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Research Article

The Solar Activity Cycles and the Outbreaks of the Gypsy Moth – *Lymantria dispar* L. (Lepidoptera: Lymantriidae) in Serbia

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Abstract
Seven outbreaks of the gypsy moth in Serbia for the last seven decades were researched in relation to the solar activity cycles and the solar flux at 2.8 GHz. Based on data analysis, three types of outbreaks were selected. A–type includes the second half of the solar cycle. This type of the outbreak doesn't get into the next cycle (the values of the solar flux at 2.8 GHz decrease in the final phases). Besides the final years of the solar cycle, B–type also includes the initial years of the next cycle. C–type appears in the beginning of the solar activity cycle. At B-type and C-type the interruption of the outbreak occurs while the solar flux at 2.8 GHz value is increasing. The outbreaks of A-type were: 1970–1976 and 2004–2007; B-type: 1952–1956, 1962–1966, 1984–1987 and 1995–1998; C-type: 2009–2014. The obtained results suggest that the gypsy moth outbreaks are caused by corresponding range of energy coming from the Sun.

Key words: gypsy moth, Lymantria dispar, outbreak, Sun, solar cycle, solar flux, Serbia.

Introduction

The gypsy moth – *Lymantria dispar* L. 1758 (Lepidoptera: Lymantriidae) has extreme tendency for overpopulation. It has wide range of distribution (Palaearctic), and it is especially significant in the Balkan Peninsula where it causes large problems in agriculture and forestry.

For the first time in Serbia, the process of overpopulation was followed through all phases throughout the outbreak 1953–1957. The previous outbreak (1946–1949) was considerably weakly studied. Especially little knowledge was on the initial phases, so that mainly subjective observations and assessments were used (Vasić 1958). Based on the assessments, the reconstruction of the course of the final phases was carried out by which it is supposed that the population decrease occurred in 1948.

The outbreaks of the gypsy moths can be acute, chronic and local. A very fast population increase occurs at acute outbreaks. At chronic outbreaks, the process develops slowly, the culmination of the population is not high and the population decrease develops gradually (Vasić *et al.* 1981). The outbreaks of the gypsy moths differ mutually by duration (3–6 years), while the periods between two outbreaks can also last differently.

In the period after the World War II, eight outbreaks of gypsy moths were recorded in Serbia: 1947–1949, 1953–1957, 1963–1966, 1970–1973, 1984–1987, 1995–1998 (Marović *et al.* 1998), 2004–2007

(Mihajlović 2008b) and 2009–2014 (Tabaković–Tošić 2015; Hlásny *et al.* 2016). The outbreaks 1970–1973 and 1984–1987 were very weak and practically without larger harmful effects, while the rest of the outbreaks were very strong (Mihajlović 2008b).

There are many theories on the causes of the insect outbreaks. However, none of them has generally been accepted so far, nor has it given clear reasons for the origin of the insect outbreak, and therefore they need to be considered as hypotheses, not theories (Mihajlović 2008a).

Authors from the USA consider that predators are of great significance for regulating the gypsy moth populations. The increase in the gypsy moth populations occurs at low population of mice *Peromyscus leucopus* (Rafinesque, 1818), which is in dependence on the fructifying of oak tree. In the case of low population, the reduction in population is mainly carried out by mice, while other factors affect high population (Elkinton *et al.* 1996). Other authors (Jones *et al.* 1998; Liebhold *et al.* 2000) also ascertained the connection among the gypsy moths, predators and the quantity of acorns. Mice *Peromyscus* represent the dominant factor of the decreasing populations of *Lymantria dispar* L. pupae in the south-eastern part of the USA. Invertebrates are the most significant predators at low population of mice (due to the lack of acorn) (Hastings *et al.* 2002). The researches were carried out in eastern Austria on the impact of predators on artificially introduced populations of *Lymantria dispar* L. pupae. It was found that mice were the most significant predators, primarily *Apodemus flavicollis* (Melchior, 1834), while *Calosoma* Weber, 1801 spp. and other invertebrates caused mortality below 8% (Gschwantner *et al.* 2002). However, Selås (2003) considers that defoliation originates more probably as the consequence of high production of acorn and explains it by changes in the chemical structure of oak leaves. On the contrary, Liebhold & Elkinton (2003) consider that there are little evidences that the quality of leaves plays significant role in the dynamics of the gypsy moth population.

