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Review of historical outbreaks of the nun moth (*Lymantria monacha*) with respect to host tree species

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ABSTRACT: *Lymantria monacha* (L.) is a polyphagous pest feeding on coniferous and deciduous trees in Eurasia. The review presents an exhaustive overview of the nun moth outbreaks in Czech forests from 1784 to 2010 in terms of host tree species. This paper is unique because the majority of utilized sources have never been published formally. At least 22 genera of host trees, shrubs and herbs were recorded in the Czech Republic. On the other hand, two genera were evaluated as non-hosts and four genera as indifferent. The nun moth defoliated mainly coniferous forests (almost 90% of all recorded outbreaks with known data on host trees) in the Czech Republic. Forests with a mixture of coniferous and deciduous trees were defoliated nine times less frequent, and only an insignificant portion was recorded in pure deciduous forests. Although the host range is wide, the nun moth has defoliated predominantly spruce forests (almost 70% of all records with known data on host trees). Mixed coniferous (with a mixture of spruce, pine, larch, fir) forests were attacked three times less frequently than the spruce forests. Pine and larch forests were defoliated to a small extent. Defoliations were sorted also according to the intensity. The spatial distribution of recorded outbreaks is shown in maps.

Keywords: Czech Republic; polyphagy; conifers; broadleaves; spatial distribution; defoliation intensity

The nun moth (*Lymantria monacha* [L.]) is a strongly polyphagous pest feeding on coniferous and deciduous trees. Spruce (*Picea* spp.), larch (*Larix* spp.) and pine (*Pinus* spp.) are typical host tree species but the nun moth also causes extensive defoliation of other tree species during its outbreaks (Komárek 1931; Schwenke 1978).

Disastrous damage to forests caused by the nun moth was known in the past. Its first massive expansion in Central Europe was recorded in 1449. At least 26 significant events of an increase were recorded from that time until the late 19th century (Hošek 1981).

Mokrý (1923), Komárek (1931) and Blažek et al. (1932) described disasters that occurred in the Czech Republic during the first half of the 20th century. Also in neighbouring countries the nun moth is considered as a serious pest. In the period 1946–1995, six outbreaks were recorded in Poland (Głowacka 1996). In Germany, Poland and Czech Republic, the nun moth outbreaks were observed in 1993–1995 (Baier pers. comm.; Liška, Šrůtka 1994; Głowacka 1996). In 2003, the nun moth caused defoliation in Poland and Germany (Wanner et al. 2005; Möler, Wenk pers. comm.).

In the Czech Republic, no comprehensive overview of nun moth outbreaks is currently available; we can usually find only short articles describing the progress and spread of the outbreaks (Mokrý 1923; Blažek et al. 1932; Liška, Šrůtka 1994). However, Švestka (1968) published a short 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 in the following year (Liška, Šrůtka 1995; Zahradník et al. 1995; Liška 1996, 1999). A fundamental publication illustrating the largest outbreaks of the nun moth in the Czech Republic in the 1920s was published by Komárek (1931).

Although the nun moth can cause severe damage to coniferous and mixed forests, the first publication evaluating the outbreaks in the Czech Repub-

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lic in the long run was written by Uhlíková et. al. in 2011. Their study evaluated historical risk regions in the Czech Republic without emphasis on host tree species.

The aims of this review were (1) to create a list of host tree species recorded in the Czech Republic, and furthermore to provide (2) a spatial and (3) quantitative overview of historical outbreaks with respect to host trees species.

MATERIAL AND METHODS

During the period 2007–2014 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, interviews with foresters were also important. Historical unpublished essays and surveys from all archives of the Forest Management Institute (FMI) were the main source of information about nun moth feeding records. It was necessary to visit the central archives of FMI plus its branches in the Czech Republic and to contact the forest districts for looking up all available unpublished sources. More than 500 historical essays and surveys with potential information about the nun moth were searched. Such a data collection has never been realized and that is why it is entirely unique.

