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Evaluation of flight phenology and number of generations of the four-spotted sap beetle, *Glischrochilus quadrisignatus* in Europe

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Abstract

The study aimed to acquire the widest possible information on the flight phenology and European distribution of the four-spotted sap beetle, *Glischrochilus quadrisignatus* (Say) (Coleoptera Nitidulidae). The field investigations were made in 2009 and 2010 in the outskirts of Csurgó (Somogy county) in Hungary. Glass traps filled with broken maize grain were placed in the maize fields in order to follow the course of flight. Besides, the number of generations was determined in Europe by accumulated day-degrees, using threshold temperature available from literature. The results showed the presence of two-generations of *G. quadrisignatus* in Hungary. In the experimental plot the second generation proved to be larger. The meteorological elements significantly influenced the possibility of trapping, but the effect of annual precipitation on the flight phenology was the most decisive. The numerous trapped individuals in monoculture maize can be explained by its overwintering site. According to the results and to the bibliographic sources the range of this nitidulid presence has extended to many countries in Central Europe, the Balkans and Italy. The distribution of this species reaches more geographic regions in Europe where one, two and three generations per year may develop.

Key words: four-spotted sap beetle, *Glischrochilus quadrisignatus*, flight phenology, European generation number.

Introduction

The four-spotted sap beetle, *Glischrochilus quadrisignatus* (Say) is a native species in North and Central America. Its endemic distribution area is Nearctic and Neotropic regions of American Continent (Parsons, 1943). Its European invasion began with introductions via transports of fruits and vegetables for American army in Europe at the end of World War II. The first dated confirmation of its presence in Germany was from 1948 (Karnkowski, 2001). Since then the range of its invasion has extended to other countries of Central and North Europe, Balkan Peninsula, Apennine Peninsula and western Russia (Audisio, 1985; Kałmuk *et al.*, 2008).

Table 1 shows the list of findings of *G. quadrisignatus* in Europe. Publications have originated from twenty countries since the first appearance of the beetle in Europe (1948) (figure 1). According to the data examined, the spreading of this invasive species has been continuous since the second part of the twentieth century. Its first invasion extended to the whole territory of Germany and the Czech Republic (Jelinek, 1984), later it appeared in Poland (Kałmuk *et al.*, 2008), Hungary (Audisio, 1980) the Netherlands (Brakman, 1966) and France (Callot, 2008), then its southward expansion began at the beginning of the decades preceding the millennium. So its presence was first confirmed in Serbia in 1983 (Balarin, 1984), in Italy in 1985 and in Moldavia in 1990 (EPPO, 1994). Due to its good adaptation and quick spreading, its southward expansion is a phenomenon of the present decades and the near future.

The *G. quadrisignatus* is an invasive, polyphagous saprophage and herbivore of high environmental tolerance, which can be appeared both in agri- and horticultural biocoenoses (Šefrová and Laštuvka, 2005). This insect generally feeds on fruits and other plant parts that are ripening or decomposing. Its host range may include tree and small fruits such as peaches, blueberries, raspberries and strawberries, melons, field- and sweet maize, stored maize and dried fruit products (Audisio, 1980; Bourchier, 1986; Davidson and Lyon, 1979).

G. quadrisignatus has been observed feeding on the silk and pollen of undamaged maize. It also invades fields with maize stalks damaged by the European corn borer (McCoy and Brindley, 1961). It is a secondary, so called “scavenger” invader in fields where ears are damaged by other pests. *G. quadrisignatus* is also associated with *Fusarium* species of maize roots, stalks, and ears (Windels *et al.*, 1976), and is capable of transmitting conidia and ascospores of *Gibberella zea* (the perithelial state of *Fusarium graminearum*) causing rot to ears (Attwater and Busch, 1983). Besides, it can appear as an important maize pest too, where the damage ratio can reach 30 % in maize acreage (Dowd, 2005; Foot, 1975; Funt *et al.*, 2004; Westgate and Hazzard, 2005). In North America it can be a serious pest of ripening fruit and vegetables and a nuisance to picnic areas (Ikin *et al.*, 1999).