Some authors studied the impact of food, i.e. leaves of different kinds of trees on the gypsy moth populations (Marković *et al.* 1997; Lobinger & Skatulla 2001; Shields *et al.* 2003; Giertych *et al.* 2005). It was found that the contents of flavonoid, total lipid fractions, fatty alcohol and alcohol increased in leaves of damaged (up to 75%) birch trees one year after defoliation, and the amounts of free sterol and triterpene decreased. These changes brought to weak vitality of insects and sharp decline of the population density (Bakhvalov *et al.* 2006).

Some authors researched the connection between the solar activity and overpopulation of insects. The strong negative connection was found between the number of the sunspots and populations of Lepidoptera in Norway. Also, the overpopulations of these species are noticed to appear in regular intervals of approximately 10 years (Selås *et al.* 2004). Stronger intensities of the gypsy moth infestations in Croatia appear along with the decreasing trend each 10–11 years (Pernek & Pilaš 2005). The data analysis from 1961 on the population of beet root weevil (*Bothynoderes punctiventris* Germ.) in Vojvodina showed certain periodicity of about 11 years. It was found that the population maximum of this species was followed by the solar activity maximum (expressed through the solar flux at 2.8 GHz) with the delay of 7 years (Jovanović *et al.* 2006). The influence of the solar flux at 2.8 GHz on the size of the population of *Drosophila melanogaster* Meigen, 1830 was also confirmed (Izmaylov *et al*. 2005; Kravchenko *et al*. 2006). The mentioned results indicate the similarity with the typical eleven-year periodicity of the solar cycles.

Milenković *et al.* (2010) used the available literature data in order to determine the periods of the gypsy moth outbreaks in Serbia: 1952–1956, 1962–1966, 1970–1976, 1984–1987, 1995–1998 and 2004–2007. The authors established that the average solar flux at 2.8 GHz values ranged between 83.8 and 101.8 sfu (unit of solar flux at 2.8 GHz) throughout these periods. On the contrary, the average values of solar flux at 2.8 GHz were between 147.9 and 188.3 sfu throughout the periods without outbreaks. The solar flux at 2.8 GHz represents the ecological factor, since the increase in the gypsy moth populations occurs at values ranging approximately between 70 and 120 sfu.

Energy which enters into the biosphere in the form of charged particles has been the catalyst of different biogeographical processes. Several researches are carried out in which the solar wind and the origin of forest fires are brought into the connection (Radovanović *et al.* 2005; Ducić *et al.* 2008; Gomes & Radovanović 2008; Radovanović & Gomes 2008; Radovanović *et al.* 2009; Gomes *et al.* 2009; Radovanović 2010; Radovanović *et al.* 2013; Radovanović *et al.* 2015a; Radovanović *et al.* 2015b).

The main hypothesis in this paper is that the types of outbreaks can be singled out on the basis of the connection between the periods of gypsy moth outbreaks and the solar activity cycles. Moreover, it is supposed that the interruption or continuation of outbreak depend on the value of the solar flux at 2.8 GHz in the years of the minimum solar activity.

Material and Methods

Analogy method has been used to confirm the potential connection between the processes on the Sun and the expansion of the gypsy moth.

The researches included only gypsy moth outbreaks in Serbia in the period of which there are complete data on the solar flux at 2.8 GHz: 1952–1956, 1962–1966, 1970–1976, 1984–1987, 1995–1998, 2004–2007 (Milenković *et al.* 2010) and 2009–2014 (Tabaković-Tošić 2015; Hlásny *et al.* 2016).

The solar flux at 2.8 GHz data (average monthly values for the period from 1948 to 2016) are downloaded from: http://www.esrl.noaa.gov/psd/data/correlation/solar.data.

Table 1 shows the solar activity cycles in the period to which the mentioned researches refer.

Table 1. The solar activity cycles in the period 1948-2016.

Solar activity cycle	period
18	February 1944 – April 1954
19	April 1954 – October 1964
20	October 1964 – June 1976
21	June 1976 – September 1986
22	September 1986 – May 1996
23	May 1996 – December 2008
24	December 2008 –

Source: http://www.solen.info/solar/cycles1_to_present.html

The types of the gypsy moth outbreaks in Serbia are singled out on the basis of the parts of the solar activity cycles in which they develop, as well as on the basis of the solar flux at 2.8 GHz trend.

On the basis of mentioned data, in this case it was not possible to use usual statistical procedure of examination of the connection.

Results and Discussion

The trend of the solar flux at 2.8 GHz values and the gypsy moth outbreaks in the period 1948–2016 are shown at Figure 1.

