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EFFECT OF EXTREME WEATHER EVENTS ON THE PHEROMONE TRAPPING DYNAMICS OF EUROPEAN SPRUCE BARK BEETLE (*IPS TYPOGRAPHUS* L.) IN VARIOUS ENVIRONMENTAL CONDITIONS OF MOUNTAIN SPRUCE STANDS

Jarosław Bielan, Dorota Haliniak
University of Agriculture in Krakow

Abstract. Hurricanes, high temperatures and drought have caused damage to forests in the Żywiec Beskids. The effect of extreme weather events on the population of *Ips typographus* was examined in the damaged spruce stands in the period of 2005-2007, using pheromone traps for catching beetles. The daily average number of trapped beetles in a single pheromone trap ranged between 32 and 72 in subsequent growing seasons. It was proved that thermal conditions at different altitudes affected the beginning and the course of *I. typographus* swarming. Three swarming peaks were observed in each of three consecutive growing seasons. Extremely high temperatures in 2006 did not increase the number of swarming peaks. In 2007 the number of beetles in pheromone traps was twice higher than in the first year of the study.

Key words: *Ips typographus*, spruce, drought, hurricane

INTRODUCTION

Systematic trapping of *Ips typographus* L. to pheromone traps is currently the most efficient way of monitoring its activity throughout the growing season [Långström et al. 2009]. *I. typographus* swarming usually begins in May, and due to the ability to the rapid population growth, which results from its high fertility, the beetles may produce in favorable circumstances up to 2-3 generations per year [Kolk and Starzyk 2009]. As Wermelinger and Seifert [1998] reported, the average time of development from eggs to imaginal stage at 20°C is about 46 days, and after this period the beetles are ready for flight to find new host trees. Only during this short period, it is possible to lure them to pheromone traps [Weslien 1992], and therefore to determine the basic parameters related to the dynamics of *I. typographus* population development, such as: number of generations, the start and end date of swarming, swarming peak periods.

Corresponding author – Adres do korespondencji: Mgr inż. Jarosław Bielan, Department of Forest Protection, Forest Entomology and Forest Climatology of University of Agriculture in Krakow, 29 Listopada 46, 31-425 Krakow, Poland, e-mail: jarekbielan@gmail.com

The dynamics of *I. typographus* growth depends mostly on atmospheric conditions. Hurricane winds, causing massive damage to spruce stands are the most important factors [Bielawska 2009, Szabla 2009] – after one of such disasters in Forest District Jeleśnia (November 2004) the size of felled tree-area has been estimated at 60 thousand m^3. A significant part of windthrows was populated by secondary pests, and dead wood has not been exported out of the forest before being left by cambiophagous insects which caused their population growth – mainly of bark beetles. Additionally, summer 2006 in this area was the driest and the hottest in the last fifty years, which definitely favored all *I. typographus* growth stages [Szabla 2009].

Considering the above facts the following objectives were proposed:

1. Demonstration of the impact of extreme weather events on the number of *I. typographus* beetles trapped to pheromone traps in spruce stands.
2. Demonstration of the relation between the altitude of pheromone traps and the beginning and ending of *I. typographus* swarming.

METHODS

The studies were conducted in 2005-2007 in spruce stands of the Forest District Jeleśnia (situated in the Żywiec Beskids between 49°50′-49°30′N and 19°00′-19°30′E [Plan... 2005]. *I. typographus* beetles were caught into Theysohn pheromone traps (Table 1). The traps were placed in groups of three, rarely four. Pheromone Ipsodor or Ipsodor W were used in all traps. The number of trapped *I. typographus* beetles was controlled in precise time limits, once per week.

Table 1. Number of Theyson pheromone traps at each altitude, pcs
Tabela 1. Liczba rozmieszczonych pułapek Theysona na poszczególnych wysokościach n.p.m., szt.