The LYMONDAT database of nun moth outbreaks in the Czech Republic was created by the authors on the basis of a historical data survey for purposes of spatial and quantitative analysis. The database contains information including the year or period of occurrence, the location of outbreaks and the area of nun moth defoliation in hectares, defoliation level, volume of harvested timber from nun moth outbreak foci, and information about a host tree species if it was mentioned. Each period was divided into individual years for the purpose of digitization. Information about defoliation levels in the primary resources was quite variable (and sometimes very brief). Therefore, each record was assigned an intensity rating (ranging from 1 to 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 defoliation (25–70%), 2 corresponds to light defoliation (less than 25%). A rating of 1 includes data with a sporadic occurrence of nun moth. In some cases the defoliation level was not identified. Special care was taken to avoid duplication of records within one year.

A list of host woody plants was created only with the use of outbreaks recorded in the Czech Republic. Sliwa (1987) published a very detailed list of host woody plants from an outbreak in 1978–1984 from neighbouring Poland; thus we added the list of Sliwa (1987) for comparing our results.

Using information from the LYMONDAT database, the percentages of coniferous, deciduous and mixed forests and separately of main coniferous tree species (spruce, pine, larch, fir and their mixture) were computed based on the number of recorded outbreaks. Furthermore, maps with the spatial distribution of outbreaks were created. For the purpose of this article, points of nun moth occurrence were recorded on the level of forest districts. Points visualized in the maps represent the coordinates of Forest District Administration. The ArcGIS 10.2 software (ESRI Inc. 1999–2013) was used for visualization of the spatial distribution of individual records.

RESULTS AND DISCUSSION

The oldest written record which was found comes from 1784. The collected data covered the period from 1784 to 2010. We found 2,557 records of nun moth outbreaks. 230 records contained precise information about host tree species.

A list of recorded host woody plants in the Czech Republic with their authors is shown in Table 1.

We obtain information about the host suitability of 7 coniferous, 25 deciduous tree genera and shrubs and 2 genera of herbs including Sliwa (1987) from neighbouring Poland. Specifically from the area of the Czech Republic we obtain information about the host suitability of 6 coniferous, 17 deciduous tree genera and shrubs and 2 genera of herbs. According to Table 1, it is clear that the nun moth was able to feed at least on 5 coniferous tree genera and 15 genera of deciduous trees and shrubs in the Czech Republic. Also 2 herbs were recorded in the Czech Republic, but it was obvious that these herbs were not main food sources. On the other hand, it was recorded that the nun moth obviously avoided *Taxus baccata* (Rašek 1922) and *Juglans* spp. (Komárek 1931). Sliwa (1987) also mentioned *Padus* spp. The feeding status of some plant genera is dubious, e.g. some authors observed feeding on *Robinia pseudoacacia* (Novák 1966) and some authors observed evasive behaviour (Rašek 1922; Komárek 1931). Some tree species like *Aesculus* spp., *Alnus* spp., *Fraxinus* spp. were recorded as strictly non-host ones (Rašek 1922;

Table 1. Review of host plants with the type of recorded relationship to nun moth caterpillars in the Czech Republic for the period 1784–2010

Host plant	Type of record	Author
Coniferous trees		
Abies spp.	+	7, 9, 13, 14, 16, 21, 26, 32, 33, 35, 36, 38, 40, 41, 52, 55, 58, 68
Larix decidua	+	7, 8, 9, 21, 26, 32, 33, 34, 36, 40, 41, 45, 46, 52, 68, 70
Pinus spp.	+	1, 2, 7, 13, 18, 19, 21, 23, 24, 26, 29, 32, 33, 35, 36, 38, 40, 41, 46, 47, 51, 52, 60, 66, 67, 68
Picea spp.	+	1, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17, 18, 19, 20, 21, 22, 23, 24, 25, 26, 27, 28, 29, 30, 31, 32, 33, 34, 35, 36, 37, 38, 39, 40, 41, 42, 43, 44, 46, 48, 49, 50, 52, 53, 54, 55, 56, 57, 58, 59, 61, 62, 63, 64, 65, 66, 67, 68, 69
Pseudotsuga menziesii	+	21, 36, 52, 68
Juniperus spp.	+	52
Taxus baccata	–	46
Deciduous trees		
Acer spp.	+	26, 52
Aesculus spp.	–/+	21–, 46–, 52+
Alnus spp.	–/+	21–, 46–, 52+
Betula spp.	+	26, 32, 33, 36, 52
Carpinus betulus	+	21, 26, 32, 36, 52
Fagus sylvatica	+	7, 19, 21, 32, 33, 36, 38, 46, 52, 67
Fraxinus spp.	–/+	21–, 46–, 52+
Juglans spp.	–	21
Malus spp.	+	21, 52
Padus spp.	–	52
Populus spp.	+	26, 52
Prunus spp.	–/+	21+, 52–
Pyrus spp.	+	21, 52
Quercus spp.	+	21, 26, 32, 33, 36, 52
Robinia pseudoacacia	–/+	21–, 32+, 46–, 52–
Salix spp.	+	26
Sorbus spp.	+	52
Tilia spp.	+	26, 52
Ulmus spp.	+	26, 52
Shrubs		
Corylus spp.	+	26, 52
Euonymus spp.	+	52
Frangula alnus	+	52
Rubus spp.	+	21, 52
Calluna vulgaris	+	46
Vaccinium myrtillus	+	21, 46, 52
Herbs		
Medicago spp.	+	21
Trifolium spp.	+	21, 46