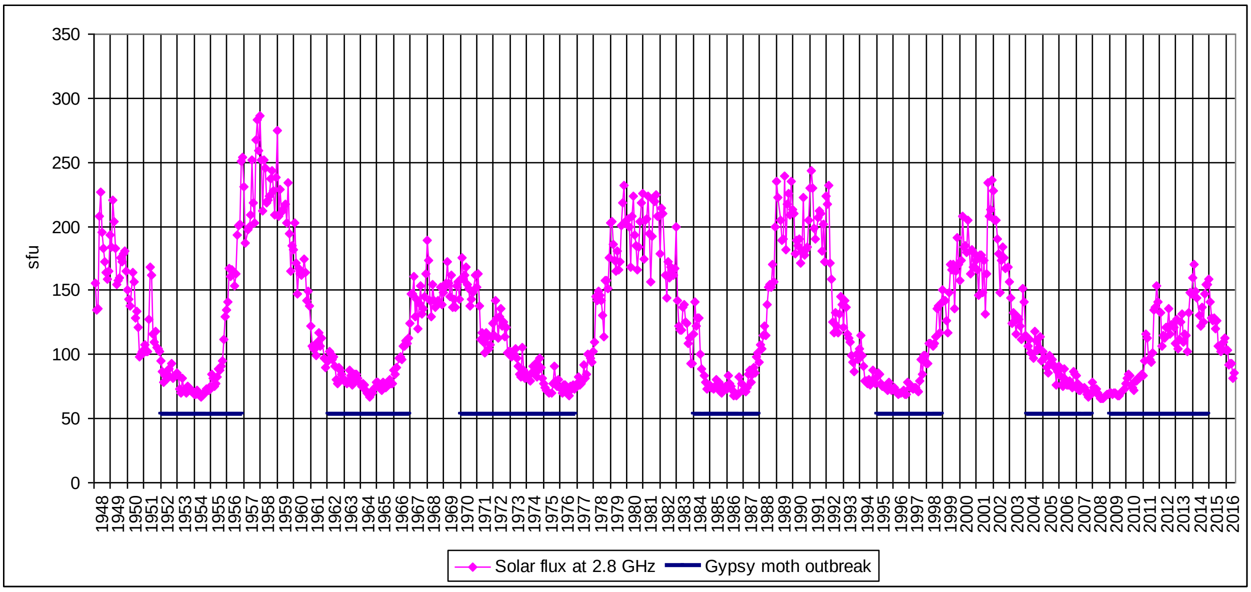

Figure 1. Gypsy moth outbreaks and the solar flux at 2.8 GHz in the period 1948–2016 (the solar flux at 2.8 GHz data source: http://www.esrl.noaa.gov/psd/data/correlation/solar.data)

Three types of outbreaks are singled out by the analysis of the last seven gypsy moth outbreaks in Serbia in relation to the solar activity cycles (Table 2).

Table 2. Types of gypsy moth outbreaks according to solar activity cycles.

Type of gypsy moth outbreak	Characteristics	Solar flux at 2.8 GHz	Outbreaks
A–type	Appears in the second half of the solar activity cycle and doesn't get into the next cycle	Decreases, may have extremely low values at the end	1970–1976 2004–2007
B–type	Comprises the final years of the solar activity cycle and the initial years of the next cycle	Decreases throughout the last cycle years, then moves within relatively low values, and increases at the beginning of the next cycle	1952–1956 1962–1966 1984–1987 1995–1998
C–type	Appears in the beginning of solar activity cycle	Increases through initial years of the cycle, decreases with high values	2009–2014

The outbreaks of the gypsy moth in Serbia during solar cycle 23 represent the characteristic examples of A–type (2004–2007) and B–type (1995–1998) (Figure 2).