Altitude a.s.l. Wysokość n.p.m. m	Year – Rok		
	2005	2006	2007
601-800	56	48	49
801-1000	26	49	66
1001-1200	19	24	32
Total – Razem	101	121	147

The course and intensity of *I. typographus* trapping depending on the location of traps was presented, applying the ratio of the number of trapped beetles in a single trap per one day (W), expressed by the formula:

$$W = \frac{L_i}{L_p \cdot d}$$

where:

L_i – the number of *I. typographus* beetles trapped in the analyzed period, pcs,
L_p – number of traps used, pcs,
d – number of days since last monitoring of traps.

In total, between 101 and 147 traps were used in the study in each year. They were distributed at different altitudes (Table 1).

To demonstrate the relationship between temperature and the number of trapped *I. typographus* beetles in 2006-2007, the Onset-Hobo U23-001 recorders were used for automatic air temperature and relative humidity measurement, which were placed in open space at a height of 0.5 m above the ground. In 2006 the recorder was placed at altitude of 1050 m a.s.l. (49°39′15″N 19°28′21″E), while in the following year 2007 – at altitude of 1100 m a.s.l. (49°34′59″N 19°21′00″E). The average weekly temperature, calculated as the average of hours: 7.00, 13.00 and 19.00 of each weekday, was used to describe the impact of thermal conditions on the course of swarming. Also the impact of extreme temperatures on the course of swarming was taken into account, by considering the maximum recorded temperature in the analyzed week. Pearson's correlation coefficient was used to determine the relation between the number of beetles caught in a single trap and the average and maximum temperature of the week. To demonstrate the effect of altitude of forest stands on the course and intensity of swarming, three zones of pheromone traps location were distinguished: 601-800 m a.s.l., 801-1000 m a.s.l. and above 1000 m a.s.l. (Table 1).

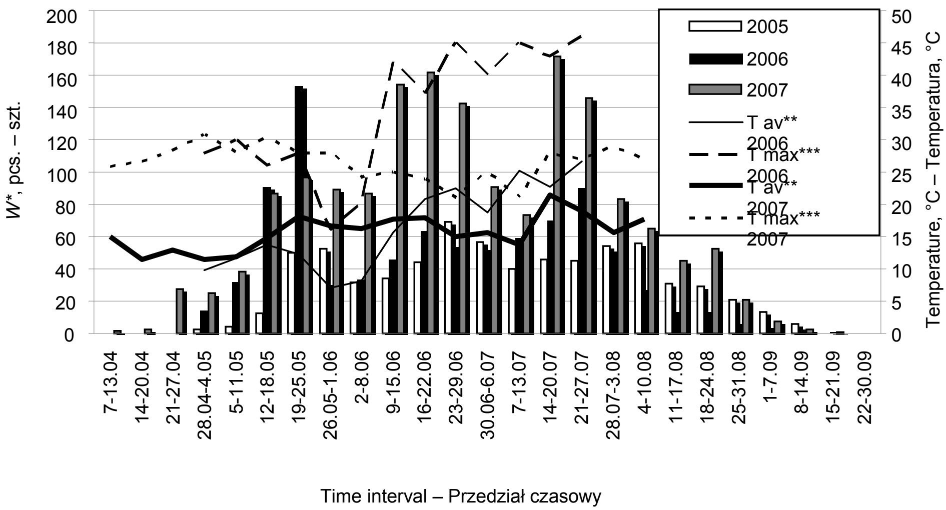
RESULTS

The location of spruce stands at different altitudes and prevailing weather conditions in various years affected the course and time of *I. typographus* swarming. The earliest favourable thermal conditions for the beginning of *I. typographus* swarming occurred in 2007. In that year swarming began at the turn of the second and third decade of April. On the other hand, in 2005 and 2006 swarming began at the turn of the first and the second decade of May (Fig. 1). The peak of spring swarming was observed from mid-May to early June. In the second decade of June, another swarming peak began and was extended in time – it lasted for about 4 weeks. In mid-July another (extended in time) intensification of *I. typographus* beetles' flight was observed and it lasted until the end of August. With the beginning of September the activity of beetles almost ceased, as evidenced by small number of trapped insects (Fig. 1).

