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Large larch bark beetle *Ips cembrae* (Coleoptera: Curculionidae, Scolytinae) in the Czech Republic: analysis of population development and catches in pheromone traps

Lýkožrout modřínový *Ips cembrae* (Coleoptera: Curculionidae, Scolytinae) v České republice: analýza vývoje populací a vzorků z feromonových lapačů

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Abstract

The paper summarises available data on the occurrence of *Ips cembrae* in the Czech Republic and analyses the effect of temperature and precipitation on its population growth; compares numbers of beetles of overwintering and offspring generation, and compares the proportion of females and males caught in pheromone traps. The analysed data of the Forestry and Game Management Research Institute about the volume of harvested wood infested by *I. cembrae* from 1994 to 2013 varied between 150 and 1,415 m^3. During the entire study period *I. cembrae* attacked more than 0.5 m^3 per ha of larch forest stands in only four districts. Temperatures over the period from March to October, from April to June and annual average temperatures during the preceding and actual years, and the ratio of the annual rainfall to long-term rainfall average obtained from the Czech Hydrometeorological Institute had no significant effect on the population growth. Adults were also caught with pheromone traps, in which two generations were documented. In 2013, the numbers of caught beetles of the offspring generation exceeded those of the overwintering generation. This was due to warm and dry weather and, probably also due to high reproductive success. Although more females were caught by pheromone trapping, numbers of males and females did not differ significantly. During the studied period several periods of local outbreak of *I. cembrae* occurred in the Czech Republic, but their causes remained unclear, although the increase of bark beetles populations is generally regarded as a result of hot and dry weather. Larch bark beetle represents only a marginal problem in the Czech Republic.

Keywords: *Ips cembrae;* population; outbreaks; Czech Republic

Abstrakt

Práce shrnuje dostupná data o výskytu lýkožrouta modřínového *Ips cembrae* v České republice, analyzuje vliv teplot a srážek na jeho populační růst, srovnává početnost brouků přezimující (rodičovské) a dceřiné (letní) generace a porovnává podíl samic a samců ve feromonových lapačích. Byla analyzována dostupná data Výzkumného ústavu lesního hospodářství a myslivosti, v.v.i. o objemech vytěženého dříví napadeného *I. cembrae* z období let 1994–2013 v České republice, které varírovaly mezi 150 a 1 415 m^3 a klimatická data Českého hydrometeorologického ústavu. V průběhu celého sledovaného období napadl l. modřínový pouze ve čtyřech okresech více než 0.5 m^3/ha modřínových porostů. Teploty od března do října, teploty od dubna do června a průměrné roční teploty předchozích let i běžného roku a procento ročního úhrnu srážek k dlouhodobému průměru neměly statisticky signifikantní vliv na populační růst tohoto druhu kůrovce. L. modřínový byl také odchytáván deskovými lapači s feromonovými odparníky, přičemž byly pozorovány jeho dvě generace . V roce 2013 byl počet odchycených jedinců z letní (dceřiné) generace vyšší než z přezimující (rodičovské) generace. Pravděpodobně v důsledku horkého a suchého počasí a možná také vysokému reprodukčnímu úspěchu. Ačkoli bylo feromonovými lapači odchyceno více samic, počty odchycených samců a samic se signifikantně nelišily.Ve studovaném časovém období nastalo v České republice několik období lokálních gradací *I. cembrae*, příčiny jejich vzniku jsou nejasné, přestože je zvětšování populací lýkožroutů obecně považováno za důsledek teplého a suchého počasí, nepodařilo se doložit vliv teplot a srážek na populační růst. V České republice představuje l. modřínový pouze marginální problém.