(+) caterpillars were feeding on the plant, (–) caterpillars avoided the plant, (–/+) both relationships were recorded by different authors. Authors: Anonymous 1903[1], Anonymous a (year not mentioned)[2], Anonymous b (year not mentioned)[3], Anonymous c (year not mentioned)[4], Anonymous 1951[5], Anonymous 1964[6], Anonymous 1969[7], Anonymous 1994a[8], Anonymous 1994b[9], Horák 1960[10], Horák 1963[11], Horák 1965a[12], Horák 1965b[13], Horák 1969[14], Horák 1973[15], Horák 1981a[16], Horák 1981b[17], Horák 1986–1987[18], Hošek, Tomandl 1965[19], Hošek 1964[20], Komárek 1931[21], Kruml 1959[22], Kruml 1963[23], Kruml 1964[24], Kruml 1972[25], Křístek, Urban 2004[26], Liška, Šrůtka 1997[27], Ministr a (year not mentioned)[28], Ministr b (year not mentioned)[29], Ministr 1964a[30], Ministr 1964b[31], Novák 1966[32], Novák 1967a[33], Novák 1967b[34], Novák 1968[35], Novák 1969a[36], Novák 1969b[37], Novák 1970[38], Novák 1971[39], Novák 1972a[40], Novák 1972b[41], Novák 1973a[42], Novák 1973b[43], Novák, Kruml 1970[44], Novotný 1965[45], Rašek 1922[46], Rulec, Trnčík 1999[47], Schleger 1966[48], Schleger 1975[49], Schrantz, Tlapák 1964[50], Schrantz 1957[51], Sliwa 1987[52], Smejkal 2001[53], Šťasný et al. 2006[54], Tlapák 1957[55], Tlapák 1959a[56], Tlapák 1959b[57], Tlapák 1961a[58], Tlapák 1961b[59], Tlapák 1963a[60], Tlapák 1963b[61], Tlapák 1964[62], Tlapák 1965a[63], Tlapák 1965b[64], Tlapák 1965c[65], Tomandl (year not mentioned)[66], Tomandl 1962[67], Tomandl 1971[68], Urban 2000[69], Žán 1994[70].

