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A Risk Assessment for the Small Hive Beetle Based on Meteorological Standard Measurements

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***Abstract*—**The Small Hive Beetle, *Aethina tumida* (Coleoptera: Nitidulidae) is a parasite for honey bee colonies, *Apis mellifera*, and was recently introduced to the European continent, accidentally. Based on the literature, a model was developed by using regional meteorological variables (daily values of minimum, maximum and mean air temperature as well as mean soil temperature at 50 mm depth) to calculate the time-point of hive invasion by *A. tumida* in springtime, the development duration of pupae as well as the number of generations of *A. tumida* per year. Luxembourg was used as a test region for our model for 2005 to 2013. The model output indicates a successful surviving of the Small Hive Beetle in Luxembourg with two up to three generations per year. Additionally, based on our meteorological data sets a first migration of SHB to apiaries can be expected from mid of March up to April. Our approach can be transferred easily to other countries to estimate the risk potential for a successful introduction and spreading of *A. tumida* in Western Europe.

Keywords*—Aethina tumida*, air temperature, larval development, soil temperature.

I. Introduction

THE Small Hive Beetle (SHB), *Aethina tumida* Murray (Coleoptera: Nitidulidae), is indigenous in sub-Saharan Africa [1] and is described as a parasite on honey bees (*Apis mellifera* L.). Adults of SHB invade bee hives, females oviposite in clusters in cracks and crevices inside the hive, mainly next to bee brood in open cells. Larvae damage the bee colony by feeding on stored resources as well as on bee brood and eggs [1], therefore SHB is called a colony scavenger [2]. Fully grown larvae leave 4the hive and enter the soil for pupation [3], [4]. After seven days young adults hatch again from the soil and can invade other bee colonies by detecting stress pheromones [5]. After one week they are sexually mature. Based on climatic conditions, several generations per year are possible. In the recent literature, it is discussed if SHB can adapt to other host organisms like bumblebees (*Bombus* ssp.) [6]. Since the last 20 years, SHB has established as an invasive species in several countries, e.g. in US [7] with an economic impact of about 3 million US $ [8]. Methods for controlling are still in early stages, except chemical control [9]. However, the use of insecticides always carries a high risk of exposure to honey bees. Parasites or relevant pathogens for SHB have not been found yet [3]. At the moment, SHB is a notifiable disease in the European Union, and even the suspicion of an infested honey bee colony must be reported to the appropriate national authorities. Recently, larvae and adults of the SHB were found in apiaries for the first time in Europe in South Italy in September 2014 [10]. European apiculture is now aware of the spreading of SHB as a new harmful pest on honey bees. A successful establishing of SHB in Europe is mainly depending on meteorological variables e.g. air and soil temperature and precipitation [9]. We established a risk assessment approach that quantifies the suitability of the meteorological conditions for first invasion of apiaries by SHB, as well as the number of generations per year of this parasite for each single year between 2005 and 2013 in Luxembourg.

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II. Methods

Luxembourg - situated in Western Europe - was chosen as a test region for our risk assessment, because it is characterized by a temperate semi-oceanic climate with mild winters and moderate summers. To characterize the long-term climate condition in Luxembourg the annual mean air temperature (Findel Airport station) is given in Fig. 1. In addition, Fig. 2 shows that the precipitation in contrast to the air temperature shows no clear trend towards higher values in the past.

Daily values of minimum, maximum and mean air temperature as well as mean soil temperature at 50 mm depth were retrieved for the period from 2005 until 2013 from the meteorological network of the official agrometeorological network of Luxembourg. The station at Remich (49° 32’ N, 6° 22’ E, 157 m AMSL) is situated in the river valley of the Mosel in the eastern part of Luxembourg. Plausibility and sanity checks were applied on all time-series of the meteorological data.