Keywords: *Ips cembrae;* population; outbreaks; Česká republika

1. Introduction

Larch bark beetle *Ips cembrae* (Heer, 1836) is a Euro-Siberian species, which practically occurs across the whole Europe (Austria, Croatia, the Czech Republic, Denmark, Finland, Sweden, France, Germany, Hungary, Great Britain, Italy, England, Wales, Scotland, the Netherlands, Poland, Romania, Serbia and Montenegro, Slovenia, Slovakia, Switzerland and Ukraine) and in central Russia (OEPP/EPPO 2005). Its occurrence was erroneously reported also from East Asia (Postner 1974). After a review, the record was corrected to a closely related species of *Ips subelongatus* Motschulsky, 1860 (Stauffer et al. 2001; Zhang et al. 2007), whose occurrence in this area was confirmed by many other authors (e.g. Terasaki et al. 1987; Yamaguchi et al. 1989; Suzuki & Imada 1993; Westhuizen et al. 1995; Yamaoka et al. 1998; Zhang et al. 1992; 2000).

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European larch (*Larix decidua* Mill.) is the main host plant of the larch bark beetle in its whole distribution range from the lowest elevations up to the subalpine zone (Postner 1974; Pfeffer & Knížek 1996; Grodzki 2008). Although larch bark beetle is occasionally able to attack Norway spruce (*Picea abies* [L.] Karsten (Pfeffer 1989)), especially during dry seasons, this happens only rarely (Holuša observ). In the past, its occurrence was also recorded on Swiss stone pine (*Pinus cembra* L.), but this record was reviewed and its accuracy could not be confirmed. It was confused with small spruce bark beetle (*Ips amitinus* (Eichhoff, 1871)) (Pfeffer 1995).

Larch bark beetle (*I. cembrae*) is considered a secondary pest of larch stands (Grégoire & Evans 2004). It reproduces on felled wood (Elsner 1997), in wind throws (Krehan & Steyer 2005), wind breaks (Luitjes 1974) or dying trees (Grodzki 2008). At naturally drier areas, periods with below-average rainfall may promote its attack of green vital trees (Bevan 1987; Knížek 2006; Grodzki 2008). In such cases, larch bark beetle reproduces and subsequently becomes a primary pest of healthy trees. Especially vulnerable to such conditions are young, but also older stands from lower and middle elevations (Grodzki & Kosibowicz 2009). With the growing population during the outbreak, larch bark beetle may act as a physiological pest of visually healthy standing trees in larch forests that succumbed to his massive raid. It can also act as a defoliator during mature feeding of young beetles in the crown twigs of healthy trees or during the regeneration feeding of older beetles in thin stems or thicker branches (Postner 1974; Krehan & Cech 2004). *I. cembrae* is considered a serious pest in several countries of Europe (Grégoire & Evans 2004). As in the case of other bark beetles of *Ips* genus, it is monitored using pheromone traps or logs and visually by searching for infested trees. The following measure then includes sanitation and the use of traps, logs, or baits in the form of slash or logging residues. Felled trees are also treated with insecticides (Grégoire & Evans 2004).

In Europe, four types of pheromone evaporators are currently in use: Cembräwit®, Cemprax (Shell Agrar Ltd.) (www.witasek.com), Cemsan (www.fluegel-gmbh.de), and Cembrodor (Glowacki 2008). In the Czech Republic, the experience with trapping *I. cembrae* is limited (Holuša et al. 2014), and the sex ratio in pheromone traps is not known yet. The ratios for *I. typograhus* and *I. duplicatus* are known, females dominate in traps (Lubojacký & Holuša 2011; 2013). In comparison with other European representatives of *Ips* genus, protection against *I. cembrae* is problematic due to several reasons: (i) they develop also in branches; (ii) a substantial portion of population may overwinter in litter (as well as other species of *Ips* genus), and (iii) trees processed with harvesters are not protected from attack (Holuša et al. 2014).

Due to the fact that in the last years an outbreak of this species occurred at many places in the Czech Republic, and its importance is growing in several regions, the goal of this work was to (i) summarise available data on the occurrence; (ii) analyse the effect of temperature and precipitation on population growth; (iii) compare numbers of beetles of overwintering and offspring generations, and (iv) compare the proportion of females and males caught in pheromone traps.

