

COMPARISON OF SEASONAL FLIGHT ACTIVITY OF *IPS TYPOGRAPHUS* AND *IPS DUPLICATUS**

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Theysohn pheromone traps were used for monitoring flight activity of bark beetles. Ten traps were installed in a line at a distance of about 20 m from the infested forest edge with a 15 m spacing between two adjacent traps at two study areas in the Czech Republic in 2010 and 2011. Traps were baited with IT Ecolure or ID Ecolure; the lures were alternated regularly. Trapping took place from April to September with traps checked in three-day intervals in 2010 and in seven-day intervals in 2011. A linear correlation was determined between the captures of *Ips typographus* and *Ips duplicatus* beetles in both years. This suggests that the phenological models of the two species are very similar.

Ips typographus, *Ips duplicatus*, pheromone trap; comparison of flight activities

INTRODUCTION

The spruce bark beetle *Ips typographus* L. is one of the most serious pests of Norway spruce (*Picea abies* (L.) Karst.) in Eurasia (Annila, 1969). While it may also colonize healthy living trees when at high population density, generally it breeds on weakened trees and breeds in the spruce cambium (Weslien et al., 1989). Although *Ips duplicatus* Sahlb. is listed as a quarantine pest by the European Union and the European and Mediterranean Plant Protection Organization (Smith et al., 1996), it also is included on some protected species lists (e.g. Bussler, Bense, 2003). Local outbreaks of *I. duplicatus* were recorded in Poland and the Czech Republic in the 1990s (Knizek, Zahradnik, 1996; Grodzki, 1997, 2003), and this has been reported since the 1950s as a major damage-causing species and has exhibited continuous outbreaks in natural spruce forests in Inner Mongolia, China (Zhang et al., 1995, 2001; Schlyter et al., 2001). The last outbreak in the Czech Republic began in 2003, but since 2005 the abundance of *I. duplicatus* has continuously been at a high level (Holuša et al., 2010). Thus, this has come to be considered an economically important species. In Central Europe the species is spreading westwards (Holuša et al., 2010) but also eastwards and southwards (Vakula et al., 2009).

After hibernation both species *I. typographus* and *I. duplicatus* emerge from the litter (or from the bark in case of *I. typographus*) of the forest floor on warm

spring days and fly to host trees that are stressed. These species use an aggregation pheromone to attract more individuals of the same species to the tree for the purposes of killing the tree and for mating. The pheromone attracts both sexes. The attracted males join the attack and secure an area for mating and oviposition, which area consists of a hole and chamber beneath the bark known as a 'mating chamber'. The females construct a tunnel ('maternal gallery') beneath the mating chamber in which to lay eggs. In all species of genus *Ips*, several females join each male in his mating chamber (Holuša et al., 2003; Wermelinger, 2004).

In order to assess the likelihood of a mass outbreak in a timely manner, appropriate monitoring tools are needed for accurately predicting the number of generations and current state of the developmental process within the bark beetle population. A comprehensive phenological model has been created for *I. typographus* (Bair et al., 2007). Within this model, the maximal daily air temperature determines the day for onset of the attack and the average bark temperature determines the speed at which the individual development stages progress. The flight activity begins after a certain sum of days at certain temperatures is reached, and similarly the development of offspring is concluded after a sum of such temperatures and days is reached. Shortening of the day length and decrease in night-time temperatures at the end of summer are the two main parameters inducing diapause, a physiological state in which the adult bark beetles overwinter (Dolezal,

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Sehnal, 2007). In the central European population, reproduction ends after the days shorten to approximately 15 hours, [i.e. approximately in mid-August (Schopf, 1985, 1989)], and transition of the beetles to diapause occurs. During diapause the individuals eat not at all or only in very small amounts (Hahn, Denlinger, 2007). Flight muscles and fat body development are reduced (Dolezal, 2002).

Based upon this model, it is evident that the number of generations of *I. typographus* is dependent upon climate, weather and change of seasons. Similarly *I. duplicatus* exhibits a multivoltine life cycle in most parts of Central Europe (Schneider, Sierpinski, 1955; Mrkva, 1994, Holusa et al., 2003), and we suggest that it follows a phenological model similar to that of *I. typographus* and likewise a photoperiodically controlled reproductive diapause in adult stage which is also its hibernating stage. In low and medium altitudes of central Europe, both beetle species usually produce two generations or three generations per year, with the main peaks of bark beetle emergence in central Europe during April/May, July and August/September (Holusa et al., 2003; Wermelinger, 2004). Moreover, parental females produce sister broods (Knižek, Holusa, 2001) as does *I. typographus* (Anderbrant, 1986, 1989; Kritsch, 2005), and that contributes substantially to its population growth. Although monitoring with the use of pheromone-baited traps helps foresters to identify the occurrence of *I. duplicatus* even in low population densities, what is important to signal an increasing threat and beginning of a rise in population density, intensive control of *I. duplicatus* is complicated by several factors. *I. duplicatus* normally attacks trees interspersedly within a stand, and the invasion is concentrated into the spruces' crowns. Its development is completed or is in a substantially advanced stage often before changes in the colouring of needles are observed visually. Only rarely does it invade trees lying on the ground, and therefore classical traps cannot be used for its control (Schneider, Sierpinski, 1955; Grodzki, 1997).