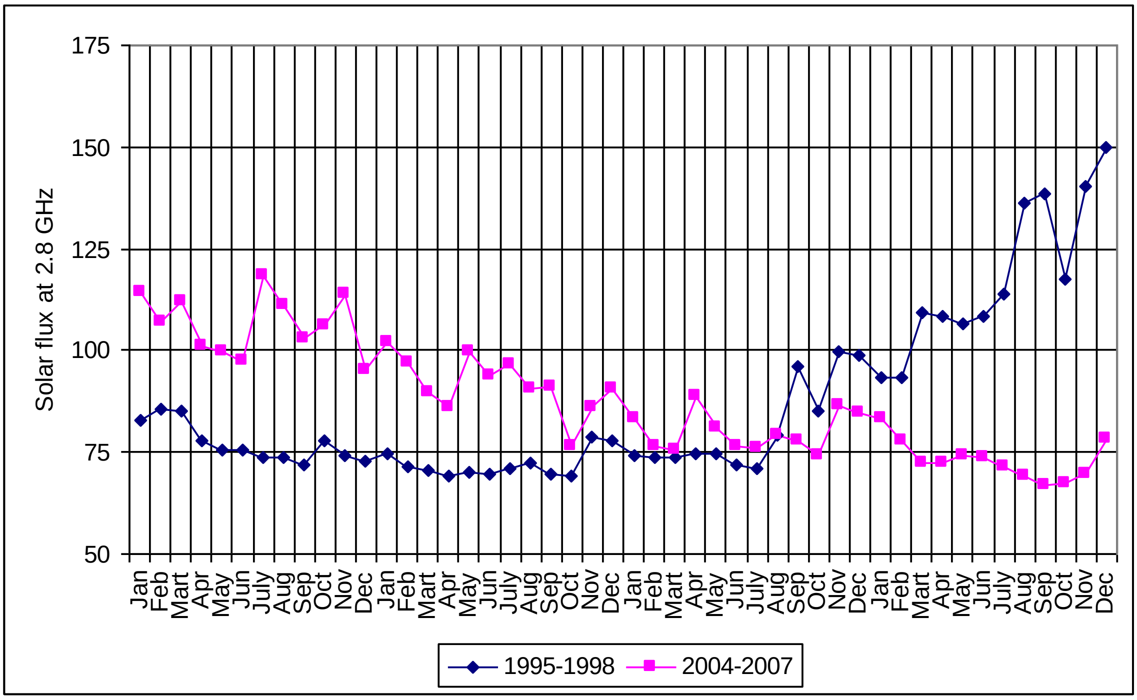

Figure 2. Average monthly values of the solar flux at 2.8 GHz throughout the gypsy moth outbreaks 1995–1998 (B–type) and 2004–2007 (A–type) (the solar flux at 2.8 GHz data source: http://www.esrl.noaa.gov/psd/data/correlation/solar.data).

The outbreak 2004–2007 developed completely in the second half of the solar cycle 23 (Table 1). The maximum average monthly value of the solar flux at 2.8 GHz was recorded on December 2001 (235.6 sfu). The outbreak occurred when the solar flux at 2.8 GHz values settled down below 120 sfu. The outbreak lasted till the solar flux at 2.8 GHz value appeared to be below 70 sfu. This is the period with the lowest values of the solar flux at 2.8 GHz ever recorded.

The outbreak 1995-1998 included the end of the solar cycle 22 and the beginning of the solar cycle 23 (Table 1). The year 1994 was the preparation year for this outbreak during which the average monthly values of the solar flux at 2.8 GHz, with an exception of January, were below 100 sfu. The lowest values of the solar flux at 2.8 GHz were recorded in 1996, April (69.3 sfu), June (69.6 sfu), September (69.4 sfu) and October (69.2 sfu). Throughout 1998, a sudden increase in values was recorded from 93.4 sfu (January and February) to 150.1 sfu (December).

The outbreaks of gypsy moths 1995–1998 (B-type) and 2004–2007 (A–type) caused significant problems in agriculture and forestry of Serbia.

The outbreak spread surface was 10,000 ha during 1995, and about 80,000 ha in the following year. The culmination was the year of 1997 when the outbreak was ascertained in the area of 500,000 ha (forests, orchards, parks). The gypsy moth control started in 1996. It continued in 1997, and mechanical, chemical and biological measures were applied (Mihajlović *et al.* 1998).

In 2003, augmented populations of *Lymantria dispar* appeared in forests of central Serbia on about 143,000 ha and about 17,000 ha in Vojvodina. Throughout 2004, the area of 347,000 ha was spread over in central Serbia, while it reduced (14,000 ha) in Vojvodina. In the following 2005, the area of 64,000 ha was infested. The infestation was very strong on 41% of the infested area (Tabaković–Tošić 2005; 2006).

It was found that the interruption of outbreak occurred upon extremely low values of the solar flux at 2.8 GHz (A–type, example of outbreak 2004–2007). B–type appeared when extremely low values of the solar flux at 2.8 GHz were absent. However, the results of the research have shown that the course, as well as the interruption of the outbreak also depends on the phase.

