(j)$, j=1,…13) a local annual temperature sum is calculated as follows:

$$TS=\sum_{j=1}^{13} T_p(j)\cdot(t_m(j)-t_a(j))$$

The **Nun temperature index** is defined:

$$NTI=\frac{TS}{T_{GS}}$$

Zwölfer stated:

- If this quotient NTI becomes less than one, the temperature sum required for the expiration of a full generation is not available at the location.
- Where the value 1 is just about reached, a minimum temperature-related limit of the distribution area must lie.
- If long-term monthly means are used, the NTI provides information as to whether the thermal conditions of a region allow the nun to appear in the long term.
- The south border of distribution is for NTI = 1.5 -1.6 (according to the knowledge of this time).
- The area of distribution of the nun is characterized in the long-term average in the border areas of approx. NTI =1.0 -1.6.
- Typical mass change areas have index values of **1.1 - 1.4** on average over many years (1935!), the year of preparation of a calamity seems to have a NTI of 1.3 (analysis of time series and data of calamities, see Möller, Walter et al. (2007) are necessary for the verification).
- The NTI can only be one of the basic conditions for the occurrence of this species. Gradations/mass reproductions of the nun are preceded by dry, warm summers; later on, gradation is temperature favourable, but also depends on random factors (Altenkirch, Majunke et al. 2002), which is not taken into account in this NTI.

References

Altenkirch, W., et al. (2002). Waldschutz auf ökologischer Grundlage. Stuttgart, Ulmer.

Möller, K., et al. (2007). Die Gefährdung der Gemeinen Kiefer durch Insekten. Die Kiefer im nordostdeutschen Tiefland - Ökologie und Bewirtschaftung. M. Brandenburg. Eberswalde, Landesforstanstalt Eberswalde**:** 245-257.

Zwölfer, W. (1935). "Die Temperaturabhängigkeit der Entwicklung der Nonne (Lymantria monacha L) und ihre bevölkerungswissenschaftliche Auswertung." Zeitschrift für Angewandte Entomologie **XXI**(3): 333-384.