Swarming in 2005 and 2006 had similar course, while in 2007 it differed significantly. The average and maximum daily temperatures from the study period of 2006 were higher than those of 2007, but they did not cause the increase in the number of trapped *I. typographus* beetles, while only in the following year 2007 the number of trapped beetles in the analysed periods increased almost twice compared to previous years. Moreover, the swarming peaks were more clear (Fig. 1).

Generally, the number of trapped *I. typographus* in each subsequent year increased in comparison with the previous year, as evidenced by the average captures in traps. Particularly significant increase in the number of trapped beetles occurred in 2007, after the previous year's drought (Table 2).

The analysis of the impact of pheromone traps altitude on the course of *I. typographus* swarming revealed a correlation between the beginning of swarming and the altitude of stands. The swarming began later with increasing height above sea level. Nonetheless, no relationship was found between altitude a.s.l. of stands and the end date of swarming (Fig. 2-4).



* number of trapped beetles in one trap per day
liczba odłowionych chrząszczy na jedną pułapkę w ciągu dnia
** average temperature – temperatura średnia
*** maximum temperature – temperatura maksymalna

Fig. 1. Course of *Ips typographus* beetles' swarming in Forest District Jeleśnia in 2005-2007 compared to average and maximum temperatures

Rys. 1. Przebieg rójki chrząszczy *Ips typographus* w Nadleśnictwie Jeleśnia w latach 2005-2007 na tle średnich i maksymalnych temperatur

Table 2. Average daily number of trapped *I. typographus* beetles in one trap depending on altitudes in 2005-2007, pcs

Tabela 2. Średnia dzienna liczba odławianych chrząszczy *I. typographus* do jednej pułapki w zależności od wysokości n.p.m. w latach 2005-2007, szt.

Altitude a.s.l. Wysokość n.p.m. m	Year – Rok			Average Przeciętna liczba
	2005	2006	2007	
601-800	37	44	90	68
801-1000	31	37	72	59
1001-1200	27	24	53	43
601-1200	32	37	72	–

Also no apparent differences were observed between the dates of each swarming peaks and the altitude a.s.l. – these differences were up to 1 week (Fig. 2-4). The uneven course of swarming in 2006 was most probably due to thermal conditions. Favourable atmospheric conditions in May intensified the spring swarming peak, but the sudden temperature drop, that occurred in late May and early June, was reflected in the number of *I. typographus* beetles trapped – the average number of trapped pests in the first week of June was over four times lower compared to the last week of May. Later on, despite

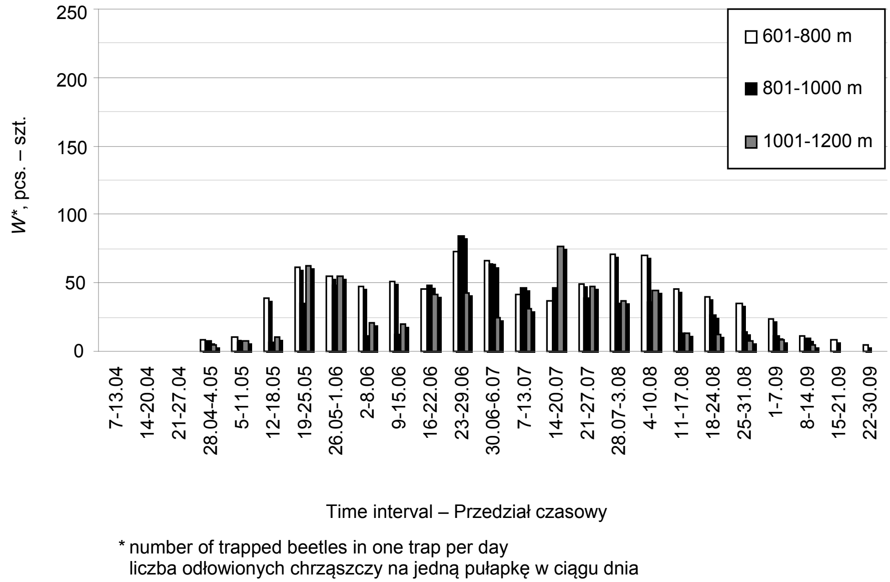


Fig. 2. Course of *Ips typographus* beetles' swarming compared to altitude a.s.l. in 2005
Rys. 2. Przebieg rójki chrząszczy *Ips typographus* w zależności od wysokości n.p.m. w 2005 roku