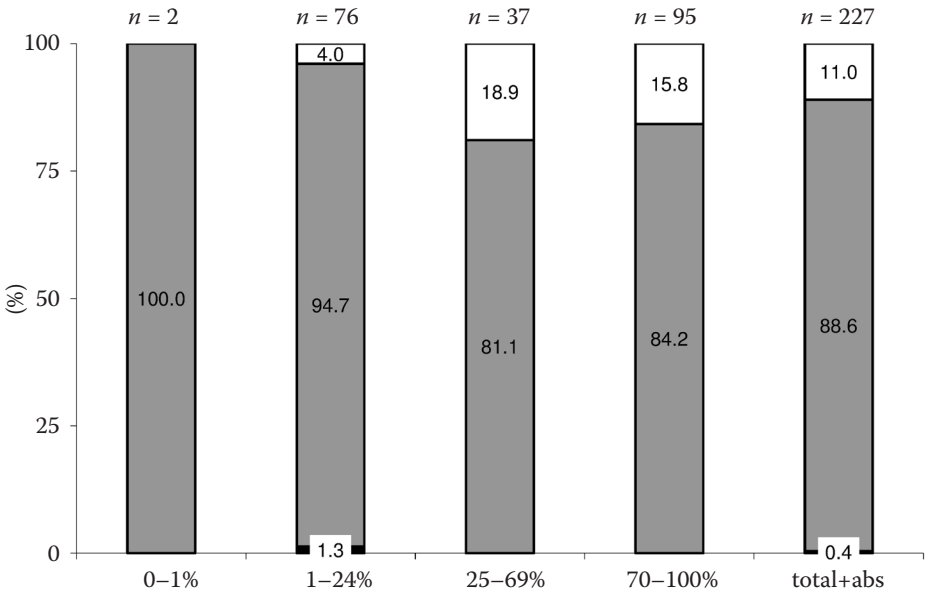

Fig. 1. Distribution of nun moth outbreaks in the Czech Republic in the period 1784–2010 according to the tree composition and defoliation intensity (black – pure deciduous forests, grey – pure coniferous forests, white – mixed forests)

Outbreaks categorized according the defoliation level with number of recoded outbreak foci

Komárek 1931) in the Czech Republic, but Sliwa (1987) considered these tree species as host trees with various range in conditions of Poland forests. On the other hand, *Prunus* spp. were recorded as host tree species in the Czech Republic (Komárek 1931) but in Poland as non-host ones (Sliwa 1987).

Generally, the nun moth is a strongly polyphagous species feeding on more than 200 host plant species (Lipa 1996) with the evident preference to *Picea abies* and *Pinus sylvestirs* (Khanislamov et al. 1962; Lipa 1996), *Abies* spp. and *Larix decidua*. (Lipa 1996). *Fagus*, *Carpinus*, *Betula* and *Quercus* are the most frequently preferred broadleaved trees (Lipa 1996). The host range is different in the latency and outbreak phase. In latency the polyphagy is restricted mainly to conifers. During the outbreak phase the polyphagy is really high (Komárek 1931).

Figs 3 and 4 illustrate the spatial distribution of outbreaks in the Czech Republic on spruce, pine, larch and fir for the period 1784–2010.

Results of nun moth outbreaks in the Czech Republic in the period 1784–2010 according to the tree composition and defoliation intensity are presented in Fig. 1. Although the host range of the nun moth is wide, the outbreaks appeared mainly in coniferous forests (88.6% of all recorded outbreaks with known data on host trees). Mixed forests of coniferous and deciduous trees were attacked less distinctly (11.0%) and only an insignificant portion (0.4%) was recorded in pure deciduous forests.

A similar situation was recorded for each category of defoliation intensity excluding the lowest defoliation intensity (0–1%) where all forests belonged to the pure coniferous forests (Fig. 1). On the other hand, this result was probably caused by a low number of recorded outbreaks. Among the categories with higher defoliation intensity (1–24, 25–69, 70–100%) the ratio between the pure coniferous, mixed and pure deciduous forest was relatively equal. Exactly, 94.7% for pure coniferous forests, 4.0% for mixed forests and 1.3% for pure deciduous forests in defoliation intensity of 1–24%, and 81.1%, 18.9%, 0.0% for defoliation intensity of 25–69%, and 84.2%, 15.8%, 0.0% for defoliation intensity of 70–100% (Fig. 1).

