

OUTBREAKS OF THE NUN MOTH (*Lymantria monacha*) AND HISTORICAL RISK REGIONS IN THE CZECH REPUBLIC

GRADACIJE SMREKOVOG PRELCA (*Lymantria monacha*) I
PODRUČJA NJEGOVE UČESTALE POJAVE U ČEŠKOJ

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ABSTRACT: The paper, based on a literature review, presents an overview of the nun moth outbreaks in Czech forests from 1784 to 2010. A database of outbreaks was created and presently contains 2,557 records. The oldest written record dates from 1784. The greatest calamity of nun moth outbreaks occurred during the years 1917–1927. The last nun moth outbreaks appeared in the years 1993–1996. A map of high-risk areas in the Czech Republic was created based on this historical data.

Key words: *Lymantria monacha*, historical outbreaks, Czech Republic

1. INTRODUCTION – Uvod

The nun moth (*Lymantria monacha* /L./) is a strongly polyphagous pest feeding on coniferous and deciduous trees. Spruce (*Picea* sp.), larch (*Larix* sp.) and pine (*Pinus* sp.) are typical host plants but the nun moth also causes extensive defoliation of other tree species during its outbreaks (Komárek 1931, Schwenke 1978). Although the phytophagous nun moth is considered one of the most damaging insects in European coniferous forests and can cause severe damage in managed forests (Altenkirch 1986, Baier 1995, Bejer 1986, Cescatti & Battisti 1992, Fischer 1942, Grönblom & Suomalainen 1950, Jahn 1973, Pivetz et al. 1959, Klimetzek 1979, Köhler 1958, Nietzsche 1891, Romanyk 1958, Sedláček 1911, Schimitschek 1947, Schmutzenhofer et al. 1975, Sliwa & Sierpinski 1986, Uhlíková & Nakládal 2010, Wilke 1931, Zederbauer 1911), there are relatively few papers focusing on and evaluating general historical outbreaks. In the Czech Republic, there is currently no integral overview of nun moth outbreaks; we can usually find only short articles describing the progress and spread of the outbreaks (Blažek et al. 1932, Mokrý 1923, Liška & Šrůtka 1994). However, Švestka (1968) described a small review of nun moth outbreaks in southwestern Moravia. It is

also possible to find an evaluation of the situation for prediction in a given year or following year (Liška 1996 and 1999, Liška & Šrůtka 1995, Zahradník et al. 1995). A fundamental publication illustrating the largest outbreaks of the nun moth in the Czech Republic in the 1920s was published by Komárek (1931).

Catastrophic damages to forests caused by the nun moth have been known in the past. Its first massive expansion in Central Europe was recorded in 1449. At least 26 significant periods of increase were recorded from that time until the late 19th century (Hošek 1981). Komárek (1931), Mokrý (1923) and Blažek et al. (1932) described disasters that occurred during the first half of the 20th century. In the period 1946–1995, six outbreaks were recorded in Poland (Głowacka 1996). In Germany, Poland and the Czech Republic, the nun moth outbreaks were observed in 1993–1995 (Baier, pers. comm., Głowacka 1996, Liška & Šrůtka 1994). In 2003, the nun moth caused defoliation in Poland and Germany (Möler & Wenk, pers. comm., Wanner et al. 2005).

More than 100 historical records were found in the Czech Republic throughout the 20th century (e.g. Anonymous a, Anonymous 1969a, Anonymous 1969b, Hošek 1958, Hošek 1959, Hošek & Žaloudík 1964, Hošek & Žaloudík 1969, Kruml 1962, Kruml 1963, Kruml 1968b, Ministr 1964, Ministr 1970, Novák 1969b, Novák 1969e, Novák 1970, Novotný 1965, Schleger 1974, Tlapák

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1960, Tlapák 1963, Tlapák 1964, Tomandl 1962, Žaloudík 1961). Extensive outbreaks and total defoliation were recorded mainly after 1900, and this situation lasted more or less until 1940 (e.g. Anonymous b, Anonymous c, Anonymous d, Anonymous 1966, Horák 1960, Horák 1965a, Horák 1965b, Horák 1968, Horák 1969, Hošek 1961, Hošek 1964, Hošek 1967, Hošek & Tomandl 1965, Kruml 1964b, Kruml 1968a, Kruml 1969, Materna 1964, Ministr a, Ministr b, Ministr 1963, Novák 1967b, Novák 1967c, Novák 1968a, Novák 1968b, Novák 1969a, Novák 1969c, Novák 1969d, Novák 1972, Schleger 1966, Starec & Tlapák 1959, Tlapák

1962, Tlapák 1965b, Tomandl 1956, Tomandl 1971). The largest calamity of the nun moth in the Czech Republic was in the 1920s. In the Central Bohemian region, optimal conditions for nun moth development were created by reduced precipitation during the later years. Since 1996 there has been no other major outbreak. However, there are traditional outbreak regions with higher population densities of the nun moth (the Brdy Hills and Bohemian-Moravian Highlands).