G. quadrisignatus develops several generations as a function of its distribution area (Luckmann, 1963). So it may have one (Funt *et al.*, 2004), two and even more generations per year. In the tropics, multiple generations may occur especially if there is enough food available throughout the year (Dowd and Nelson, 1994). The threshold temperature for the development of pest is 10.5 °C (Luckmann, 1963) and its accumulated day-degrees for the entire development (egg to adult) is 535.9 DD (Mussen and Chiang, 1974). *G. quadrisignatus* overwinters as an adult and becomes active on warm

Table 1. List of the *G. quadrisignatus* bibliographical sources in Europe (in order of publication date).

Country	Sources
Austria (A)	Kofler *et al.*, 1989; Kofler and Schmölzer, 2000; Köppl, 2003; Wieser *et al.*, 2004; Ressl, 2005; Wittenberg *et al.*, 2005; Frauenschuh and Kromp, 2009
Bosnia and Herzegovina (BIH)	Balarin, 1984; Audisio, 1985; Kałmuk *et al.*, 2008
Bulgaria (BG)	Audisio, 1985; Kałmuk *et al.*, 2008
Byelorussia (BY)	Tsinkevich *et al.*, 2005; Alekseev and Nikitsky, 2008
Croatia (HR)	Balarin, 1984; Audisio, 1985; Merkl, 1998; Kałmuk *et al.*, 2008
Czech Republic (CZ)	Jelinek, 1984, 1997; Sefrova and Lastuvka, 2005
France (F)	Brua and Callot 2010; Callot 2008
Germany (D)	Adeli, 1963; Lienemann *et al.*, 2003; Kałmuk *et al.*, 2008; Müller *et al.*, 2008
Hungary (H)	Audisio, 1980; Rakk *et al.*, 1992; Slipinski and Merkl, 1993; Merkl, 1998, 2001; Horváth *et al.*, 2004; Merkl and Vig, 2009; Vig *et al.*, 2010
Italy (I)	Audisio, 1985; 1990; 1993; Ciampolini *et al.*, 1994; EPPO, 1994; Angelini *et al.*, 1995; Audisio and De Biase, 2005; Audisio *et al.*, 1990
Lithuania (LT)	Tsinkevich *et al.*, 2005; Ferenca *et al.*, 2006; Alekseev and Nikitsky, 2008; Fossestol and Sverdrup-Thygesonb, 2009
Moldavia (MD)	EPPO, 1994; Kałmuk *et al.*, 2008
Poland (PL)	Lasoń, 1999; Karnkowski, 2001; Błochowiak, 2004; Boroń and Mrówczyński, 2005; Przewoźny, 2007; Ruta, 2007; Beres and Pruszynski, 2008; Kałmuk *et al.*, 2008
Romania (RO)	EPPO, 1994; Kałmuk *et al.*, 2008; Merkl, 2008
Russia (RUS)	Koval, 1987; Kyrejshuk, 1999; Alekseev and Nikitsky, 2008
Serbia (SRB)	Balarin, 1984; Audisio, 1985; Glavendekic *et al.*, 2005; Kałmuk *et al.*, 2008
Slovakia (SK)	Jelinek, 1984; Kałmuk *et al.*, 2008
Slovenia (SLO)	Balarin, 1984; Kałmuk *et al.*, 2008
Switzerland (CH)	Wittenberg *et al.*, 2005
The Netherlands (NL)	Brakman, 1966; Cuppen and Oude, 1996; Oude, 1999; Reemer, 2003; Oude, 2005; Cuppen and Drost, 2007
Ukraine (UA)	Audisio, 1985; Kałmuk *et al.*, 2008