It is very important, therefore, to know how the development of *Ips duplicatus* is progressing within a given year. On the basis of reference data from several years it appears that *I. typographus* and *I. duplicatus* in central Europe develop practically the same, with similar seasonal distributions (Holusa et al., 2003). In this work, we compare the flight activity of *I. duplicatus* with *I. typographus* according to the capture of beetles in pheromone traps and discuss whether the phenological model of *I. typographus* could be applicable to *I. duplicatus*.

MATERIAL AND METHODS

Experiments were conducted during 2010 and 2011 in stands of Norway spruce (*Picea abies* Karsten)

in the eastern Czech Republic. At the locality Pustá Polom (49°50'46.897"N 18°1'39.713"E), ten traps were installed in a line at a distance of about 20 m from the infested forest edge (as recommended by Chen et al., 2010), with a 15 m spacing between two adjacent traps parallel to the forest edge of 70–100 years old, growing at altitude 395 m a.s.l. At the locality Hlubočec (17°56'36"E, 49°50'33"N; 17°56'42"E, 49°51'17"N; 17°57'35"E 49°51'41"N, plots were approximately 1 km apart from each other) ten pheromone traps were installed at each plot, along the edge of a forest stand 96–109 years old at elevations of 475–495 m a.s.l., alternating in a single line with 10 m spacing.

Black window-slot traps of type Theysohn pheromone slot traps with a total active surface area of 4284 cm² (42 × 51 cm by two sides) (Niemeyer et al., 1983) baited separately with IT Ecolure (odd-numbered traps) or ID Ecolure (even-numbered traps). The different types of lures were alternated regularly. The active ingredient for ID Ecolure and IT Ecolure, respectively, is ipsdienol and (S)-cis-verbenol (www.fytofarm.cz).

The pheromone dispensers were placed on 24 April 2010 and 18 April 2011, refreshed after eight weeks. The traps were checked and beetles collected every third or seventh day. The trapping was discontinued on 30 September 2010 and 8 October 2011. Regression analysis of data (mean per locality) was performed in program Statistica 9.0.

RESULTS

A total of 28,649 *I. typographus* beetles were captured in 2010. The first beetles flew out in late-April and early-May. The second peak of flight activity occurred in mid-July. Between these peaks there were several more numerous captures in mid- and late-May and in early-June (Fig. 1). After mid-July, when there occurred a clear peak signifying the second generation, the numbers of beetles were dropping irregularly and from late-August their captures were negligible (Fig. 1).

A total of 11,172 *I. duplicatus* adults were captured in Pustá Polom in 2010. The flight activity began at the end of April and was disrupted for a short time at the beginning of May (Fig. 1). Trap catches increased again at the end of June and generally remained high until the end of July (there was a disruption in early July). Only a relatively small number of beetles were trapped outside of these two periods (Fig. 1).

A total of 37,335 *I. typographus* beetles were captured in Hlubočec in 2011. The first beetles flew out in late-April. In break April/May the numbers of collected beetles were very small. Very irregular numbers of beetles were captured during the whole May, June and July.

High numbers of beetles were caught again in August with end of flight activity in September.

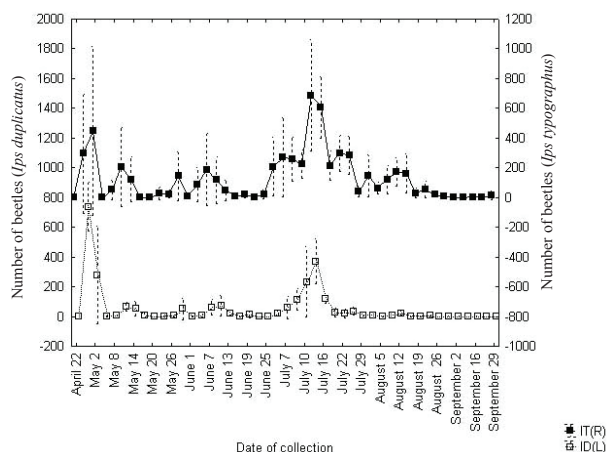


Fig. 1. Number of *Ips typographus* (full squares) and *Ips duplicatus* (empty squares) adults captured in pheromone traps at the Pustá Polom location for 2010 (pheromone IT Ecolure, five traps). Values are means \pm SD