Results of nun moth outbreaks in the Czech Republic in the period 1784–2010 according to the tree composition and defoliation intensity in coniferous forests are presented in Fig. 2. The nun moth has defoliated predominantly spruce forests (67.6%) and also mixed coniferous (spruce, pine, larch, fir) forests (22.4%). Pine and larch forests were defoliated to a small extent (4.5% and 2.5%, respectively). A similar situation was recorded for all categories with higher defoliation intensity. We recorded 75.0% for spruce forests, 22.5% for the mixture of conifers, 1.3% for pine forests and 1.2% for larch forest in 70–100% defoliation intensity (Fig. 2). The situation for 25–69% defoliation intensity was as follows: 73.3% for spruce forests, 16.7% for the mixture of conifers and 10% for pine forests; and 55.6% for spruce forests, 33.3% for the mixture of conifers and 5.6% for pine forests and 5.5% for larch forest in 1–24% defoliation intensity. Completely different percentages were recorded for the lowest defoliation category (0–1%) where 100% of outbreaks were recorded only for the mixture of coniferous trees (Fig. 2). Also this result was caused by a low number of recorded outbreaks in this category. Generally, outbreaks with low defoliation intensity probably have often escaped foresters' notice.

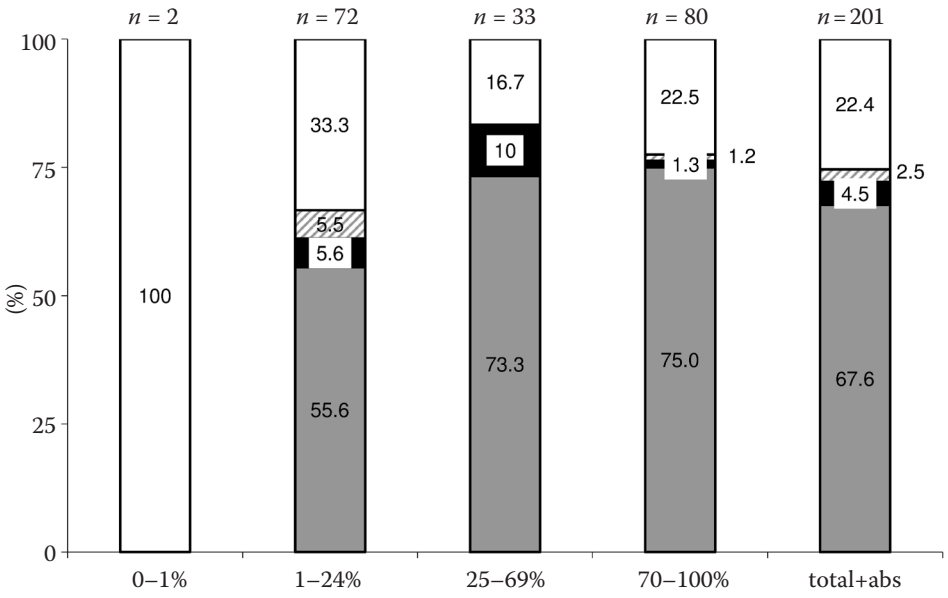

Fig. 2. Distribution of nun moth outbreaks in the Czech Republic in the period 1784–2010 according to the tree composition and defoliation intensity in coniferous forests (black – pure pine forests, grey – pure spruce forests, grey shaded – pure larch forests, white – forests with a mixture of coniferous species – spruce, pine, larch, fir)

Outbreaks categorized according the defoliation level with number of recoded outbreak foci

Although the fir was recorded as a host species of the nun moth by many authors in the Czech Republic (Table 1), no outbreaks were recorded in pure fir forests in the Czech Republic. On basis of our data, the fir was defoliated only when it was growing in a mixed stand. On the other hand, the presented review results only from historical literature records and does not reflect the historical species composition in those forests. That is why we cannot interpret our results like host preferences of the nun moth. We must take it like preferences in forests with a certain available tree species composition.

The spatial distribution of nun moth outbreaks in the Czech Republic in the period 1784–2010 according to the tree composition is presented in Figs 3 and 4 and corresponds with Figs 1 and 2, respectively. Fig. 3 shows the spatial distribution of outbreaks and coniferous, deciduous and mixed forests are distinguished. Pure coniferous forests are shown spatially according to the species presence in Fig. 4.