Based on literature results, we defined thermal relations to describe those stages of SHB which are relevant for establishment. It is described that no activity of adult beetles could be observed below air temperature of 21 °C [11]. Therefore, we used this threshold as starting point for invasion of SHB into the bee hives. We also included in our approach a seven day period for reaching sexual maturity of females [1]. While the thermal regime within the bee hive is stable, larval development lasts 21 days [12]. Larval of the first invaders will leave the hive and immigrate into soil. The duration of pupal development is depending on the soil temperature [13]. Therefore, we derive (1) to calculate the number of days for pupal development based on the literature [14]. This equation is only valid for soil temperature values >10 °C and <35 °C because according to [13] no development of SHB pupae can be observed below/above these thresholds:

$$\mathrm{Pd} = 1244.4e^{-0.177T_{soil}} \quad (1)$$

with Pd = pupal development in days and T_{soil} = soil temperature in 50 mm depth in °C.

The derived pupal development time in days is normalized and afterwards summed up until a threshold of 1 is reached. After pupal development is finished, a maximum soil temperature of 21 °C is pre-requisite for emergence [13]. When life cycle of first generation of SHB ends due to fulfilled meteorological conditions, the second generation starts with the invasion of bee hives. Based on the meteorological data-sets, predictions on the number of SHB generations, time-points of hive invasions and the development duration of SHB pupae were calculated.

III. Results and Discussion

SHB is able to build 2 up to 3 generations per year under recent climatic conditions in Western Europe (see Fig. 3). In three out of the nine years, the thermal conditions allowed a third generation: 2005, 2006 and 2009. These findings are in line with results from the literature based on comparable temperature ranges in laboratory studies; e.g. a length of a full development cycle of 41 days was detected in experiments at a temperature between 18 and 25 °C [15].

On average, hive invasion starts on 7 April, when maximum air temperature above 21 °C triggers flight activity. SHB is a very good flyer [1], and especially in Western European countries with a high density of apiaries the risk of a rapid spreading of SHB is high. Cold weather condition e.g. in 2008 lead to late invasion (27 April) while early warming in spring in 2005 (16 March) and 2012 (17 March) caused early activities. March is a typical month for a first visual inspection of bee colonies by the beekeeper. Working on the hives can stress bees [3] and therefore can increase the risk to attract young adults of SHB by stress volatiles to infest colonies. After finishing first generation, young adults of SHB invade hives for a second (on average 19 June) and a third life cycle (on average 10 August) based on our calculations (see Fig. 3).

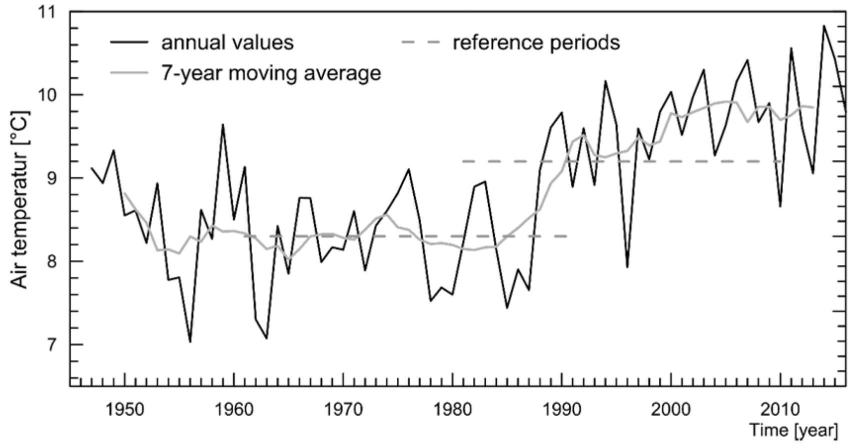

Fig. 1 Annual values of mean air temperature as well as a 7-year running average for the meteorological station Findel; period 1948 until 2016