At total 20,917 *I. duplicatus* individuals in total (7,191 males and 13,726 females) were collected in Hlubočec in 2011. The first beetles flew out in mid-April. In break April/May the numbers of collected beetles were very small. Another peak was found in June. High numbers of beetles were caught again in August with end of flight activity in September. A conclusive linear correlation between the average captures of *I. typographus* and of *I. duplicatus* for the entire vegetation season was determined in 2010 as well in 2011 (Fig. 2).

DISCUSSION

Flight activity of *I. typographus* and *I. duplicatus* monitored in 2010 using pheromone window-slot traps was characterized by two main peaks which occurred in early-May and on the turn of June and July. Only two generations were observed in both species, which corresponded to the influence of weather. In a period when it is warm and sunny weather and the beetles would normally fly out, it was instead cold and rainy (Lubojacký, Holusa, 2011). The flight activity of *I. typographus* was similar to situation in 2010, with several peaks occurring between the two main peaks and which could have been caused by the existence of a sister generation. Usually, the majority of parental beetles of *I. typographus* re-emerge 2–3 weeks after their initial attack and establish at least one sister generation (Martinek, 1956, 1957; Thalenhorst, 1958; Annala, 1969; Anderbrant, 1989; Kritsch, 2005). In addition to being density-dependent and influenced by intra-specific competition (Anderbrant et al., 1985), the residence time of parental beetles is mainly temperature-dependent (Annala, 1969; Anderbrant, 1986; 1989; Baier et al., 2007). In 2011 occurrence of two generations per year is not clear.

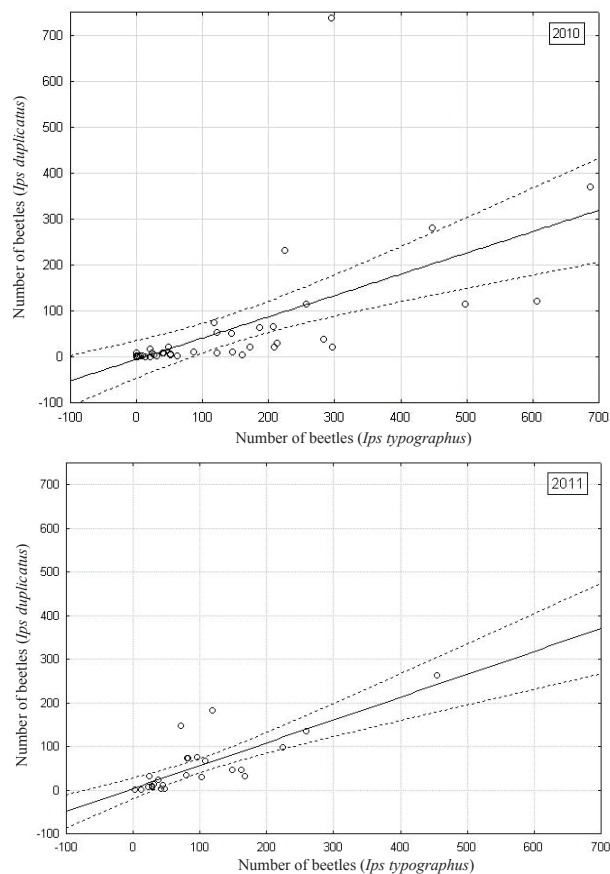


Fig. 2. Correlation between the average numbers of captured beetles of the individual species on traps during the monitored flight activity in 2010 (upper: $y = 5.68 + 0.46x$, $r = 0.59$, $P < 0.0001$) and in 2011 (lower: $y = 3.80 + 0.52x$; $r = 0.80$, $P < 0.00001$). Circles indicate average capture on the individual dates. Bands show the 95% confidence interval

The flight activity of overwintering generation was interrupted by cold weather with snowing. Therefore the peak in second part of June could be represented by overwintering beetles, reemerging beetles as well as offspring beetles (we observed the high numbers of brown beetles = callow adults after transforming from pupae are initially white and then medium brown and in the end become darker). The peak in August was represented by offspring beetles.

These facts are in accordance with the knowledge about the two generations in both *I. typographus* (Wermelinger, 2004) and *I. duplicatus* (Schneider, Sierpinski, 1955; Mrkva, 1994; Holusa et al., 2003, 2006) within central Europe during normal climatic conditions.

