

THE INFLUENCE OF THE SOLAR FLUX AT 2.8 GHZ ON OUTBREAKS OF GYPSY MOTH (*LYMANTRIA DISPAR* L.) (LEPIDOPTERA: LYMANTRIIDAE) IN SERBIA

M. MILENKOVIĆ¹, V. DUCIĆ² and B. MILOVANOVIĆ³

¹ Faculty of Forestry, 11030 Belgrade, Serbia

² Faculty of Geography, 11000 Belgrade, Serbia

³ Geographical Institute "Jovan Cvijić" Serbian Academy of Sciences and Arts, 11000 Belgrade, Serbia

Abstract - The connection between the solar flux at 2.8 GHz (based on mean monthly values) and the outbreaks of gypsy moths (*Lymantria dispar* L.) in Serbia was investigated. The researches included six outbreaks from 1952 to 2007. The average values of the solar flux ranged between 83.8 and 101.8 sfu during the outbreaks, whereas they were between 147.9 and 188.3 sfu for the periods without outbreaks. The results of the research showed that the increase in the number of gypsy moths appears when the values of the solar flux at 2.8 GHz range from 70 to 120 sfu.

Keywords: Gypsy moth, *Lymantria dispar*, outbreak, solar flux, solar activity, Serbia

UDC 632.786:595.786(497.11)

INTRODUCTION

The region of gypsy moth includes the Palaearctic, whereas the largest damage caused by this species appears in the Balkan Peninsula. In the period from 1862 to 1998, sixteen gypsy moth outbreaks were recorded in Serbia (Marović et al., 1998).

The subject of research in this paper refers to gypsy moth outbreaks in Serbia from the Second World War: 1947-1949, 1953-1957, 1963-1966, 1970-1973, 1984-1987, 1995-1998 (Marović et al., 1998) and 2004-2007 (Mihajlović, 2008).

Little data can be found on outbreaks from 1947 to 1949. The first gypsy moth outbreak in Serbia that was followed through all its levels was in the period from 1953 to 1957 (Vasić, 1958).

Mihajlović (2008) stated that the outbreaks from 1970 to 1973 and 1984 to 1987 were of weak intensities and without excessive harmful effects, while the rest of the 5 outbreaks were of very strong intensity.

The gypsy moth outbreaks differ mutually both by duration (3-6 years) and type (acute, chronic and

local). The number of years between two outbreaks also varies. Apart from much scientific knowledge, the causes of overpopulation of gypsy moth and other species of insects are not well enough known.

Gschwantner et al. (2002) and Hastings et al. (2002) ascertained the significance of predators in the decline of large numbers of gypsy moths. Elkinton et al. (1996) and Liebhold et al. (2000) emphasized the connection between gypsy moths, mice and the fructifying of acorn. Selas (2003) considered that defoliation occurs as a consequence of the high production of acorns and also emphasized the changes in the chemical structure of the foliage of the oak tree. Marković et al. (1997), Bakhvalov et al. (2006) and Milanović (2010) dealt with the influence of food on the population of gypsy moths. Perić-Mataruga et al. (2001) and Lazarević et al. (2007) researched the differences between the population of gypsy moths from oak trees and black locust, while Lazarević et al. (2008) studied the genetic variability of different gypsy moth populations. Ilijin et al. (2010) investigated the influence of the increased density of breeding on the medial neurosecretory neurons of the protocerebrum of gypsy moth larvae.

There are many hypotheses for the causes of outbreaks of insects, but none of them have given a satisfactory explanation. In the past, among other things, there have been attempts to bring outbreaks into connection with the number of sunspots.

In recent times, some authors have used the number of sunspots as the solar activity index. Thus, Selas et al. (2004) established the strong negative connection between the number of sunspots and the number of some Lepidoptera in Norway. The overpopulations were observed at regular intervals of approximately 10 years, which is near to the typical eleven-year period of sunspots.