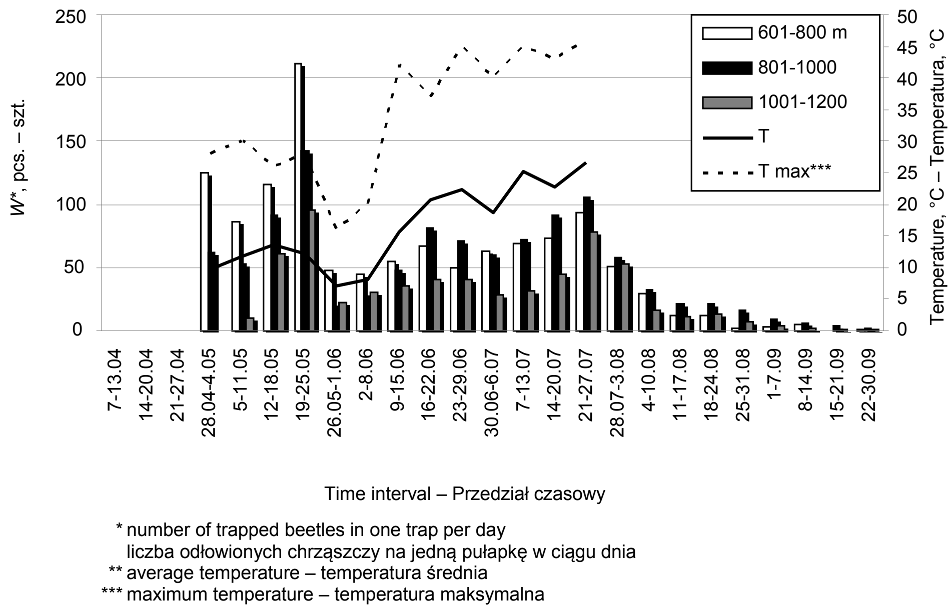


Fig. 3. Course of *Ips typographus* swarming depending on altitude a.s.l. compared to average and maximum temperatures in 2006
Rys. 3. Przebieg rójki chrząszczy *Ips typographus* w zależności od wysokości n.p.m. na tle średnich i maksymalnych temperatur w 2006 roku