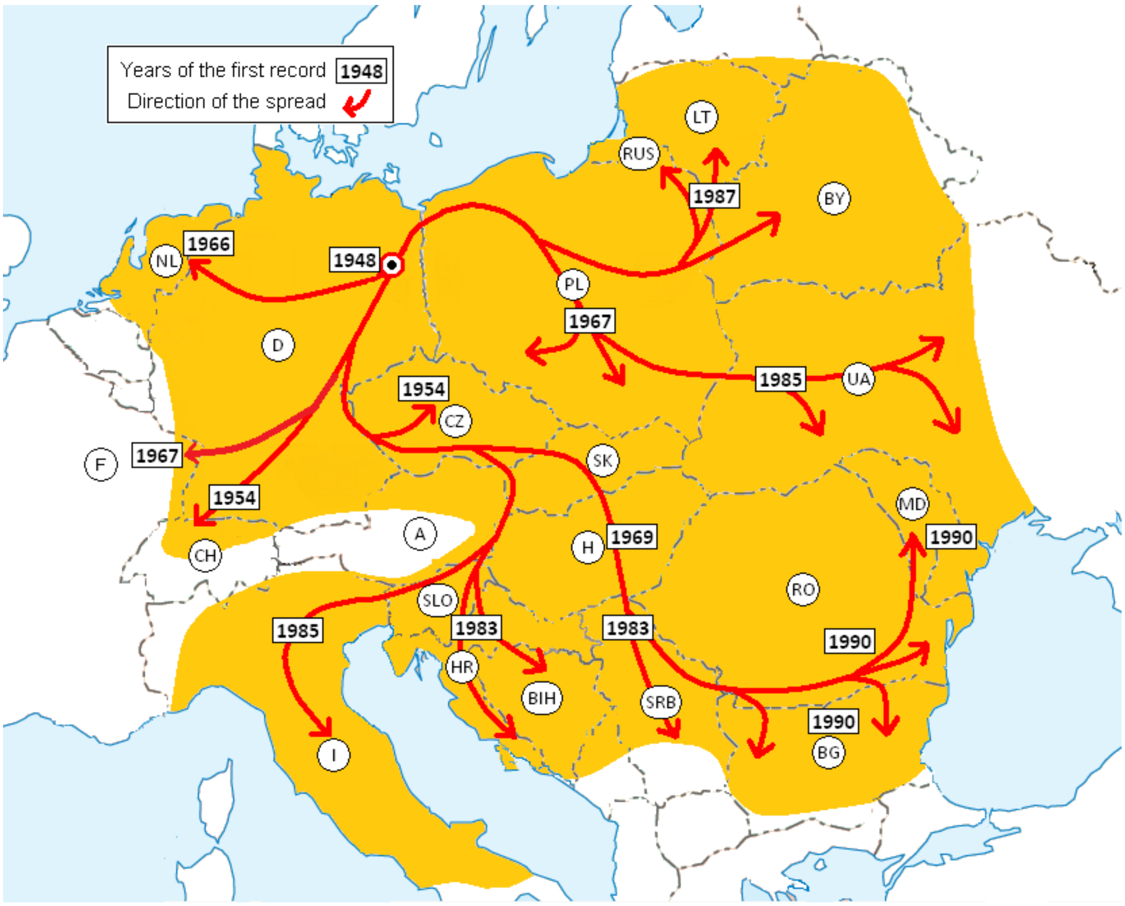

Figure 1. One of the theoretical spreadings of *G. quadrisignatus* in Europe (based on Kałmuk *et al.*, 2008).

days in late winter or early spring. Most eggs are deposited in May. Females can oviposit up to 400 eggs in their lifetime. To be suitable for oviposition and larval development, food material must either be buried in the soil or be in contact with the soil and must be moist. Active adults of the new generation begin leaving the soil in June. They fly to fields of ripening or damaged berries, tree wounds and maize. Adults live long time (40-60 days) and late in June various life stages including both the new and overwintering generation can be found together in the soil (Blackmer and Phelan, 1995). Food source has a significant effect on the development time of *G. quadrisignatus* from neonate larvae to adult, with the shortest mean development time of 41.2 days on multiple-species rearing diet and the longest mean of 63.4 days on sap beetle diet (Peng and Williams, 1991).