However, there are some other indexes of the solar activity besides sunspots. The solar flux at 2.8 GHz (2800 MHz) (Solar flux at Earth) is a significant integral index that is represented by solar flux units (sfu). These are the units of the solar radio radiation per unit of frequent interval, equal to 10^{-22} W per m^2 per Hz on Earth.

Jovanović et al. (2006) researched the influence of the solar activity on the dynamics of the number of *Bothynoderes punctiventris* Germ. in Vojvodina. Analyzing the data on the number of this species from 1961, they established that certain eleven-year periods appears. It was concluded that the maximum number of *B. punctiventris* follows the maximum of the solar activity (expressed over the solar flux at 2800 MHz) with a seven-year delay.

Researching outbreaks of gypsy moth in Croatia, Pernek and Pilaš (2005) concluded that stronger intensities of attacks appear with decreasing trend every 10-11 years.

Milovanović and Radovanović (2009) established the connection between solar activity and the circulation of atmosphere in the period from 1891 to 2004. Ducić et al. (2008), Gomes and Radovanovic (2008), Radovanović and Gomes (2008), Radovanović et al. (2009), Gomes et al. (2009), Rado-

vanović (2010) brought the solar wind into connection with forest fires.

The main hypothesis in this paper is that there is a linkage between the solar activity (over the solar flux at 2.8 GHz) and gypsy moth outbreaks.

MATERIALS AND METHODS

The data for solar flux at 2.8 GHz were used in the paper (average monthly values) for the period from 1948 to 2009 (1948 is the first year with complete data; <http://www.esrl.noaa/psd/data/correlation/solar.data>)

Based on these values, the average solar flux values were calculated for the periods of outbreaks and periods without them (by calendar years).

The last six outbreaks of gypsy moths in Serbia were recorded in: 1953-1957, 1963-1966, 1970-1973, 1984-1987, 1995-1998 and 2004-2007. The outbreak in 1947-1949 was not taken into consideration due to the lack of data, either for the solar flux at 2.8 GHz, or the outbreak itself.

Since temporal series and small numbers of cases were available, the Wilcoxon test was chosen for testing the significance of the difference in the solar flux at 2.8 GHz in the years of presence/absence of an outbreak of gypsy moths. The test was based on ranks of differences between observed variables, so that it is considered to be a successful non-parametrical alternative to the t test for dependent samples.

RESULTS AND DISCUSSION

Outbreaks of the gypsy moth in Serbia originate under lower values of the solar flux at 2.8 GHz (Tab. 1).

At the level of significance $p < 0.01$ there is a statistically significant difference between the values of the solar flux at 2.8 GHz in the years/epochs of outbreak and the years/epochs of absence of gypsy moth outbreak (Tab. 2 and Fig. 1).

Table 1. Average values of the solar flux at 2.8 GHz throughout the periods of outbreaks and periods without outbreaks

Period	Outbreak (Periods of outbreaks are marked by number 1, periods without outbreak by 0)	Average value of solar flux at 2.8 GHz (sfu)
1953-1957	1	131.3
1958-1962	0	159.8
1963-1966	1	83.1
1967-1969	0	147.9
1970-1973	1	122.2
1974-1983	0	135.4
1984-1987	1	83.8
1988-1994	0	156.9
1995-1998	1	87.0
1999-2003	0	164.6
2004-2007	1	87.8