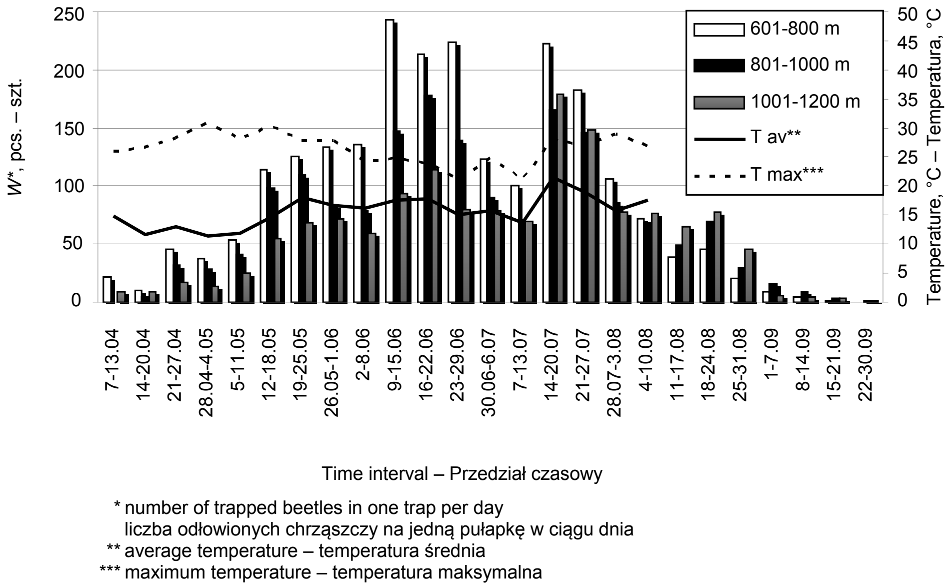


Fig. 4. Course of *Ips typographus* swarming depending on altitude a.s.l. compared to average and maximum temperatures in 2007
Rys. 4. Przebieg rójki chrząszczy *Ips typographus* w zależności od wysokości n.p.m. na tle średnich i maksymalnych temperatur w 2007 roku

more favourable thermal conditions than in May, the number of trapped *I. typographus* pests was about twofold lower in comparison with the beginning of the study period. The spring swarming peak occurred at the average daily temperature about 15°C, when the maximum temperatures reached 30°C, while the next two peaks occurred at the average daily temperature of about 20°C, and the maximum of up to 45°C (Fig. 3). The course of swarming in 2006 at altitudes of 801-1000 m a.s.l. showed medium correlation with average temperatures (r = 0.44, n = 13), while for the other altitudes, as well as for the maximum temperature, these relationships were weak or did not occur at all (Table 3).

The temperature decrease, recorded during the observation period in 2007, as well as periods of high temperatures, affected the number of trapped *I. typographus*. Flights of *I. typographus* beetles increased in mid-May, when the average daily temperatures reached 15°C. Swarming culmination occurred when the average temperatures reached about 20°C and maximum temperatures were up to 30°C (Fig. 4). In 2007 the correlation coefficient between the number of trapped *I. typographus* beetles and the average temperatures for all ranges of pheromone traps' altitudes was very high ($0.74 \le r \le 0.89$, n = 18). No correlation was found between the number of trapped pests and maximum temperatures (Table 3).

Table 3. Relation between the average temperature T_{av} (°C), maximum temperature T_{max} (°C) of the week and the average weekly number of trapped *Ips typographus* beetles expressed as Pearson's correlation coefficient for different ranges of altitudes

Tabela 3. Zależność między temperaturą średnią T_{av} (°C) oraz temperaturą maksymalną T_{max} (°C) z danego tygodnia a średnią tygodniową liczbą odłowionych chrząszczy *Ips typographus* wyrażoną wskaźnikiem korelacji Pearsona dla poszczególnych przedziałów wysokości n.p.m.

Altitude a.s.l. Wysokość n.p.m. m	Year – Rok			
	2006		2007	
	T_{av}	T_{max}	T_{av}	T_{max}
601-800	–0.18	–0.18	**0.74**	–0.39
801-1000	0.44	0.36	**0.83**	–0.32
1001-1200	0.23	0.13	**0.89**	–0.18
601-1200	0.28	0.16	**0.80**	–0.31

Bolded values show that a correlation between the average weekly temperature and average weekly number of trapped *Ips typographus* beetles is statistically different (α = 0.05).

Wartości pogrubione oznaczają, że współczynniki korelacji prostoliniowej pomiędzy średnią temperaturą z danego tygodnia a średnią tygodniową liczbą odłowionych chrząszczy *Ips typographus* są istotne na poziomie α = 0,05.

Wartości pogrubione oznaczają silną zależność pomiędzy średnią temperaturą z danego tygodnia a średnią tygodniową liczbą odłowionych chrząszczy *Ips typographus*.

DISCUSSION

Weather conditions may induce destructive processes in forests and inflict enormous damage [Baier et al. 2007, Szabla 2009]. Large-area destruction of tree stand in the hurricane, as it happened in autumn 2004, coupled with extremely high temperatures, drought (2005-2006) and high population of *I. typographus*, creates optimal conditions for its gradation.