2. Material and Methods

We summarised the volume of harvested wood in the Czech Republic that was infested by *I. cembrae* from 1994 to 2013 (Fig. 1 and 2), which is annually documented at a district level on the base of forest owners reports on forest disturbance factors and their predicted impact in the following year and published by the Forestry and Game Management Research Institute (Knížek 2001; 2002; 2003; 2005; 2008; 2009; 2010a; 2010b; Zahradník et al. 1996; 1997; Zahradník & Knížek 1998; 1999; 2000; Knížek & Zahradník 1996; 2004; Knížek & Holuša 2006; 2007; Lubojacký & Knížek 2013; Knížek & Lubojacký 2011; 2012; www.vulhm.cz). The volume of infested wood is not high due to the small portion of larch in tree species composition of the Czech Republic. Larch (*Larix* sp.) covers 115,159 ha or 4.2% of the total forest area of the Czech Republic (CR), which is 2,712,080 ha.

At elevations below 400 m a.s.l., larch covers 4.4% (27,600 ha), between 401 and 700 m a.s.l. it is 5.2% (84,400 ha), and above 700 m a.s.l. it is 0.7% (3,200 ha) of the forest area. The total number of larch trees in the Czech Republic was 192.1 million of trees (http://www.czechterra.cz/vystup.php?firstpage=26&lastpage=31). This explains the unbalanced amount of infested wood (Fig. 2), which depends on the area of larch stands in districts.

Air temperature is a key factor affecting the development of *Ips typographus* (Baier et al. 2007). Higher temperatures

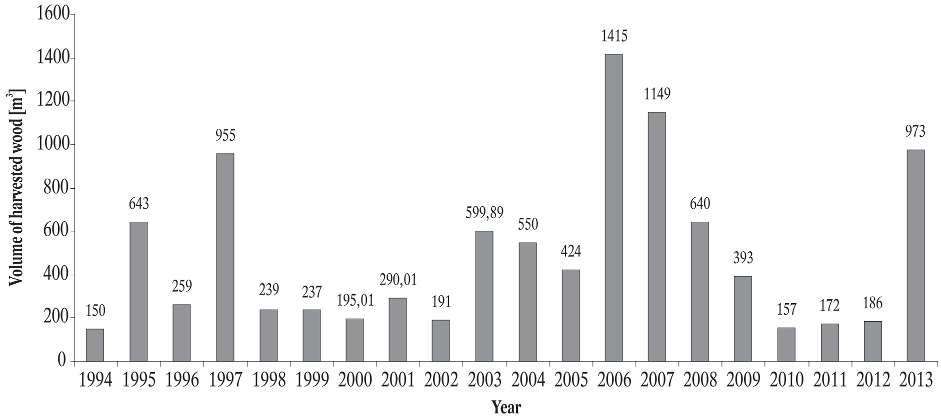

Fig. 1. The volume of harvested wood infested by *Ips cembrae* in the Czech Republic from 1994 to 2013.

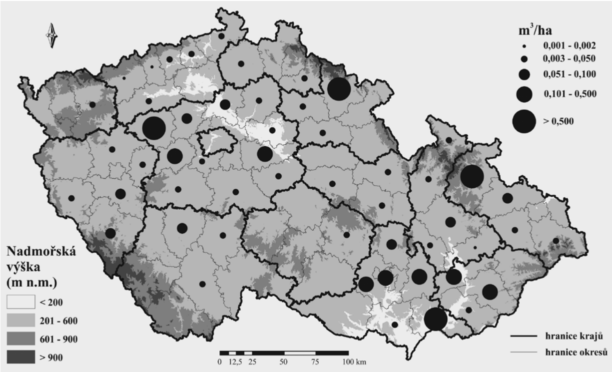

Fig. 2. The volume of harvested wood infested by *Ips cembrae* in the districts related to the area of larch forests (m^3/ha) from 1994 to 2013.

in spring and summer may have a positive impact on the population growth of bark beetles (Berryman 1989). Increasing temperatures during spring and summer resulting from global warming are considered to be the factors that increase the probability of insect outbreak in semiarid and temperate regions (Dobbertin et al. 2007). Rising temperature coupled with constant precipitation may increase water stress of trees (Rebetez & Dobbertin 2004), which is also one of the aspects that increase stand susceptibility to bark beetle attack.