The only C–type outbreak was recorded in the period 2009–2014. During 2008 the values of the solar flux were extremely low. Average monthly value in June was 65.9 sfu and in July 65.7 sfu. After the beginning of the new solar cycle (December 2008) the values increased. According to Tabaković–Tošić (2015) during the following years some areas of Central Serbia were particularly endangered and the end of the outbreak was in 2014 due to the entomopathogenic fungus *Entomophaga maimaiga* Humber, Shimazu and R.S.Soper (1988).

Among researched cases, certain specifics are noticed with the outbreak 1970–1976. As the outbreak didn’t get into the next solar activity cycle, it has been classified into A–type. In this case however, the extremely low values of the solar flux at 2.8 GHz were not recorded at the end of the outbreak. The exception is July 1976 (67.5 sfu), whereas the average values of the solar flux at 2.8 GHz of the other months were over 70 sfu. Having in mind that the periods of gypsy moth outbreaks in Serbia are given differently, the question is whether this outbreak began in 1970 or 1971. Throughout 1971, the increase in the gypsy moth population was recorded, but also the decline of the solar flux values below 120 sfu (116.7 sfu in April). Moreover, the solar cycle 20 was relatively weak. This outbreak was of the weak intensity, but the increased expansion lasted unusually long. Based on the mentioned, it can be supposed that the gypsy moth does not have biological potential for outbreaks longer than 6 years.

The periods of the gypsy moth outbreaks in Serbia are differently presented in literature (for example: Marović *et al.* 1998 and Mihajlović 2008b). This caused difficulties during the research. The outbreaks given by the calendar years and not by periods which represent one generation of gypsy moths make an additional problem. Namely, the gypsy moth has one–year generation and it swarms and lays eggs approximately in the middle of the year, so it would be more regular to present data in this way. Nevertheless, the outbreaks are given in the calendar years in this paper due to discordance of data on the gypsy moth outbreak in Serbia.

The unevenness of the phenomenon of gypsy moths within geography has been another problem. Namely, it occurs that large populations of gypsy moths are present in some area and on contrary such cannot be seen in the surroundings, even though the environmental conditions are almost equal. Sometimes these examples can be found in the same forest.

Biotical factors (reproduction, quantitative indexes, diseases, parasites, etc.) are primarily used for gypsy moth and other insect population prognosis. However, the prognoses are usually short–term.

If the values of the solar flux at 2.8 GHz are used for the long–term prognosis of the development of the gypsy moth outbreak, one should bear in mind that the solar flux increases at higher speed in the beginning of the cycle than it decreases in the second half of the cycle. It turned out that the gypsy moth outbreaks in Serbia do not appear under the maximum solar flux at 2.8 GHz values throughout the solar activity cycle. At stronger cycles, the periods unfavourable for the increase in gypsy moth population last longer. On the contrary, the solar flux at 2.8 GHz increases more slowly and achieves considerably lower maximum values at weaker cycles, so that the periods unfavourable for the increase in the gypsy moth population are shorter. Therefore, longer duration of the outbreak could be expected in the case of weaker cycle.

In addition, Boberg & Lundstedt (2002) determined the connection between solar activity and the North Atlantic Oscillation (NAO). NAO is defined as the sea–level pressure difference between the subtropical anticyclone over the Azores and the subpolar depression over Iceland. It affects the weather in Europe and some parts of the North America (Hurell & Van Loon, 1997). Ducić *et al*. (2012) determined the correlation between NAO index and the damage in Serbian forests caused by gypsy moth. These results could also be used in the prognosis of the future gypsy moth outbreaks.

The further research of the outbreaks of the gypsy moth should be concentrated on the solar flux at 2.8 GHz and other solar activity parameters, as well as on the climate indices.

Conclusion

The types of the gypsy moth outbreaks in Serbia are singled out according to the parts of the solar activity cycle they comprise.

A–type appears in the second half of the solar activity cycle and doesn't get into the next cycle. Throughout the outbreak of this type, the solar flux at 2.8 GHz decreases and the interruption occurs upon very low values (outbreak 2004–2007). Also, the outbreak 1970–1976 which ended in the same year as the solar cycle 20 is classified into A–type.

B–type includes the years at the end of the solar activity cycle, as well as the first years of the cycle. This type includes the outbreaks 1952–1956, 1962–1966, 1984–1987 and 1995–1998.

C–type appears in the beginning of solar activity cycle (outbreak 2009–2014).

The obtained results indicate that astrophysical parameters are necessary to be taken into consideration while making the prognostic models for the gypsy moth outbreaks.

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