This regularity could be observed in spruce forests of the Żywiec Beskids in 2005--2007. In the first year after the wind damage (2005) the average number of beetles caught in a single trap per one day was approximately 30 pcs, in the following year this number increased to about 40 pcs, while the gradation peak occurred in 2007, when the number exceeded 70 pcs. Capecki [1978] claimed that gradation of *I. typographus* after wind damage in spruce stands lasts about 3-5 years. In the first year *I. typographus* almost exclusively inhabits fallen trees. In the following two years it attacks another windthrows, and in the absence thereof-weakened standing trees. In the third and fourth year *I. typographus* attacks both weakened and healthy trees, and in the consecutive year the gradation ends due to lack of breeding material. Similarly, Wermelinger [2004], analyzing Swiss forests, stated that gradation peak of *I. typographus* occurs in the second or third year after the storm events. Gugerli et al. [2008], while conducting their research in Switzerland, found that in one of the regions the gradation peak occurred already in the second year after the hurricane, while in two other regions – it occurred only in the fourth year, which was mainly caused by very dry and hot summer of that year. On the other hand, Stolina [1982] claimed that the population of this pest grows significantly in the second and third year after windfalls and it reaches a peak in the fourth and fifth year of gradation. Grodzki et al. [2006], after the studies in the Gorce mountains, observed the increased dieback of spruce trees colonized by *I. typographus* in the second year after the damage, while the peak of trapping of this species was already observed in the first year after the windfall. These differences probably arise from different output population number of *I. typographus* before the appearance of large number of damaged, suitable for invasion, trees. Various thermal and humidity conditions in consecutive seasons could also affect the gradation period of this species.

Capecki [1978] argued that favourable thermal conditions in spring cause rapid activity resumption after a period of insects' wintering and affect the dynamics of their development. Annila [1969] stated that swarming of *I. typographus* starts when the air temperature exceeds 20°C. Wermelinger [2004] shared the opinion of Lobinger [1994] that the minimum temperature at which the *I. typographus* beetles begin flying is about 16.5°C. On the other hand, Grodzki [1998, 2007] related the beginning of *I. typographus* swarming with the ambient temperature within the range of 12-15°C. It was found that in Forest District Jeleśnia the flight of *I. typographus* began with the average daily temperature of 10-13°C. Thus, in the mountains at altitudes of 600-1200 m a.s.l. in favorable weather conditions swarming may begin at the turn of the second and third decade of April, although it usually occurs at the turn of the first and second decade of May. This regularity was also observed by Kawka [1995], Grodzki [2007], Kolk and Starzyk [2009] and Pogoński [2010], and also the research conducted by Baier et at. [2007] in similar altitude zone at the Kalkalpen National Park in Upper Austria.

No correlation was observed between extreme temperatures in 2006 and the number of trapped *I. typographus* beetles. Grodzki [2007], conducting the research in Gorce and the Tatra Mountains, also did not find any relationship between these factors. Despite very high average daily temperatures in 2006, which in the period from mid-June to late July at an altitude of 1050 m a.s.l. reached 25°C, maximum temperatures reaching 40°C and prolonged drought, there was no sharp increase in the number of trapped beetles. Numerous authors, who studied the effect of temperature on the course of swarming [Lobinger 1994, Grodzki 1998, Wermelinger and Seifert 1998, 1999] claim that swarming of *I. typographus* proceeds more intensively in the temperature of 25-30°C. Baier et al. [2007] share similar opinion, and based on a developed model, they estimated the optimum temperature for the development of *I. typographus* as about 30°C. These results were confirmed in spruce forests of Forest District Jeleśnia – in 2006 the largest numbers of trapped beetles were noted in May, when average daily temperatures reached 15°C, and maximum temperatures were up to 30°C, while the other two peaks occurred when the average daily temperature reached 23-25°C and the maximum temperatures exceeded 40°C and the numbers of *I. typographus* caught in these two periods were definitely lower. The research conducted by Wermelinger and Seifert [1998] seem to explain this situation, because, according to the authors, the temperature reaching 40°C presents strong inhibitory effect on the growth of this species.