The objective of this study was to know more accurately the flight phenology of the *G. quadrisignatus* adults in Hungary and to predict the number of generations in Europe based on a degree-day model. The results may also indicate the optimal timing of chemical control.

Materials and methods

Comprehensive experiments were carried out on the population number and flight dynamics of *G. quadrisignatus* on the basis of catching data. The places of trapping were in maize fields at Csurgó (Hungary, Somogy county: 17°5'47"E, 46°15'18"N): 22.3 ha in 2009, and 18.6 ha in 2010. In the experimental fields maize was grown both in rotation and in monoculture in these years. After the harvest of the previous year's sunflower, PR37Y12® (FAO 390), maize hybrids were sown in the fields. Soil disinfection (Force 1.5G®; 14 kg/ha) to control western corn rootworm (*Diabrotica virgifera virgifera* LeConte) was carried out in maize monoculture both in 2009 and 2010. Insecticides were not applied either in the fields with maize grown in rotation, or during the growing season when different cropping techniques were used.

To determine the *G. quadrisignatus* yearly appearance and the flight phenology in Hungary the so called „glass traps" were used during the growing season of maize in two years (2009: 9th March - 4th October; 2010: 8th March - 3rd October). The same numbers of traps were placed out with both cultivation techniques. The traps were fixed to stakes at a height of 140-150 cm, then when the plants reached the right size the traps were placed above the ear at the same height (figure 2). The attractant was an alcoholic fermented broken maize grain, which was replaced weekly. The number of caught beetles was assessed every week.

The values of abiotic environmental factors (soil and air temperature, precipitation) were obtained from March to October for the area concerned at Csurgó (Monsanto® online website: www.dekalbmet.hu).

Student t-test ($P \leq 0.05$) was applied to ascertain the significant differences among dates and cultivation practices. The effects of abiotic factors on the trapped individuals were statistically examined with the regression and correlation analyses. Statistical examinations were performed by means of Microsoft Excel 2007 and SPSS 11.5 for Windows.

In addition to the flight observation, and based on the European distribution provided by Kałmuk *et al.* (2008), the yearly generation number (G) was calculated at different points using the threshold temperature for the development (t_0 = 10.5 °C) (Luckmann, 1963) and the accumulated day-degrees (C = 535.9 DD) (Mussen and Chiang, 1974). The cumulated temperature amount in the growing season was calculated as [$T = \Sigma_n \times (t_{aver.} - t_0)$; where: Σ_n = number of days in growing season, $t_{aver.}$ = daily average temperature]. For the calculations of generation numbers, adults appearance in early April was taken into consideration after a short maturation feeding and copulation period (10 days). This calculation based on the growing season (from 15 April to 30 November) uniformly, independently of examined areas and times.

$G = [\Sigma_n \times (t_{aver.} - t_0)]/C$

The international temperature data originated from the online meteorological website, Wounder Underground® (www.weatherground.com). Besides these, the appearance of this species in Hungary was analysed by using the average winter and summer temperatures of the last 107 years (from the beginning of the twentieth century to 2007). These meteorological data were taken from the publication of the Hungarian Meteorological Service (Bihari *et al*., 2008).