In this paper, we present a quantitative and qualitative historical overview of the available data on nun moth outbreaks in the Czechlands.

2. MATERIAL AND METHODS – Materijali i metode Historical data of the nun moth outbreaks

Povijesni podaci o gradacijama smrekovog prelca

During the period 2007–2010 a large amount of historical records of nun moth outbreaks was collected and processed. Information was obtained from books, proceedings, journals, surveys, protocols, and also from records in the forest districts. Besides these written records, oral interviews with foresters were also important. The historical essays and surveys from the archives

of the Forest Management Institute (FMI) were the main source of information. It was necessary to visit the central archive of FMI plus its branches in the Czech Republic and contact the forest districts. The collected data covered the period from 1784 up to 2010. We found more than 2.5 thousands of records. The main nun moth outbreaks periods are in Table 1.

Table 1 Selected main periods of the nun moth outbreaks in the Czech Republic.

Tablica 1. Odabrana glavna razdoblja gradacija smrekovog prelca u Češkoj

Period/year of outbreak <i>Razdoblje/ godina gradacije</i>	Locality/ region <i>Lokalitet/ područje</i>	Details <i>Podrobnosti</i>	References <i>Izvori</i>
1784-1790	Krukanice	the oldest written evidence of defoliation <i>najstariji podatak o defolijaciji successful</i>	Tomandl (year unknown) <i>Tomandl (nepoznata godina)</i>
1785	Doupov Mountains	eradication (setting fires at night) <i>uspješna eradikacija (paljenjem vatri noću)</i>	Schleger (1974)
1788-1790	Carlsbad Highlands	the oldest complete records of defoliation; heavy/ <i>P. abies</i> /24 000 m ³ <i>najstariji potpuni podatak o defolijaciji; jaka defolijacija/P. abies/24 000 m³</i>	Ministr (1970)
1838-1840	Rakovník, Křivoklát, Opařany	<i>P. sylvestris</i>	Kruml (1964a), Novák (1966)
1899	Sokolíčko	heavy/36 ha <i>jaka defolijacija/36 ha</i>	Horák (1987)
1892	Žirovnice	26 ha	Kruml (1968b)
1901-1903	all regions / <i>sva područja</i>	autochthonous outbreaks in lower altitudes <i>autohtone gradacije u nižim nadmorskim visinama</i>	Hošek (1981), Novák (1970)
1906-1910	Ledeč n. Sázavou, Ronov n. Doubravou, Jindřichův Hradec region, the Třeboň region, Děčín, Frýdlant, Zákupy, Grábštejn, the Drahan Highlands, lower altitudes of the Jeseníky Mountains	heavy/3 600 ha; ended through polyhedral disease <i>jaka defolijacija/3 600 ha; okončana poliedrijom gusjenica</i>	Tomandl (1962)