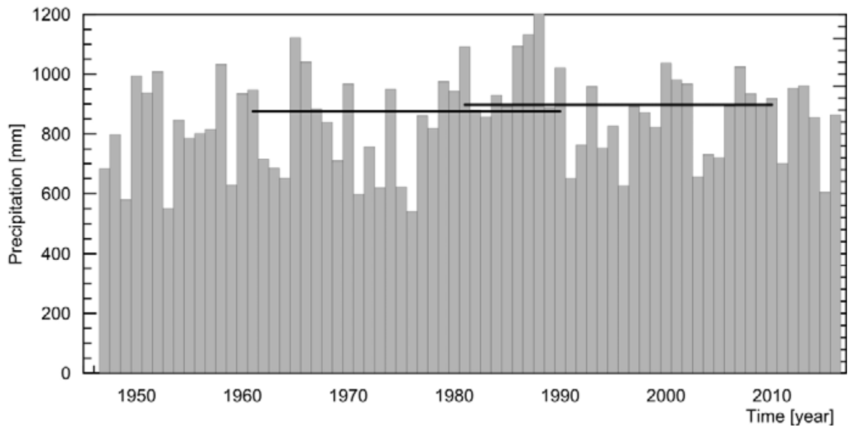

Fig. 2 Annual values of precipitation totals for the meteorological station Findel; period 1948 until 2016. Horizontal black lines represents the mean value of the two reference periods (1961 – 1990 and 1981 – 2010)