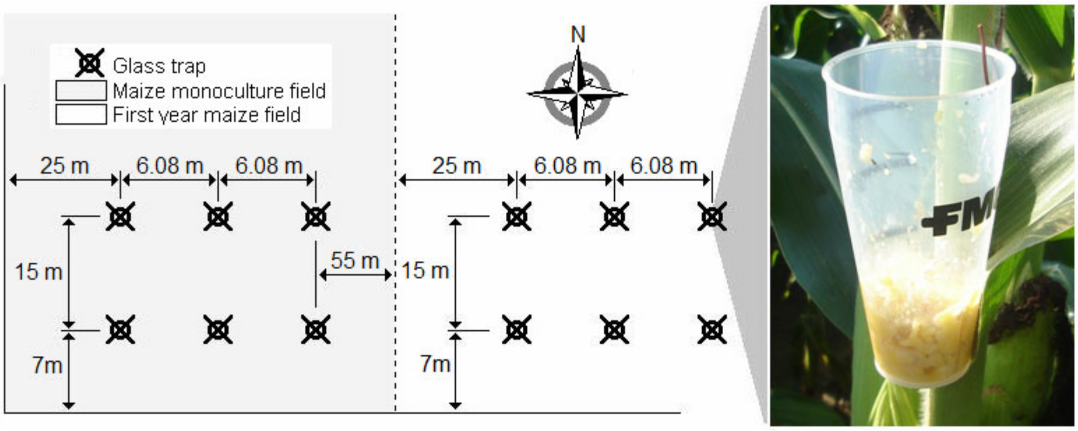

Figure 2. The applied glass trap, and the location of these prognostic gears in maize acreage in 2009, 2010.

Results

The catching results of the glass traps observed at Csurgó in 2009 and 2010 can be seen in figures 3 and 4. The meteorological values are shown together with the captures.

The flight phenology was more or less similar in the two years studied. The appearance of the first beetle coincided with an increase in soil temperature in the middle of spring. The appearance of overwintered beetles and the beginning of their flight can be noticed when the soil temperature is about 10-11 °C. The flight activity was gradually intensified by the increasing daily temperature. Warmer, arid periods in the growing season provide possibility for a more extended flight. The separation of two generations is conspicuous in both years. The escalating of the later generations, the increasing number of trapped beetles from the middle of summer and the dominant later flight peaks can be observed in the phenology diagrams.

The flight periods were a little dissimilar, which can unequivocally originate from the different climatic features. The abundant precipitation especially influenced and decreased the number of trapped insects in 2010. The first beetle was trapped on 18th April and the last one on 4th October in 2009. So the period of flight was especially long, exactly 170 days. The first beetle was trapped on 12th April and the last one on 12th September in 2010. So the period of flight was only 154 days in that year. The time of appearance for the different generations was calculated by taking into considerations the beetles maturation feeding time and the 10 days copulation period. Based on these facts it is confirmed that the first generation appeared on 6th July in 2009, and on 30th June in 2010, while the second generation on 25th August in 2009 and on 18th August in 2010.

A higher number of trapped individuals can be observed exceptionally well in the case of maize monoculture. The Student-t value (t = 0.012) for the numbers of trapped individuals was significant in different cultivation practices.

The tested data to regression and correlation analyses showed normal distribution. The statistical examination confirmed a positive linear correlation in the case of the number of trapped individuals and the average temperatures ($p = 0.044$; $r = 0.363$), and a negative linear correlation between the trapped individuals and the precipitation values ($p = 0.011$; $r = -0.450$). Besides, this examination confirms the dominant effect of precipitation, because this factor influenced the trapped population number by 20.3% ($R^2 = 0.203$), in contrast to the 13.2% ($R^2 = 0.132$), value of the effect of temperature.

The number of predicted generations in Europe is shown in figure 5. *G. quadrisignatus* presence covers more geographic regions. The one- (Lithuania, Netherland, Germany, France, Czech Republic, Poland, Switzerland, Austria) and two-generation (Belorussia, Ukraine, Slovakia, Hungary, Romania, Moldavia, Serbia, Bosnia and Herzegovina, in northern parts of Croatia, Slovenia, Bulgaria and Italy) populations are located in the largest area in Europe, while the three-generation populations only in a relatively smaller area (in southern parts of Croatia, Slovenia, Bulgaria and Italy), on the southern border of the habitat.