Period/year of outbreak <i>Razdoblje/ godina gradacije</i>	Locality/ region <i>Lokalitet/ područje</i>	Details <i>Podrobnosti</i>	References <i>Izvori</i>
1917-1927	Bohemia, west Moravia	the greatest catastrophe of the nun moth in the Czech Republic; <i>P. abies</i> , <i>P. sylvestris</i> , <i>L. decidua</i> , <i>A. alba</i> , <i>P. menziesii</i> , broadleaves <i>razdoblje najjače gradacije smrekova prelca u Češkoj</i> ; <i>P. abies</i> , <i>P. sylvestris</i> , <i>L. decidua</i> , <i>A. alba</i> , <i>P. menziesii</i> , <i>listače</i>	Horák (1982), Hošek (1981), Hošek & Tomandl (1965), Komárek (1931), Novák (1966), Novák (1967a), Novák (1967b), Novák (1967c), Novák (1968b), Novák (1969a), Novák (1969e), Novák (1972), Novák (1975), Tlapák (1965a), Tlapák (1965b)
1931-1938	Křivoklát, Milevsko, Světlá nad Sázavou, Nové Syrovice	ended through polyhedral disease <i>okončana poliedrijom gusjenica</i>	Hošek (1981), Novák (1966), Novák (1967b), Novák (1975)
1947	Teplá, Sokolíčko	52 000 m ³	Hošek (1981), Ministr (1970), Tlapák (1963)
1965-1967	Náměšť n. Oslavou, Jaroměřice, Jemnice	chemical spraying <i>suzbijanje kemijskim insekticidima</i>	Hošek (1981), Švestka (1968)
1993-1996	Hořovice, Zbiroh, Rájec, Tišnov, Brdy Hills, Jindřichův Hradec, Pacov, Jihlava, Trutnov, Dvůr Králové, Horní Maršov, Boskovice	heavy/ <i>P. abies</i> , <i>L. decidua</i> /34 000 ha; chemical spraying <i>jaka defolijacija/ P. abies, L. decidua/34 000 ha; suzbijanje kemijskim insekticidima</i>	Liška & Šrůtka (1998), Zahradník et al. (1995)

Data processing – Obrada podataka

The database LYMONDAT of nun moth outbreaks in the Czech Republic was created on the basis of historical data survey. Today, there are 2,557 records. The database contains information including the year or period of occurrence, the location of outbreaks and extent of nun moth feeding, feeding level, volume of nun moth timber harvested, and information about host tree species, if it was mentioned.

Each period was divided into individual years for the purpose of digitalization. Information about defoliation levels in the primary resources is quite variable (and sometimes very brief). Therefore, each record was assigned an intensity rating (ranging from 1–4). A rating of 4 indicates data where we know that there was heavy defoliation (70–100%). A rating of 3 equals strong nun moth feeding (25–70%), 2 corresponds to light feeding (less than 25%). A rating of 1 includes data with a sporadic occurrence of nun moth. In some cases the feeding level was not identified.

Using information from this database, two maps of feeding levels were created. In order to visualize the spatial distribution of individual records in ArcGIS, WGS84 coordinates were assigned to individual records. Special care was taken to avoid duplication of records within one year. The first map is a simple map showing the feeding intensity in stands. For the purpose of this article, points of nun moth occurrence were recorded on the level of forest districts.

For the second map we gave cumulative values to each point and subsequently, spatial interpolation using Ordinary Kriging was used to predict the risk outbreak regions of the nun moth. The correlation between source data, expressed in as a variogram, determines the estimated value at an unsampled location. The variogram is a function describing the degree of spatial dependence of data investigated. It is defined as the expected squared increment of the values between two locations (Wackernagel 2003). Formally, this is given as:

$$\gamma(h) = \frac{1}{2N(h)} \sum_{i=1}^{N(h)} [z(x_i) - z(x_i + h)]^2$$

where $z(x_i)$ is variable at position x , $z(x_{i+h})$ denotes a variable separated by vector h (lag), with specified magnitude and direction. $N(h)$ is the total number of pairs used to compute the value of the variogram for a specified lag.

Ordinary Kriging is a univariate stationary technique for spatial interpolation. This is of the form:

$$Z(x_0) = \sum_{i=1}^k \lambda_i Z(x_i) \quad \text{subject to} \quad \sum_{i=1}^k \lambda_i = 1$$

where $Z(x_0)$ is an estimator at site x_0 given by the linear combination of random variables $Z(x_i)$ at sites x_i .

Impartiality of the prediction and the smallest mean square error of prediction (prediction variance) are ensured. A more detailed description can be found in

Isaaks & Srivastava (1989), Wackernagel (2003) and Olea (1999).

3. RESULTS AND DISCUSSION – Rezultati i rasprava

The first map (Fig. 1) shows spots (on the level of forest districts) where the nun moth occurred in relation to feeding intensity during the years 1784–2010 (the oldest written record comes from 1784). There are areas where the nun moth was recorded at least once. This map however, does not reflect the fact that the nun moth could occur there repeatedly.

As can be seen, there are regions where the nun moth has never been recorded. It is mainly in south Moravia and the Šumava Mountains, upper parts of the Giant Mountains, part of the Labe Basin, the Aš region, as well as others. The reason for the absence of this species was probably an absence of host plants (at lower elevations) or adverse climatic conditions (in high-elevation forests).