The forests were defoliated by the nun moth time by time in all regions in the Czech Republic excluding southern Moravia and around the Labe river in Bohemia. Exact data on tree host species of defoli-

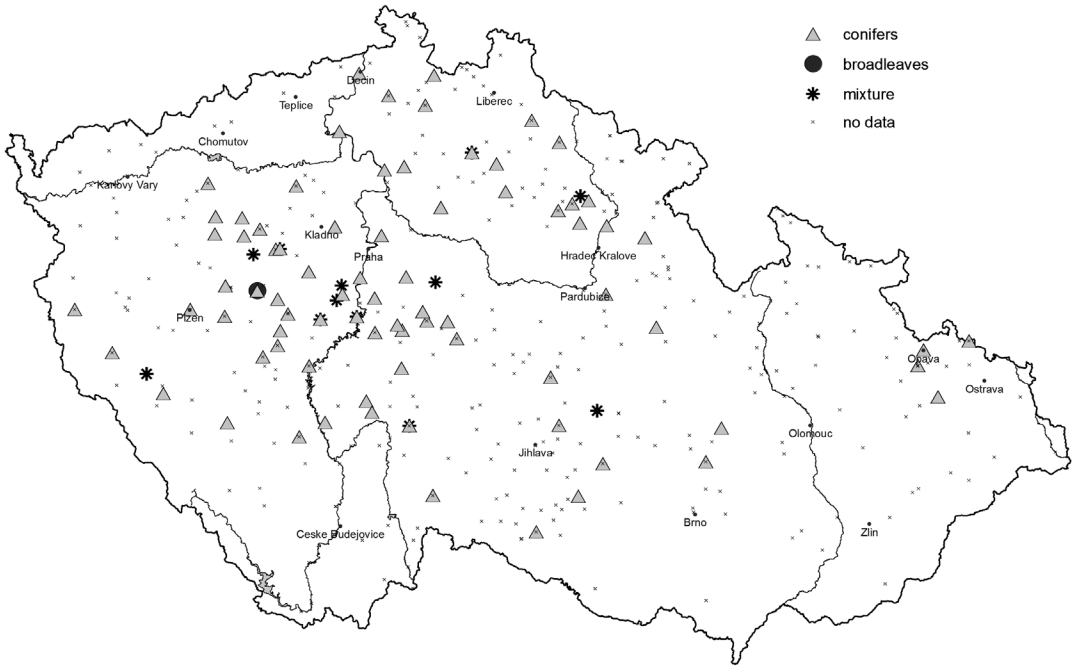

Fig. 3. Spatial distribution of nun moth outbreaks in the Czech Republic in the period 1784–2010 according to the type of forest (each point represents forest district with at least 1 outbreak separately by the type of forest)