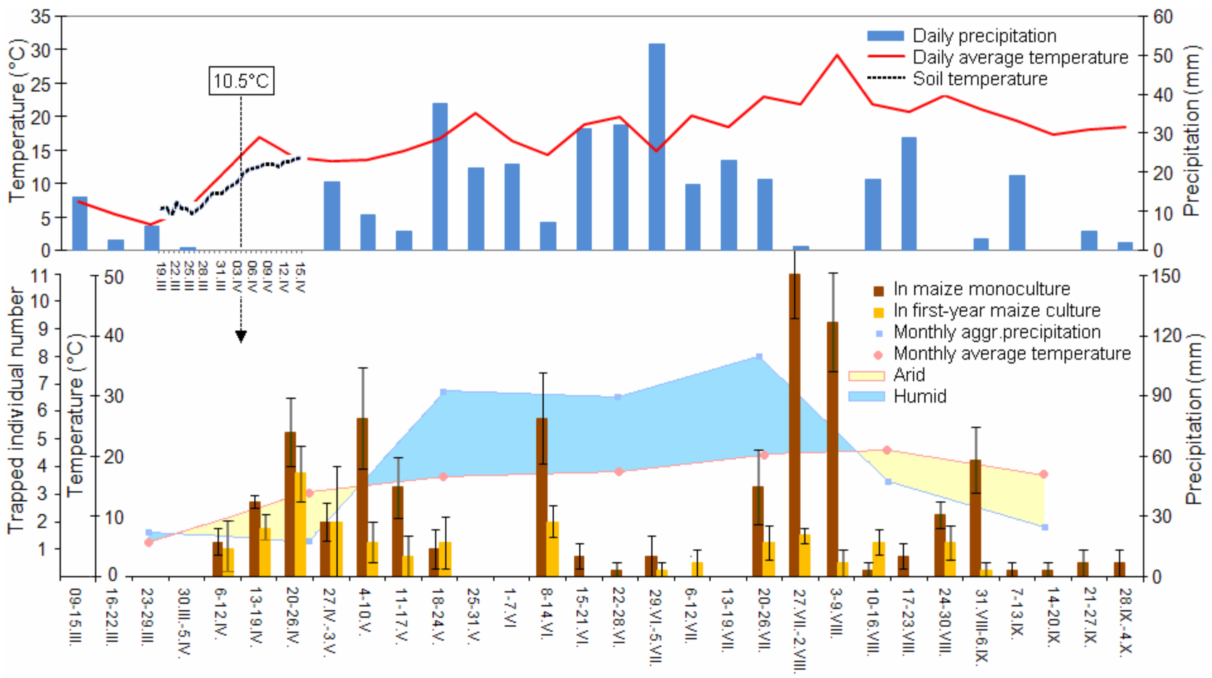

Figure 3. Flight diagram of *G. quadrisignatus* at Csurgó (Somogy county, Hungary) in 2009 correlate with abiotic factors. The average temperature and the aggregated precipitation were indicated on the vertical axis of Walter-Lieth climatediagram (1:3) according to weather of Central-Europe.