Thus, using simple regressions we examined relationships between the population growth and mean temperatures over certain periods (from April to June, from March to October, whole year), annual precipitation total, ratio of annual precipitation total to long-term mean (annual precipitation sum as a percentage of long-term mean in the years 1961–1990), and Ellenberg climatic quotient. Ellenberg climatic quotient is calculated as EQ=MTWM / AP × 1000, and defined as a ratio of mean air temperature of the warmest month from the long-term perspective (MTWM) and the annual precipitation total (AP). Ellenberg (1988) climatic quotient is a simple index evaluating landscape aridity. We used climatic series from the Czech Hydrometeorologic Institute available at www.chmi.cz, and represented by mean values for the whole regions (for the areas of regions see Fig. 2). Population growth was related to all factors in the same year and the two preceding years n–1 and n–2 (Table 2) using multiple regressions. Population growth (–log n/n–1) was calculated as a ratio between the proportion of harvested wood infested with *Ips cembrae* in year n and in year n–1 in individual regions (Jarošík 2005). Population growth was calculated only when the records of the harvests in the two subsequent years included bark beetle infested wood. Climatic factors, that are known from literature to have a most likely effect on the bark beetle population growth (see above), entered the multiple regression together with the volume of wood infested by bark beetle in year n–1 (Table 3). Data normality was not ensured, hence, Spearman correlation coefficient was used. In the year 2013, larch bark beetles were being caught using flat pheromone traps (Theysohn®) with pheromone evaporators (Cembräwit®: WITASEK PflanzenSchutz GmbH, Austria) at three locations (Table 1). At each location, five traps were mounted at a distance of 10–15 m from the forest edge. Pheromone evaporators were activated at the end of April and replaced after eight weeks. They were emptied every 1 to 2 weeks until September. Trapped beetles were counted, and from each trap and each collection sample sexes of max. 100 individuals were determined on the basis of dissection and reproductive organs to estimate the ratio between females and males. Caught beetles were divided to overwintering and offspring generations according to a significant decrease in flight activity and the occurrence of callow beetles at the end of June. Regression analyses and comparisons of the frequency between overwintering and offspring generations, and between females and males in the samples from pheromone traps were performed with Mann Whitney U-test in Statistica 12.0 (StatSoft 2007). All hypotheses were examined at a 0.05 significance level.

Table 1. Studied locations with pheromone traps set for *Ips cembrae*.

Location	Altitude [m a.s. l.]	GPS
Havířov	300	49°48'35.608"N, 18°24'16.584"E
Hradec nad Moravicí	400	49°51'26.520"N, 17°53'6.559"E
Kostelec nad Černými lesy	400	49°59'1.902"N, 14°48'29.537"E

GPS – geographical coordinates for given locations.

3. Results

3.1. Volume of wood infested by bark beetle

In the Czech Republic, the total volume of harvested wood infested by *I. cembrae* varied between 150 and 1,415 m^3 in the years from 1994 to 2013. The largest volume was recorded in 2006 (Fig. 1). None of the analysed climatic factors alone had a significant impact on the population growth (Table 2). Multiple regression analysis revealed one positive significant relationship of the population growth to the harvest volumes of bark beetle infested wood in the preceding year (Table 3).

Table 2. Results of the regression analysis of the influence of climatic factors on population growth, for all regions together.

Parameter / Year	r	p
Temperatures from April to June of the actual year (n)	−0,020	0,852
Temperatures from April to June of the preceding year (n–1)	−0,001	0,990
Temperatures from April to June of the year before last (n–2)	0,170	0,149
Temperatures from March to October of the actual year (n)	0,016	0,877
Temperatures from March to October of the preceding year (n–1)	0,005	0,958
Temperatures from March to October of the year before last (n–2)	0,111	0,349
Average annual temperature of the same year (n)	-0,069	0,514
Average annual temperature of the preceding year (n–1)	0,052	0,622
Average annual temperature of the year before last (n–2)	0,172	0,146
Annual rainfall precipitation of the actual year (n)	0,059	0,574
Annual rainfall precipitation of the preceding year (n–1)	−0,047	0,652
Annual rainfall precipitation of the year before last (n–2)	−0,197	0,095
Percentage of annual rainfall precipitation vs long term average of the actual year (n)	0,128	0,221
Percentage of annual rainfall precipitation vs long term average of the preceding year (n–1)	−0,079	0,449
Percentage of annual rainfall precipitation vs long term average of the year before last (n–2)	−0,155	0,189
Ellenberg quotient in the actual year (n)	−0,118	0,262
Ellenberg quotient in the preceding year (n–1)	0,050	0,634
Ellenberg quotient in the year before last (n–2)	0,289	0,013