The second map (Fig. 2) gives a better idea of which areas were attacked repeatedly. From a historical view, the riskiest regions appear to be the Bohemian-Mora-

vian Highlands, Třeboň Basin, Brdy Hills, Nový Bor region and Opava region. In the long run, it shows that an optimum range of nun moth has shifted in the Czech Republic. Based on historical data, the Třeboň Basin (average altitude is 457 m a. s. l.) was determined as a risk region where the nun moth defoliated pine there, mainly up to the end of the 19th century (Anonymous 1967). Nowadays the hot spots do not arise in lower altitudes. On the contrary, the Brdy Hills (average altitude is 640 m a. s. l.) are attacked more than the historical data would indicate. It is obvious that the hot spots are shifting to the higher altitudes. Some distortion in the map is due to numerous records from the largest calamity of the nun moth in the Czech Republic in the 1920s. The nun moth has also occurred in the regions where there were not optimal conditions for development (with regard to altitude and climatic conditions).

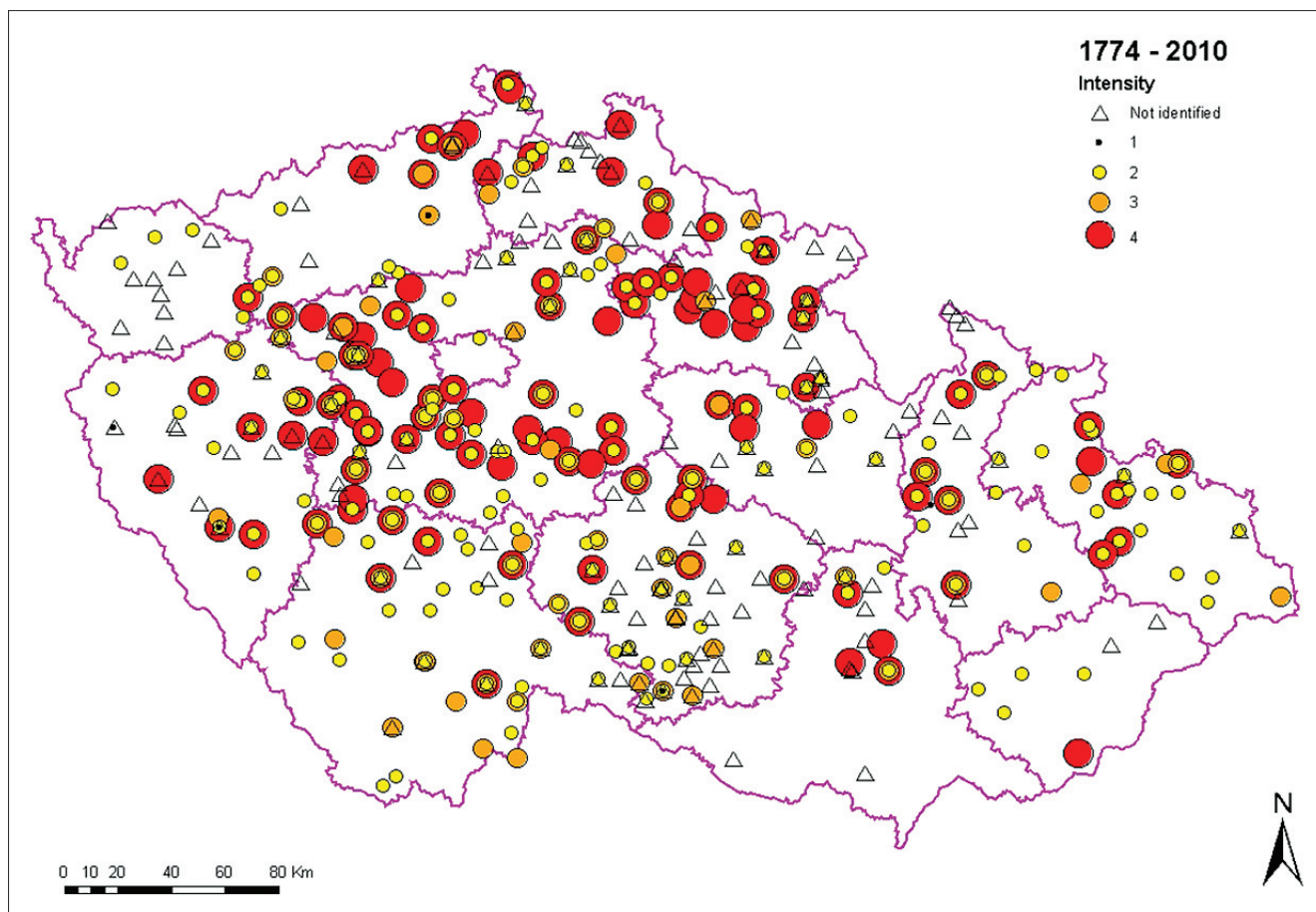


Figure 1 Location of the nun moth outbreaks (on the level of forest districts) in relation to feeding intensity in the Czech Republic (1784–2010). 4 – defoliation 70–100%, 3 – defoliation 25–70%, 2 – defoliation <25%, 1 – sporadic occurrence, Δ – not identified.

Slika 1. Područja gradacija smrekova prelca (na prostornoj razini gospodarske jedinice) u odnosu na jačinu defolijacije u Češkoj (1784–2010). 4 – defolijacija 70–100%, 3 – defolijacija 25–70%, 2 – defolijacija <25%, 1 – sporadična pojava, Δ – jačina defolijacije nepoznata.