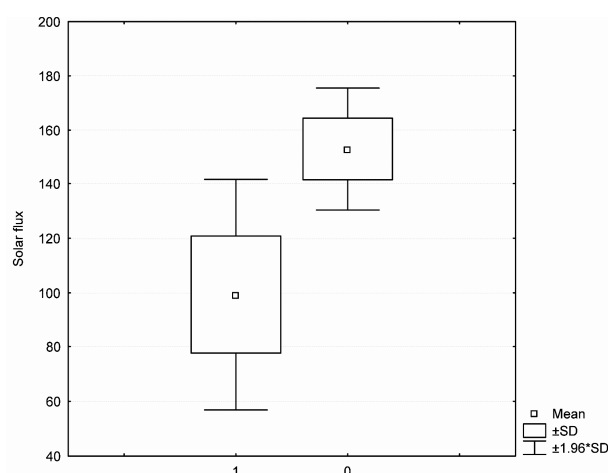
There are certain deviations in literature when mentioning the periods of gypsy moth outbreaks in Serbia. Therefore, we made the analysis and correction and repeated the procedure of statistical analysis with new periods of outbreak on the basis of available literature (Vasić, 1958; Mihajlović et al., 1998; Tabaković-Tosić, 2005; Mihajlović, 2008) (Tab. 3).

Using corrected values, the results of the Wilcoxon test are identical with the results in which the data from the literature were used. Differences can be noticed on the basis of the graphic representation of data (Fig. 2).

The average values of the solar flux at 2.8 GHz throughout the periods of outbreaks of gypsy moth in Serbia were between 83.3 and 101.8 sfu. The average values throughout the periods when outbreaks of gypsy moths were not recorded in Serbia were between 147.9 and 188.3 sfu. This implies that the outbreaks of gypsy moth in Serbia do not appear under

Table 2. Wilcoxon test of difference in the solar flux at 2.8 GHz in the years of presence/absence of outbreak of gypsy moths

Solar flux/outbreaks	Number of cases	Z	p-level
	11	2.934	0.003

**Fig. 1.** Values of the solar flux at 2.8 GHz in the years/epochs of outbreak (sign 1) and absence of outbreak (sign 0) of gypsy moth

high values of solar flux at 2.8 GHz, which are characteristic for the middle of the solar activity cycle, but only the low ones, characteristic for the beginning and the end of the cycle. However, throughout 2008 and 2009 there were no outbreaks of gypsy moth and very low values of solar flux were registered. The average value for the period from January 2008 to November 2009 was 69.4 sfu, whereas it was 66.2 sfu in the period from June to September 2008 (calculated over the average monthly values). These are the lowest values of solar flux throughout the researched period and they are not favorable to the increase in the number of gypsy moths.

Analyzing the values of the solar flux, it was concluded that the increase in the number of gypsy moths occurs in the range of approximately 70-120 sfu.

Table 3. Average values of the solar flux at 2.8 GHz throughout the corrected periods of outbreaks and periods without outbreaks

Period	Outbreak (Periods of outbreaks are marked by number 1, periods without outbreak by 0)	Average value of solar flux at 2.8 GHz (sfu)
1952-1956	1	101.8
1957-1961	0	188.3
1962-1966	1	84.5
1967-1969	0	147.9
1970-1976	1	103.5
1977-1983	0	159.8
1984-1987	1	83.8
1988-1994	0	156.9
1995-1998	1	87.0
1999-2003	0	164.6
2004-2007	1	87.8

There is a possibility that deviations in the number of gypsy moths between different fields were due to the different influence of factors such as cloudiness which cause the loss of energy of the solar flux.

The results of our researches show that the solar flux at 2.8 GHz is a very significant ecological factor which regulates the number of gypsy moths.

The assumption is that solar activity can also be of significance to the biotic factors that influence the population dynamics of gypsy moths (parasitoids, predators and diseases). Moreover, the anthropogenic measures of control also influence the courses of the outbreaks.

Precise data on the course of an outbreak will be necessary for this type of research. Only periods in which there is an increase in the number of insects will be taken into consideration, not the total course of outbreaks which includes the sudden decrease in numbers at the end.