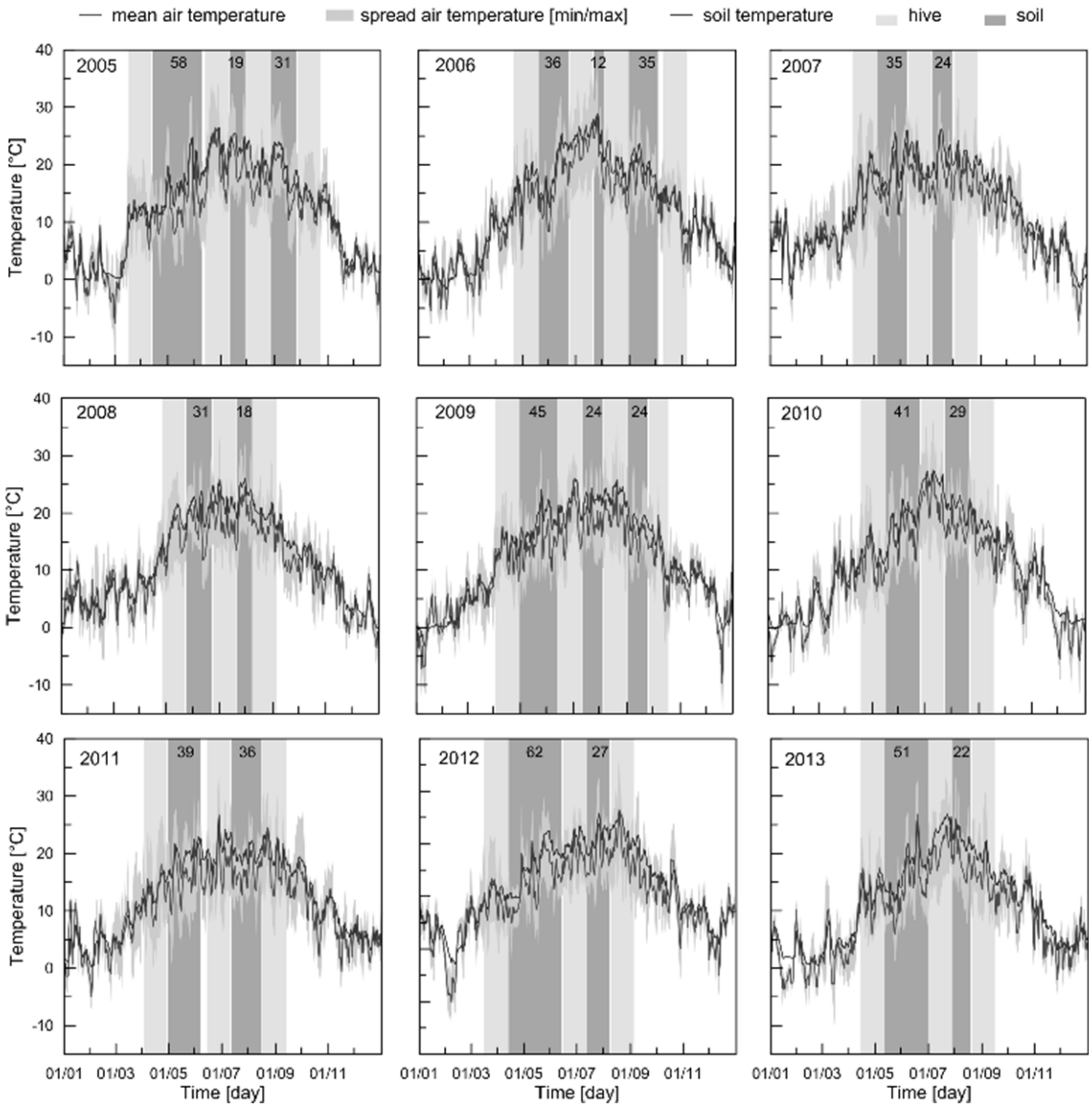

Fig. 3 Daily values of mean, minimum and maximum air temperature as well as mean soil temperature for the meteorological station Remich/Luxembourg; period 2005 until 2013. Larval stages of the SHB in the bee hive are given in light, pupal development in the soil in dark grey. Numbers on top indicate the duration (days) of the pupal development of the SHB in the soil

Whereas survivorship of pupae is depending on the depth of the soil substrate [16], duration of pupal development is mainly driven by soil temperature [9], [14]. In our study, only in 3 of 9 years (2005, 2006 and 2009) SHB could be able to cover a full pupation of larvae from third generation. In the other years, cumulated soil temperature sums were too cold for a full development of these larvae, which can be also found in the literature [14]. Pupation could be finished within average time of 44 days of the first generation at the end of spring time and 23 days of the second generation of SHB in mid-summer. The third generation was only finalized in three years and took 30 days on average. On the average the total pupal development covered 32.6 days, which is comparable to results from the literature [13], where a pupation period of 32.7 days was detected under laboratory conditions. Lower temperatures cause slower development of all life stages and therefore significant changes of temperature can impact the abundance of SHB [13]. Additionally, the soil water content seems to play an important role for duration of pupal development [14], but it was not included in our approach due to a lack of information in the literature. Anyhow, regional climatic conditions seem to be the key for spreading SHB in Western Europe. So far, it is expected that very hot and dry conditions, as well as very cold conditions will hamper to build up large populations [3], [13], [14]. Also very cold climatic conditions like in Western Canada are expected to lower the risk of a rapid spreading of SHB [9]. In comparison, typical environmental conditions in Western Europe would support the development of a severe SHB population like shown in our data-set.

It is described in literature that all European honey bee subspecies like *A. mellifera carnica* are more susceptible to infestation with SHB than African subspecies that are originally adapted to this scavenger in bee colonies [10]. This could increase the risk of becoming SHB established based on our risk assessment approach. It can be expected that smaller African bee colonies – in comparison to European ones – hamper the setting up of a huge SHB population and therefore might result in a less severe infestation level and damage for African colonies [3]. Species like *A. mellifera scutella* are able to protect themselves towards SHB by aggressive behavior [3], whereas the behavior of bee species occurring in Western Europe to SHB is not documented so far. Beekeeping in Western Europe is characterized by a number of interventions in colonies activity, e.g. by frequent inspections, by Varroa control strategies as well as operations to avoid absconding [17]. These disturbances could increase the risk to attract individuals of SHB by releasing stress volatiles [3] and could be an indicator that SHB will spread rapidly in Western Europe.

Based on regional meteorological conditions, SHB has the potential to establish in Western Europe and to build up sustainable populations at the apiaries, outside of its endemic range. For the moment the importation of bee colonies is strictly regulated by legal guidelines in the European Union, especially when originated from areas with SHB infestation [18]. The control of pathways is a prerequisite to avoid a carry-over of this honey bee pest in European Countries [18]. Intensive survey activities by beekeepers, local authorities and stakeholders are necessary to cover the risk of unintentional introduction of SHB to apiaries in Western Europe [10], [18]. Our approach can be easily applied to comparable meteorological regions to estimate the risk of a successful establishment of SHB in those regions and therefore can be a link in the chain of controlling this severe honey bee pest

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