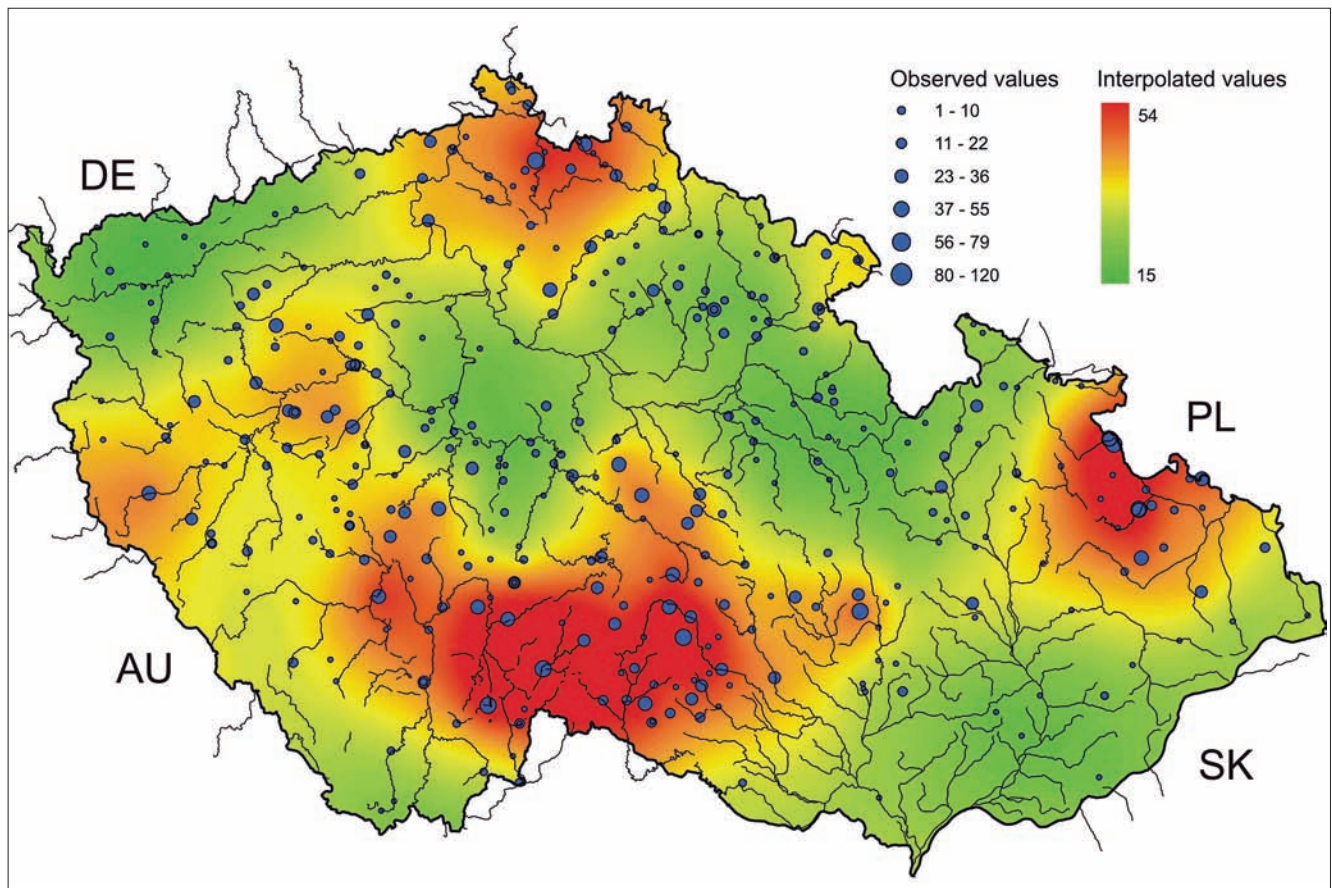


Figure 2 Spatial distribution of the nun moth outbreaks using Ordinary Kriging based on historical data (1784–2010). The observed values are cumulative values of feeding intensity. Red colour means regions with the highest feeding intensity (difference in ranges of observed and interpolated values are due to the smoothing effect of interpolation and its inability to reproduce extreme values in observed data in some cases).

Slika 2. Prostorna distribucija gradacija smrekova prelca dobivena metodom običnog kriginga temeljenog na povijesnim podacima u razdoblju 1784. – 2010. g. Točkasti podaci predstavljaju kumulativne vrijednosti jačine defolijacije. Crvena boja označuje područja najjačih defolijacija (diskrepancija točkastih-opažanih defolijacija i obojanih-geostatistički izvedenih podataka, posljedica je izgladivanja uslijed interpolacije i nemogućnosti prikaza ekstremnih vrijednosti defolijacije u nekim slučajevima).

There are areas where the nun moth damaged forests only in 1920s (e.g. Jeseníky Mountains, Ostrava region, north part of Ore Mountains).

Spruce, pine and larch are typical host plants. During a massive expansion, caterpillars have also fed on *Abies* sp., and broadleaves such as *Quercus* sp., *Fagus* sp., *Carpinus* sp., *Betula* sp., *Acer* sp., *Ulmus* sp., *Alnus* sp., *Tilia* sp., *Salix* sp. and *Populus* sp. (Komárek 1931, Křístek & Urban 2004). Rašek (1922) mentions that caterpillars are also able to defoliate clover fields (*Trifolium* sp.), *Vaccinium myrtillus* (L.), *Calluna vulgaris* (L.) in times of need. Defoliation of *Fraxinus* sp however, has never been recorded. Historical records show an important change of main host plant. Whereas