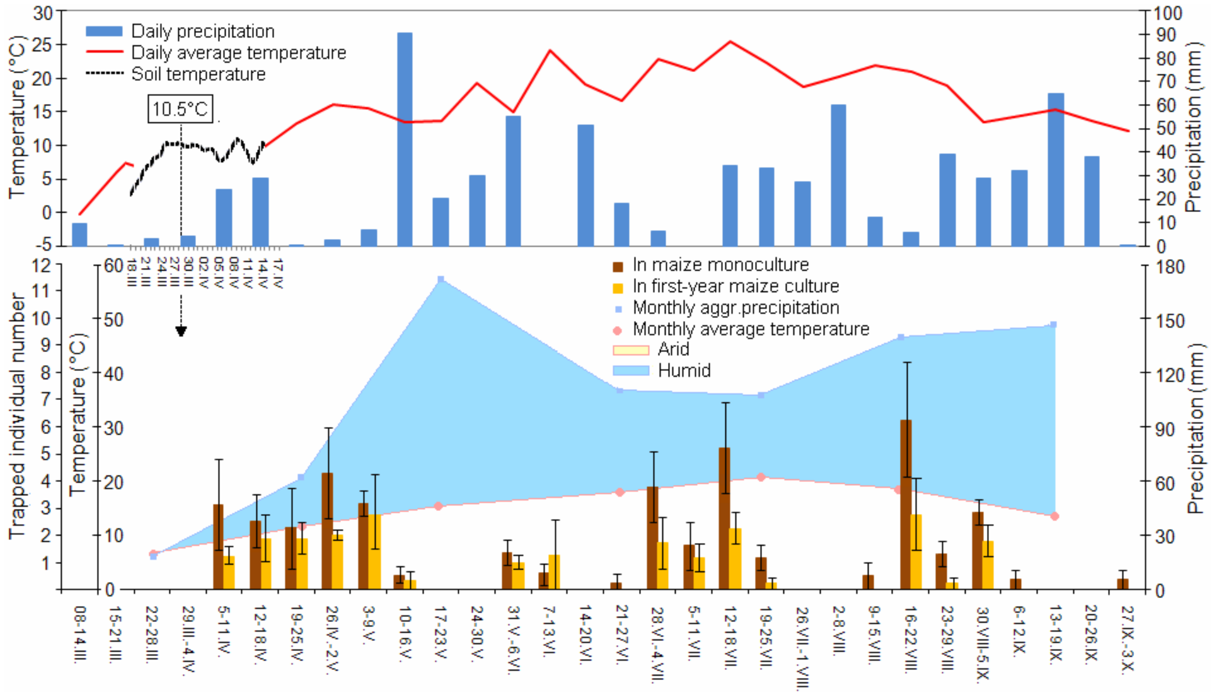

Figure 4. Flight diagram of *G. quadrisignatus* at Csurgó (Somogy county, Hungary) in 2010 correlate with abiotic factors. The average temperature and the aggregated precipitation were indicated on the vertical axis of Walter-Lieth climatediagram (1:3) according to weather of Central-Europe.