A linear correlation was determined between captures of the two species, even though extreme values could not be removed from the analysis, as they mostly constitute the peaks of flight activity for the overwintering and summer generations. This supports the assertion that in comparing flight activity no statistically significant difference in the course of the cumulative curves of total captures was determined,

i.e. that the development of both species was probably similar (Holusa et al., 2003). This uniformity results most probably from the fact that both species have similar requirements. In central Europe, the total development from founding the gallery to emergence of the new generation is 4–8 weeks (Mrkva, 1995) and 5–8 weeks (Wermerlinger, 2004) for *I. duplicatus* and *I. typographus*, respectively. While *I. duplicatus* beetles can overwinter consistently only in the adult stage (Holusa et al., 2003). *I. typographus* can also hibernate in the larvae or pupa stage, but overwintering in the adult stage dominates (Zumr, 1985; Christiansen, Bakke, 1988). Therefore, the development cycle significantly synchronized.

The PHENIPS phenological model for *I. typographus* differs from other bark beetle phenology models (Logan, Bentz, 1999; Ungerer et al., 1999) in that it is developed for estimating the phenology and development of *I. typographus* by explicitly considering the strong effects of regional topography and stand conditions on local air and bark temperature. In practice, forest inventory data about stand density and canopy closure may be used for roughly estimating the insulation below the canopy, whereby the solar irradiation decreases exponentially with increasing canopy closure (Pennerstorfer, 2000). As a comprehensive model for simulating the phenology of *I. typographus*, PHENIPS can be used to estimate brood development, to predict the onset of spring swarming and tree infestation, and to estimate the development of sister broods and number of generations that can be completed prior to hibernation (Baier et al., 2007). The observed onset of spring swarming and flight activity in *I. typographus* within the study area confirmed the temperature threshold of 16.5°C for flight activity (Lobinger, 1994). After chilling during hibernation, diapause is terminated and followed by a quiescence stage until the temperature rises and ovarian development can proceed (Dolezal, Sehnal, 2003). At the end of the vegetation season, multivoltine populations also are restricted in their reproductive activities by short-day photoperiods (Schopf, 1985, 1989; Dolezal, Sehnal, 2003; Kraitsch, 2005).

Although *I. duplicatus* is a species substantially adapted to northern conditions, it has the ability for multivoltine reaction to higher temperature. According to most authors, this species has one generation in the taiga and in northern Poland (Saalas, 1923; Karpinski, 1933; Schnaider, Sierpinski, 1955; Pfeffer, 1955) while in central Europe it usually has two to three generations per year (Schnaider, Sierpinski, 1955; Grodzki, 1997; Holusa et al., 2003, 2006). Although *I. duplicatus* mostly does not occur at higher altitude (Holusa et al., 2010), when it does appear there it seems to copy the pattern of *I. typographus* with a single generation (Holusa et al., 2006).

Although it is a smaller species in comparison to *I. typographus* (Pfeffer, 1955), and logically it should require lower cumulative effective temperatures, it seems that in the conditions of central Europe the temperature model for *I. duplicatus* could be a copy of the PHENIPS model for *I. typographus*. For purposes of practical forest management, the most important fact is that flight activity of the two species begins at the same time.

CONCLUSION

Two peaks of flight activity of *Ips typographus* were recorded in 2010. The first peak occurred in the last decade of April, but it was not so striking as in early July. There were several smaller upward spikes in flight activity between these two, so the flight activity quite fluctuated. The first peak of *Ips duplicatus* occurred in early May representing the flight activity of the overwintered generation, whereas the second peak occurred in late June–early July representing the flight of the filial generation. A linear correlation suggests that the phenological models of the two species are very similar.

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Srovnání sezónní letové aktivity *Ips typographus* a *Ips duplicatus*

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Feromonové pasti typu Theysohn byly použity pro monitorování letové aktivity kůrovců. Deset pastí bylo instalováno v řadě ve vzdálenosti 20 m od okraje lesa s 15 m vzdáleností mezi dvěma sousedními pastmi ve dvou studijních oblastech v České republice v roce 2010 a 2011. Pasti byly navnazeny IT Ecolure a ID Ecolure, které se pravidelně střídaly. Odchyt probíhal od dubna do září, pasti byly vybírány ve třídních intervalech v roce 2010 a v sedmidenních intervalech v roce 2011. Statisticky signifikantní korelace byla zjištěna mezi odchyty *Ips typographus* a *Ips duplicatus* v obou letech. To naznačuje, že fenologické modely obou druhů jsou velmi podobné.

Ips typographus; *Ips duplicatus*; letová aktivita; feromonový lapač; srovnání letové aktivity

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