the nun moth particularly defoliated pine stands in lower altitudes in the years 1830–1890 (Kruml 1964a, Novák 1966), at the end of the 19th century and the beginning of the 20th century, the nun moth began to attack spruce (Anonymous 1951, Tlapák 1965a). It shows a shift of optimum conditions for development towards the highlands. Extensive planting of spruce monoculture also contributes to the change of host plant.

An interesting fact is that the nun moth feeding began in larch stands and caused a total defoliation there (Brdy Hills in 1993–1996) (Uhlíková & Nakládal 2010), although Komárek (1931) mentions that the nun moth does not feed in pure larch stands.

5. CONCLUSIONS – Závěry

The oldest written record of nun moth outbreaks in the Czech Republic comes from 1784. The greatest calamity of the nun moth was during the years 1917–1927, especially in Bohemia, where the damage

was widespread. The last nun moth outbreaks appeared in the years 1993–1996.

In the Czech Republic, there are regions where the nun moth has never caused damage to forests (e.g.

south Moravia and the Šumava Mountains, upper parts of the Giant Mountains and others). Many large areas were defoliated only during the greatest catastrophe outbreak in the 1920s. From the forestry aspect, the most important areas are those where the nun moth has the most optimal conditions for development (primary outbreak foci). In these areas, the nun moth reproduces most regularly and the earliest within a given area. The Brdy Hills and the Bohemian-Moravian Highlands are such areas nowadays. A main host plant of the nun

moth was pine to the beginning of 20th century and spruce replaced it in the following decades.

Vanhanen et al. (2007) shows that predicted climate change will affect the distributions of the nun moth by causing a range shift towards the pole. Based on our historical data it is evident that there has been a distribution shift from lower to higher elevations over the long term. This confirms the assumption that the distribution area is changing, and therefore the foresters should take this into account.