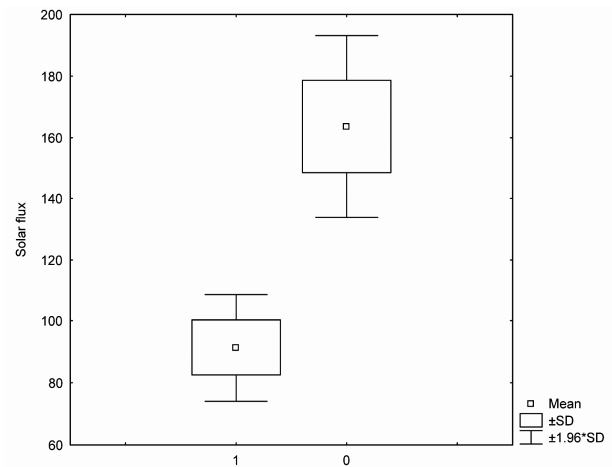


Fig. 2. Values of the solar flux at 2.8 GHz in years/epochs of outbreak of gypsy moths (sign 1) and absence of outbreak (sign 0) (corrected values)

REFERENCES

- Bakhvalov, S. A., Shults, E. E., Martemjanov, V. V., Markina, Zh. O., and G. A. Tolstikov (2006). Response of the gypsy moth *Lymantria dispar* L. (Lepidoptera, Lymantriidae) to the content of allelochemicals in birch leaves (*Betula pendula* Roth). *Entomological Review*, **86**, 866-872.
- Ducić, V., Milenković, M., and M. Radovanović (2008). Contemporary climate variability and forest fires in Deliblatska pescara. *Journal of the Geographical institute "Jovan Cvijic" SASA*, **58**, 59-74.
- Elkinton, J. S., Healy, W. M., Buonaccorsi, J. P., Boettner, G. H., Hazzard, A. M., and H. R. Smith (1996). Interactions among gypsy moths, white-footed mice, and acorns. *Ecology*, **77**, 2332-2342.
- Gomes, F. P. J., and M. Radovanovic (2008). Solar activity as a possible cause of large forest fires — A case study: Analysis of the Portuguese forest fires. *Science of the total environment*, **394**, 197-205.
- Gomes, F. P. J., Radovanovic, M., Ducic, V., Milenkovic, M., and M. Stevancevic (2009). Wildfire in Deliblatska pescara (Serbia) – Case analysis on July 24th 2007. In: *Forest Fires: Detection, Suppression and Prevention* (Eds. E. Gomez, and K. Alvarez), 89-140, Nova Science Publishers, New York.
- Gschwantner, T., Hoch, G., and A. Schopf (2002). Impact of predators on artificially augmented populations of *Lymantria dispar* L. Pupae (Lep., Lymantriidae). *Journal of Applied Entomology*, **126**, 66-73.
- Hastings, F. L., Hain, F. P., Smith, H. R., Cook, S. P., and J. F. Monahan (2002). Predation of gypsy moth (Lepidop-