It is interesting that a strong correlation was observed in 2007 between the average daily temperature and the number of *I. typographus* trapped in spruce stands of Forest District Jeleśnia. In summer 2007 optimum conditions occurred for development and swarming of this species, as the average daily temperature did not exceed 20°C, while maximum temperatures reached 30°C. Nevertheless, temperature fluctuations of even several degrees caused a significant change in the number of *I. typographus* caught to pheromone traps. Clarification of these relations requires further detailed studies.

Bakke [1992] stated that the number of *I. typographus* caught into pheromone traps may be correlated with average temperatures in the preceding year. Twofold increase in the number of trapped pests in Forest District Jeleśnia in 2007 compared to previous years can be explained by favourable conditions for their growth in May, and then in the period from mid-June to late July of the previous year. Favourable atmospheric conditions for the development of this beetle repeated in 2007. The first swarming peak in 2007 could have been related to the part of *I. typographus* population, which survived winter in imaginal stage. However, the second swarming peak was almost twice as intense and probably involved the generation of beetles that established sister generation and those individuals that survived winter in preimaginal stage, and did not reach the imago stage until May. Such evolution of *I. typographus* population in mountain conditions is confirmed by studies of Ząbecki et al. [2007] and Pogoński [2010].

In favourable atmospheric conditions of Polish lowland *I. typographus* may produce two or three main generations, and two sister generations per year [Grodzki 1998, Łabędzki 2003, Kolk and Starzyk 2009]. However, the opinions on this phenomenon in mountain conditions are different. Mazur et al. [2004 b] claimed that at high altitudes *I. typographus* beetles produce usually one generation per year and do not produce sister generations. In favourable conditions, however, they may produce two generations. Grodzki [2007] stated that in the Tatra mountains the beetles produce one complete and one incomplete generation, which means that they hibernate usually in preimaginal stages. On the contrary, in the Gorce mountains and the Żywiec Beskids this species can produce two main generations and two sister generations. Different opinion, however, is shared by Kawka [1995], Ząbecki et al. [2007] and Pogoński [2010]. They argue that it is difficult to clearly demonstrate the number of generations produced by *I. typographus* in one growing season in the mountains, because in the mountains *I. typographus* swarm continuously, and the trees are populated simultaneously by all developmental stages of this species. Results of the study conducted in Forest District Jeleśnia seem to confirm these observations, as during the growing seasons of 2005-2007 the number of trapped *I. typographus* beetles still remained at high level, and swarming intensity fluctuations were observed mainly in three peaks and in adverse thermal conditions.

Capecki]1978] and Grodzki [2007] stated that the number of produced *I. typographus* generations in the mountains mainly depends on thermal conditions, which are directly reflected in the length of growing seasons. Their studies suggest that three peaks of swarming occur in the Żywiec Beskids regardless of altitude and the length of growing season. Moreover, even extremely hot and dry summer of 2006 did not cause more frequent swarming peaks, which could be associated with higher number of *I. typographus* generations. This fact denies the assertion of Grodzki [2007] and Kolk and Starzyk [2009] that under favorable conditions *I. typographus* may derive up to five generations. On the other hand, Baier et al. [2007], based on the measurement of the daily solar radiation dose, daily air temperature and effective daily bark temperature at a known number of *I. typographus* insects trapped to Theyson's pheromone traps and collected trap-trees, created a model (PHENIPS), under which they determined the number of generations in each of the analysed growing seasons. They found, that this number depends on the a.s.l. altitude of tree stands and mainly on prevailing thermal conditions in a studied year, which affect the length of a period needed by *I. typogra-*

phus for its full development (about 557 degree-days). Under such conditions *I. typographus* may produce, depending on a growing season, from one to three generations.

Swarming culminations in subsequent years at all altitudes occurred in the same period. This could have been impacted by a long, hot and dry growing season, which created favourable conditions for the growth of *I. typographus* even in the stands situated above 1000 m a.s.l.