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SAŽETAK: *Smrekov prelac (Lymantria monacha) izraziti je polifag, čije se gusjenice hrane iglicama četinjača i lišćem mnogih listača. Smreka (Picea sp.), ariš (Larix sp.) i bor (Pinus sp.) najčešće su napadnuti ovim štetnikom, ali jake defolijacije mogu se pojaviti i na drugim vrstama tijekom njegovih gradacija. U Hrvatskoj je rijedak i javlja se tek sporadično, podjednako u različitim šumskim sastojinama. Unatoč velikom broju dokumentiranih gradacija u Europi, mali je broj radova u kojima se analizira prostorno gledište njegove pojave. Prvi masovni napad smrekovog prelca zabilježen je u Središnjoj Europi 1449. godine. Do kraja 19. stoljeća zabilježeno je barem 26 značajnijih razdoblja njegovih gradacija. U Češkoj je evidentirano više od 100 pojava defolijacije smrekovog prelca tijekom 20. stoljeća. Izrazite i prostorno značajne gradacije bilježene su uglavnom nakon 1900. godine i takva je situacija potrajala do 1940. godine. Najveće kalamitete smrekov prelca uzrokovao je u Češkoj u dvadesetim godinama 20. stoljeća. Od 1996. do danas nisu zabilježene izrazitije gradacije. Različita učestalost pojave, kao i jačina defolijacije u pojedinim dijelovima teritorija, autorima rada bili su poticaj za pokušaj izrade prostorne analize i izrade karte povišenog rizika ovog defolijatora na području Češke. Koristeći metodu običnog kriginga, analizirali su i geostatistički obradili više od 2 500 izvornih povijesnih podataka defolijacija i gradacija smrekovog prelca na području Češke od 1784. do 2010. godine. Glavna razdoblja i područja masovne pojave i najžešćih gradacija prikazana su u Tablici 1. Intenzitet defolijacije preuzet iz brojnih literaturnih i ostalih izvora klasiran je u 4 kategorije (vidi sliku 1). Rezultat ovako klasiranih izvornih podataka prikazan je na dvije karte (slika 1 i slika 2). Na slici 1 prikazana je distribucija pojave i žestine defolijacije smrekovog prelca, svedeno prostorno na gospodarske jedinice. Na slici je vidljiva neujednačena distribucija registriranih defolijacija, kao i činjenica da u dijelu teritorija nikada nije zabilježena šteta od ovog defolijatora. Ovo se objašnjava izrazito nepovoljnim klimatskim uvjetima (visoka planinska područja) ili izostankom biljke domaćina (u nižim područjima). Jasno se uočavaju područja jakih gradacija (crvene točke). Na drugoj slici jasnije se razaznaje koja su područja napadnuta jače i češće (crvena boja). Također, autori dolaze do zaključka da je u promatranom razdoblju došlo do prostornog pomaka optimalnog područja pridolaska i gradacija smrekovog prelca. Taj se pomak dogodio u smislu povećanja nadmorske visine na kojima su se javljale gradacije. Na početku istraživanog razdoblja najžešće gradacije bilježene su na srednjoj nadmorskoj visini od 457 m n.m. Intenzitet i učestalost gradacija kasnije se javlja na srednjoj nadmorskoj visini od 640 m n.m. Autori zaključuju kako je očigledno kako se izvorišta gradacija "sele" na veće nadmorske visine. Također, analizom podataka utvrđeno je kako je glavna vrsta na "udaru" ovog defolijatora početkom 20. stoljeća bio bor, dok se u desetljećima koja su sljedila najveće štete bilježe na običnoj smreci. Dijelom se kao razlog tomu navode obimna pošumljavanja ovom, nekad popularnom šumskom vrstom drveća. Bez obzira na nedostatke kojih su autori svjesni u korištenju metode kriginga, zaključuju kako se ovim putem, zahvaljujući velikom broju podataka, može pokazati prostorna dinamika pojave smrekovog prelca na teritoriju Češke, uočiti "izvorišna područja" odakle započinju gradacije, kao i trend prostornog pomaka kojega povezuju s promijenjenim stanišnim uvjetima. Kao jedan od mogućih scenarija utemeljenih na recentnim klimatskim promjenama (povišenje temperature) navode pomicanje gradacijskih žarišta ovog važnog defolijatora Središnje Europe na veće nadmorske visine, odnosno više geografske širine. Prevedeno na naše geografsko područje, ovo bi značilo da bi smrekov prelac mogao postati još rjeđi u područjima gdje je i do sada bio prisutan u niskoj gustoći populacije.*

Ključne riječi: Lymantria monacha, povijest gradacija, Češka