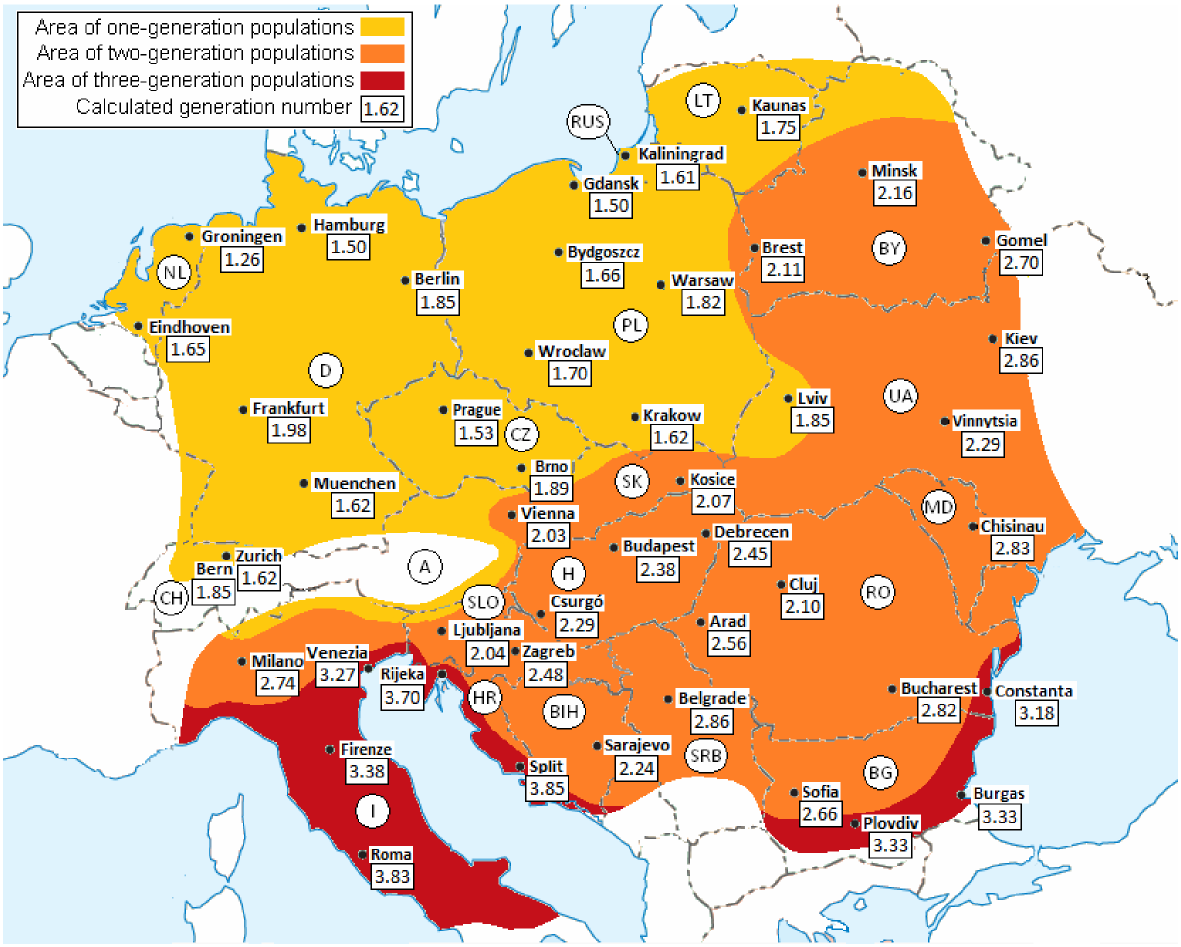

Figure 5. Distribution area of *G. quadrisignatus* in Europe, and the calculated borderline of its different generation number populations in 2010. Decimal numbers indicate the theoretical generation numbers. Natural integers show the numbers of the entire developing cycle (from egg to adult).

Discussion

The temperature of the growing season has profound effects on generation number of *G. quadrisignatus*, but the amount and distribution of precipitation principally influence the flight phenology of this insect. As seen from the figures changes in the population number of *G. quadrisignatus* were proportionately followed by a change in the values of meteorological data in both years.

The numerous trapped individuals in maize monoculture can be explained with its overwintering site, because the maize ears found in the soil as *G. quadrisignatus* food can give shelter to the overwintering adults (Blackmer and Phelan, 1995; Luckmann, 1963). So its overwintering is more successful.

This insect develops different generation numbers in its distribution area, with a maximum of three at present. Naturally, the borderlines between number of generations may change depending on the climatic effects of different years.

In all probability the maximum European northward expansion is as far as 66-68°N latitude in view of the thermal requirement of the species. *G. quadrisignatus* gradual southward distribution can be forecasted from its rapid spreading, where four-generation populations may appear in the future.

In addition, any warming period may quickly and substantially increase the number of generations as well as the arrival of adventive, thermophilic insect species (Kozár, 1997). Hereinafter the global warming could provide perfect conditions to the European expansion of this species. Most adventive species originating from America settled in Southern Europe (e.g. *D. virgifera virgifera*), and their northward expansion is continuous as a function of the yearly average temperature. In contrast, *G. quadrisignatus* appearing in Northern Europe can be presupposed to have a rapid, quick expansion in the southern, warmer areas in Europe after the relatively slower initial spread. Its spreading can be delayed by relief barriers such as the mountain chains of the Alps, the Carpathians or Dinarides. In addition, because of the absence of their natural enemies, the new invader insects can cause serious problems in agriculture through long term outbreaks.

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