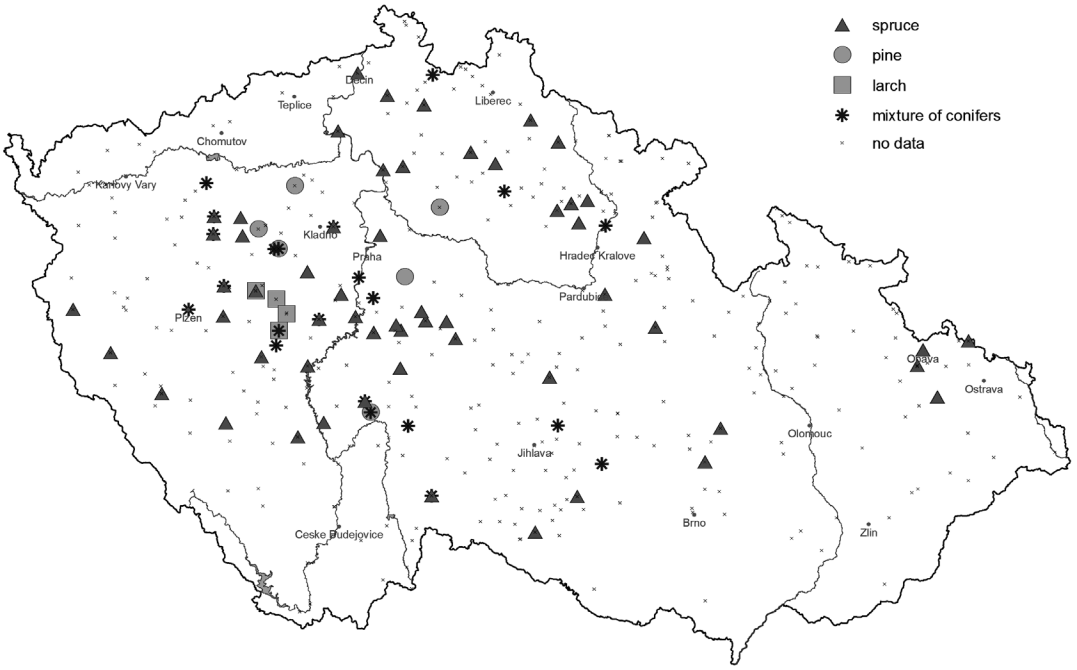

Fig. 4. Spatial distribution of nun moth outbreaks in the Czech Republic in the period 1784–2010 according to the tree composition in coniferous forests. Each point represents forest district with at least 1 outbreak separately by the type of recorded tree species

ated forests were missing in many cases especially in the western part of Bohemia around the city of Karlovy Vary, in the area of northern Moravia, in the zone along the eastern border of Moravia, and also in southern Bohemia and partially in southern Moravia (Fig. 3). Dominance of outbreaks in coniferous forests was obvious. These outbreaks were distributed throughout all the Czech Republic but they were more concentrated in Bohemia and western part of Moravia. Scarce occurrence of outbreaks in mixed forests was relatively regularly distributed in Bohemia and only one such outbreak occurred in Moravia, concretely in the environs of Žďár nad Sázavou. Only one outbreak occurred in pure deciduous forests, namely in the environs of Zbiroh in central Bohemia (Fig. 3).

Historical outbreaks in coniferous forests were the most frequent in pure spruce stands where they occurred more or less regularly throughout the whole of the Czech Republic (Fig. 4). These outbreaks were followed by outbreaks occurring in coniferous stands with a mixture of spruce, pine, larch and fir at their various ratio excluding the eastern part of Moravia. Only six outbreaks (environs of the cities of Rakovník, Opařany, Křivoklát, Benátky nad Jizerou, Panenský Týnec, Říčany) were recorded in pure pine stands. It is interesting that outbreaks in pure larch forests were recorded only in the area of the Brdy Mts., concretely in Zbiroh, Hořovice, Jince and Obecnice managed forests (Fig. 4).

CONCLUSIONS

The nun moth is a highly polyphagous species with documented polyphagy in the Czech Republic. Although historical outbreaks were recorded in all the Czech Republic, more records belong to the Bohemian region compared with Moravia. Almost 90% of attacked stands belong to coniferous stands, only approximately one tenth belongs to mixed forests of deciduous and coniferous trees. Outbreaks in pure deciduous stands were very sporadic. The majority of the outbreaks in coniferous forests were recorded in spruce stands (approximately 70%), the outbreaks in mixed coniferous stands were 3 times less frequent. Pure pine stands or even pure larch stands were attacked exceptionally. Despite the fact that pure coniferous stands are growing at higher elevations, the nun moth defoliated coniferous stands especially at middle altitudes in the central part of the Czech Republic. This fact obviously suggests the existence of climatic optimum for nun moth outbreaks. With respect to predicted climate change (Vanhanen et al. 2007) we can suppose a shift of the climatic optimum of nun moth occurrence towards the higher elevations. Spruce as the main commercial tree species has been cultivated in managed forests in Central Europe, thus we can suppose relatively the same tree composition in Czech managed forests especially at higher altitudes in the future. Therefore also the nun moth outbreaks

should still occur in forests with the tree species composition recorded by us on the basis of historical records. Furthermore, as a result of the shift of risk regions in the Czech Republic, the risk regions should became smaller. However, attacked forests will probably have more or less the same tree species composition or they will have a little more coniferous tree composition in the future. Also we assume that the nun moth outbreaks could start to occur in current protected areas with natural dynamics of high-elevation forests and also with dominance of coniferous trees. Recently, *Ips typographus* (L.) has played the role of so-called keystone species (Müller et al. 2008) in protected areas. In the future the nun moth could play a similar role in protected areas like *I. typographus* (L.) nowadays. During the severe outbreaks the nun moth is able to do damage even very young stands. Furthermore, spruce stands have a very weak ability of regeneration after strong defoliation. The importance of the nun moth will probably remain stable in the future.

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