Table 3. Results of the multiple regression analysis of the influence of climatic factors on population growth, all parameters represent the preceding year, for all regions together.

Proměnná	r[1)]	P[2)]
Constant term		0,193
Volume of harvested wood	0,348	0,003
Average temperature from April to June of the preceding year	0,196	0,230
Average temperatures from March to October of the preceding year	0,100	0,530
Percentage of annual rainfall precipitation vs long term average of the preceding year	0,038	0,760
Ellenberg quotient in the preceding year	0,225	0,093

Explanatory notes: [1)] Correlation coefficient; [2)] p–value 0.05.

During the whole analysed period, larch bark beetle attacked more than 0.5 m^3/ha of larch stands only in four districts (Fig. 2). In all cases, mature stands were attacked (on the base of the references given in methods).

3.2. Catches in pheromone traps

In the year 2013, we caught in total 15,766 individuals of larch bark beetle using pheromone traps (Havířov 13,852; Hradec nad Moravicí 291; Kostelec nad Černými lesy 1,623). In the samples from traps we also recorded 1% of other bark beetle species. At all locations, the numbers of caught beetles of the offspring generation was higher than the numbers of caught beetles of the overwintering generation, but the difference was significant at one location only (Fig. 3).

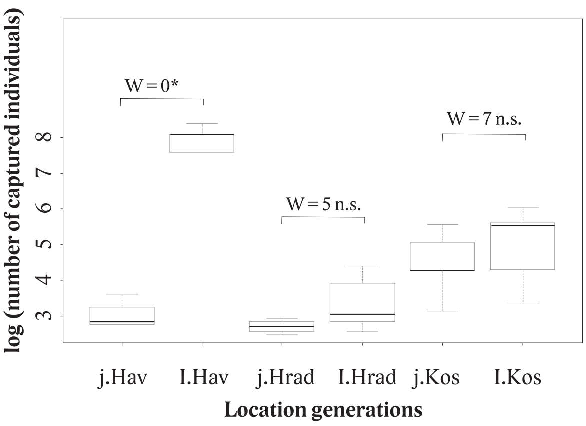

Fig. 3. Numbers of *Ips cembrae* of overwintering and offspring generations caught in pheromone traps at studied locations (Mann-Whitney test; * significant at the 0.05 significance level; n.s. – non-significant) (for localities see Table. 1).

In all examined seasons, we observed a clear peak of flight activity in July, while in May the catches were very small. Flight activity started in the second half of April and lasted until the mid-September. The sex ratio fluctuated between 1.03 and 2.18 of female beetles per one male beetle, but the frequencies of female and male beetles in traps were not significantly different (Fig. 4).

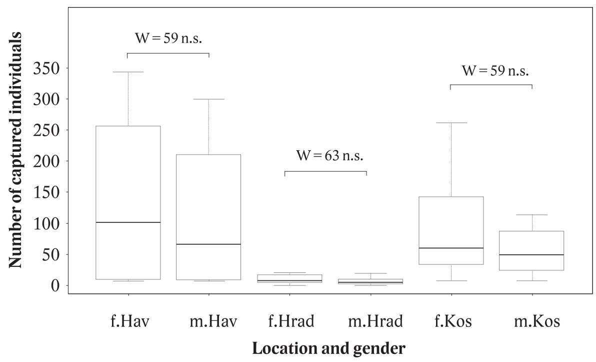

Fig. 4. Numbers of *Ips cembrae* males and females caught in pheromone traps at studied locations (Mann-Whitney test; n.s. – non-significant) (for localities see Table. 1).