- tera: Lymantriidae) pupae in three ecosystems along the southern edge of infestation. *Environmental Entomology*, **31**, 668-675.
- Ilijin, L., Perić-Mataruga, V., Radojičić, R., Vlahović, M., Mrdaković, M., Mirčić, D., and J. Lazarević (2010). The influence of increased rearing density on medial protocerebral neurosecretory neurons of *Lymantria dispar* L. caterpillars. *Arch. Biol. Sci.*, **62**, 27-38.
- Jovanović, B. D., Čamprag, D. S., Sekulić, R. R., and T. B. Kereši (2006). Solar activity influence to the numerosness dynamics of *Bothynoderes punctiventris* Germ. in Vojvodina. *Proc. Nat. Sci. Matica Srpska* (Novi Sad), **110**, 239-248.
- Lazarević, J., Nenadović, V., Janković-Tomanić, M., and S. Milanović (2008). Genetic variation and correlations of life-history traits in gypsy moth (*Lymantria dispar* L.) from two populations in Serbia. *Arch. Biol. Sci.*, **60**, 619-627.
- Lazarević, J., Perić-Mataruga, V., Nenadović, V., and M. Janković-Tomanić (2007). Trypsin activity in the midgut of gypsy moth (*Lymantria dispar* L.) larvae during the intermold period. *Arch. Biol. Sci.*, **59**, 59P-60P.
- Liebold, A., Elkinton, J., Williams, D., and R.-M. Muzika (2000). What causes outbreaks of gypsy moth in North America? *Population Ecology*, **42**, 257-266.
- Marković, I., Norris, D. M., and E. V. Nordheim (1997). Gypsy moth (*Lymantria dispar*) larval development and survival to pupation on diet plus extractables from green ash foliage. *Entomologia Experimentalis et Applicata*, **84**, 247-254.
- Marović, R., Marović, M., Jančić, G., and V. Lazarev (1998). Gypsy moth outbreaks in Serbia. In: *The gypsy moth outbreaks in Serbia. Acta Ent. Serb.*, Special Issue (Ed. Ž. Adamović), 1-6, Belgrade.
- Mihajlović, L. (2008). The gypsy moth (*Lymantria dispar* L.) (Lepidoptera, Lymantridae) in Serbia. *Forestry*, Belgrade, **1-2**, 1-26. (In Serbian with English summary).
- Mihajlović, L., Grbić, P., and D. Vandić (1998). The latest outbreak of gypsy moth *Lymantria dispar* L. (Lepidoptera, Lymantridae) in the region of Serbia in the period 1995-1998. In: *The gypsy moth outbreaks in Serbia. Acta Ent. Serb.*, Special Issue (Ed. Ž. Adamović), 81-88, Belgrade.
- Milanović, S. (2010). Preference and performance of the gypsy moth caterpillars on sweet chestnut and some oak species. *Bulletin of the Faculty of Forestry*, Belgrade, **101**, 113-124. (In Serbian with English summary).
- Milovanović, B., and M. Radovanović (2009). The connection between the solar activity and the circulation of atmosphere in the period from 1891 to 2004. *Journal of the Geographical institute "Jovan Cvijic" SASA*, **59-1**, 35-48. (In Serbian).
- Perić-Mataruga, V., Lazarević, J., and V. Nenadović (2001). The effect of the allelochemical quercetin on the survival of *Lymantria dispar* L. *Arch. Biol. Sci.*, **53**, 37P-38P.
- Pernek, M., and I. Pilaš (2005). Gradations of gypsy moth - *Lymantria dispar* L. (Lep., Lymantriidae) in Croatia. *Journal of Forestry Society of Croatia*, **129 (5-6)**, 263-270. (In Croatian with English summary).
- Radovanović, M. (2010). Forest fires in Europe from July 22-25, 2009. *Arch. Biol. Sci.*, **62**, 419-424.
- Radovanovic, M., and J. F. P. Gomes (2008). *Solar activity and forest fires*. 1-139, Nova science publishers, New York.
- Radovanović, M., Milovanović, B., and J. Gomes (2009). Endangerment of undeveloped areas of Serbia by forest fires. *Journal of the Geographical institute "Jovan Cvijic" SASA*, **59-2**, 17-35.
- Selas, V. (2003). Moth outbreaks in relation to oak masting and population levels of small mammals: an alternative explanation to the mammal-predation hypothesis. *Population Ecology*, **45**, 157-159.
- Selas, V., Hogstad, O., Kobro, S., and T. Rafoss (2004). Can sunspot activity and ultraviolet -B radiation explain cyclic outbreaks of forest moth pest species. *Proc. R. Soc. Lond. B* **271**, 1897-1901.
- Tabaković-Tošić, M. (2005). A new gypsy moth outbreak in Serbia. *Plant Doctor*, **33 (1)**, 44-50, Novi Sad. (In Serbian with English summary).
- Vasić, K. (1958). Comparative analysis of the respective courses of the gypsy moth gradation in the intervals 1946-1950 and 1953-1957. *Plant Protection*, **49-50**, 9-22. (In Serbian with English summary).