Mazur et al. [2004 a, b] argued that in the Karkonosze mountains climatic conditions limit the intensive development of *I. typographus* in the stands above 1000 m a.s.l. Moreover, at this altitude this pest is less aggressive and its role in this area is limited. This thesis was not confirmed in the period of 2005-2007 in Forest District Jeleśnia – in summer, both in 2006 and 2007, maximum temperatures at an altitude above 1000 m a.s.l. reached 30-40°C. Also, above 1000 m a.s.l. on average 25-35 individuals were trapped per one day in the period of 2005-2006 and about 50-60 in 2007. The number of trapped *I. typographus* beetles above 1000 m a.s.l. often did not differ from the number of individuals trapped at an altitude of 801-1000, and even 601-800 m a.s.l.

It is a fact, that swarming begins later in stands located at higher altitudes [Grodzki 1998, Mazur et al. 2004 b], and is sometimes two weeks delayed [Mazur et al. 2004 b]. The research in spruce stands of the Forest District Jeleśnia confirm this regularity, as evidenced by the lower number of *I. typographus* beetles trapped in the initial period of swarming in higher parts of mountains. This was most probably affected by atmospheric conditions, particularly temperature.

Later research confirmed the observations of Kawka [1995], Grodzki [2007] and Pogoński [2010] regarding the ending of swarming. In mountain conditions, both in Western Carpathians and Sudetes, trapping of *I. typographus* beetles usually cease at the end of August and in September usually small numbers are found in pheromone traps. Sometimes, however, there are relatively high temperatures in September, which can significantly extend swarming.

CONCLUSIONS

1. The beginning of *I. typographus* swarming is affected by thermal conditions. In the Żywiec Beskids it begins when the average daily temperature reaches 10-13°C, which happens mostly in the first and second decade of May, and exceptionally in mid-April.

2. The highest intensity of *I. typographus* swarming is recorded when the average daily temperature reaches about 20°C.

3. Altitude a.s.l. of the stands affects the beginning of *I. typographus* swarming. In the stands of the Żywiec Beskids located at an altitude of 600-800 m a.s.l. swarming usually occurs two weeks earlier than in those located above 1000 m a.s.l.

4. Swarming of *I. typographus* in mountain conditions lasts continuously until mid-September and the intensity of catching this cambiophagous pest into pheromone traps increased only during swarming peaks. Such peaks were observed three times in each growing season of 2005-2007. This shows that despite exceptionally high temperatures in summer 2006 the number of *I. typographus* generations was not so higher than in other years.

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WPŁYW EKSTREMALNYCH ZJAWISK METEOROLOGICZNYCH NA DYNAMIKĘ ODŁOWU KORNIKA DRUKARZA (*IPS TYPOGRAPHUS* L.) DO PUŁAPEK FEROMONOWYCH W RÓŻNYCH WARUNKACH ŚRODOWISKOWYCH GÓRSKICH DRZEWOSTANÓW ŚWIERKOWYCH

Streszczenie. Huragan oraz wysokie temperatury i susza spowodowały szkody w lasach Beskidu Żywieckiego. W uszkodzonych drzewostanach świerkowych badano wpływ ekstremalnych zjawisk meteorologicznych na rozwój populacji *Ips typographus* w latach 2005-2007, stosując pułapki feromonowe do odłowu chrząszczy. Średnio dziennie do jednej pułapki feromonowej odławiano od 32 do 72 chrząszczy w kolejnych sezonach wegetacyjnych. Stwierdzono, że warunki termiczne panujące na różnych wysokościach n.p.m. wpływały na termin rozpoczęcia i przebieg rójki *I. typographus*. W każdym z trzech kolejnych sezonów wegetacyjnych wystąpiły trzy okresy kulminacji rójki. Ekstremalnie wysokie temperatury w 2006 roku nie wpłynęły na wzrost liczby kulminacji rójki. W 2007 roku liczba odławianych chrząszczy do pułapek feromonowych była dwukrotnie większa niż w pierwszym roku badań.

Słowa kluczowe: *Ips typographus*, świerk, susza, huragan

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