4. Discussion

In the analysed time horizon (1994–2013) several periods of local outbreak occurred and lasted three years at maximum, during 2003–2005 and 2006–2008. Similarly, three one-year-long periods with greater harvests (1995, 1997, 2013) were recorded, although the year 2013 can be the beginning of a longer lasting outbreak. The causes of their occurrence are unclear, because we could not prove the impact of temperatures and precipitation on the population growth, although it is expected that on naturally drier sites periods with below-average precipitation totals may also promote the attacks of green vital trees (Bevan 1987; Knížek 2006; Grodzki 2008). The increase of infested wood in the year 2003 is generally considered to be the result of warm and dry weather in the Czech Republic (Knížek & Zahradník 2004) and in the neighbouring countries (Krehan & Cech 2004; Stratmann 2004), although we could not prove this relationship. However, we need to note that the processed data are rough, as they represent districts, but no information at a lower spatial level was available. In addition, we were not able to account for the intensity and the quality of processing trees infested by bark beetle. The increase in the harvest of infested wood in the year 2013 corresponds with the high number of trapped bark beetles of the offspring generation in pheromone traps. A surprisingly positive impact of bark beetle harvests on the population growth of this beetle indicates that the beginning of *I. cembrae* outbreak is not captured by forestry service, and the intensity of protection measures is low. Protection measures become more frequent (complemented with intense installing of traps) only during the outbreak.

While in the Czech Republic, outbreak peaked in the year 2006 and these local outbreak were attenuated by intense search for attacked trees in the year 2007 (Holuša et al. 2014), in the neighbouring Poland, the volume of harvested wood infested by the bark beetle increased six times more (Grodzki & Kosibowicz 2009). However, local long-term outbreak in Poland have different reasons, namely unfinished cutting of larch trees during first clearings which resulted in a large amount of wood attractive for bark beetle occurring on the site for a long time (Hutka 2006). In the year 2013, two generations were detected, which corresponds to the climate of Central Europe (Schneider 1977). Two generations were recorded also in the years 2006 and 2007 (Holuša et al. 2014). Although females prevailed in the pheromone traps, the difference between sexes was not significant. Many studies showed significant differences between the sexes for *Ips typographus* and *Ips duplicatus* caught in pheromone traps with males being less abundant than females (Annila 1971; Zumr 1982; Lindelöw & Weslien 1986; Schlyter et al. 1987; Weslien & Bylund 1988; Faccoli & Buffo 2004; Lubojacký & Holuša 2011; 2013). It is assumed that there are behavioural differences between males and females. For example, female beetles of *Ips paraconfusus* Lanier fly directly towards higher concentrations of pheromones of male beetles colonising attacked (felled) trees, while male beetles have a tendency to land on adjacent non-colonised spots (Byers 1983). Byers (1983) also recorded a higher number of male beetles of *I. paraconfusus* flying several metres from traps that never occurred in the traps containing a large number of caught female beetles. Flat traps do not have a shape similar to their host plants.

5. Conclusion

In the examined time horizon (1994–2013), several periods of local outbreak of *I. cembrae* occurred. However, during these outbreak only a limited number of larch trees was attacked because the proportion of larch in the Czech Republic is not high. The causes of these local outbreak remained unclear. Although the population growth of bark beetles is in general connected to warm and dry weather, we could not confirm the impact of temperatures and precipitation on the population growth of larch bark beetle. The climate impact on the population growth of *I. cembrae* was insignificant, which may however result from rough data of insufficiently detailed information. In the current period of droughts and unbalanced climate it is important to monitor the population of *I. cembrae* mainly in the areas with higher proportion of larch. In spite of that, total damage is low and *I. cembrae* does not represent an important pest in the Czech Republic. Nevertheless, we may assume that the reaction of *I. cembrae* to expected climate change will be similar to the one of *I. typographus* or *I. duplicatus*, which could cause a greater threat to larch forests. Thus, it would be suitable to have pheromone evaporators for monitoring, although so far registeration of pheromone traps for larch bark beetle has not been needed due to the low amount of infested harvests.

Acknowledgements

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