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Review

Distribution, Habitat Preference, and Management of the Invasive Ambrosia Beetle *Xylosandrus germanus* (Coleoptera: Curculionidae, Scolytinae) in European Forests with Emphasis on the West Carpathians

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Abstract: The black timber bark beetle *Xylosandrus germanus* (Blandford) is an invasive ambrosia beetle originating from Southeastern Asia that has become successfully established within Europe and North America. Herein, we provide a review of the spread and distribution of this pest of trees and timber across Europe before and after 2000, along with a review of its habitat preferences. Since the spread of *X. germanus* across Europe has accelerated rapidly post-2000, emphasis is placed on this period. *X. germanus* was first recorded in Germany in 1951 and since then in 21 European countries along with Russia. Ethanol-baited traps were deployed in oak, beech, and spruce forest ecosystems in the Western Carpathians, Central Europe, Slovakia, to characterize the distribution and habitat preference of this non-native ambrosia beetle. Captures of *X. germanus* within Slovakia have been rising rapidly since its first record in 2010, and now this species dominates captures of native ambrosia beetles. *X. germanus* has spread throughout the whole Slovakia from the south-southwest to the north-northeast over the period of 5–10 years and has also spread vertically into higher altitudes within this country. While living but weakened trees in Europe and North America are attacked by *X. germanus*, the greatest negative impact within Slovakia is attacks on recently felled logs of oak, beech and spruce trees providing high quality timber/lumber. We suggest that the recent rapid spread of *X. germanus* in Central Europe is being facilitated by environmental changes, specifically global warming, and the increasing frequency of timber trade. Recommendations for management of *X. germanus* in forest ecosystems are proposed and discussed, including early detection, monitoring, sanitary measures, etc.

Keywords: black timber bark beetle, biological invasion, Xyleborini, ambrosia beetle, spread, occurrence, ethanol, forest management

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1. Introduction

Invasive ambrosia beetles (Coleoptera: Curculionidae, Scolytinae) can cause severe damage in forest systems [1,2]. In particular, ambrosia beetles in the tribe Xyleborini are among the most successful insect invaders worldwide [2-6]. Key traits likely contribute to their establishment and proliferation success, including a cryptic lifestyle, fungivory, broad host tree range, haplodiploid reproduction, and sibling mating [6,7]. Notably, ambrosia beetles are among the true fungus farming insects, whereby the adults and larvae live within wood in symbiosis with their ambrosia fungi [8]. Consuming the fungal symbiont is the sole source of nourishment for the adults and larvae, and is required for proper development [9-11].

X. germanus (Blandford), also known as the black stem borer or black timber bark beetle [12], is a highly successful xyleborine invader and destructive wood-boring pest. Adult female *X. germanus* tunnel into the heartwood of trees and logs, whereby they cultivate fungal gardens of *Ambrosiella grosmanniae* C. Mayers, McNew & T.C. Harr. [13]. A variety of secondary microorganisms have also been isolated from galleries of *X. germanus*, including bacteria, yeasts, and filamentous fungi [14,15]. Ranger et al. [16] reviews additional important aspects related to the biology and ecology of *X. germanus* in detail.

X. germanus is native to Eastern Asia [4,12], but has become established in Europe and North America [6,12,17]. In North America, *X. germanus* was first recorded in New York in 1932 [18], and is now established in 28 US states and three Canadian provinces [6]. The first record of *X. germanus* in Europe was in Germany in 1951 [19,20]. As described in greater detail below, populations are now established in many parts of the European Union, and it has been detected in 21 European countries, along with Russia [12,21] (Figure 1). In most of these countries *X. germanus* is considered a pest species and is expected to spread into other suitable sites, but it could go undetected for many years due to its cryptic behavior [12,21]. The main pathways are human assisted movement via infested wood and wood products, along with natural dispersal [21].

A Rapid Pest Risk Analysis was prepared for *X. germanus* in the United Kingdom [22] and Sweden [21] 2017, both of which concluded a high likelihood of entry, establishment, and spread. However, the species is not listed in the EU Annexes and is not on the EPPO Alert or Action lists due to its wide distribution in Europe [22]. Since the spread of *X. germanus* across Europe has accelerated rapidly post-2000, a comprehensive review on its distribution, habitat and host preference within the European regions is needed. We hypothesize the accelerated spread of *X. germanus* is being facilitated by climate change in combination with trade in timber and wooden packaging material. This article reviews the spread and distribution of this pest within Europe, including a detailed account of its spread in Slovakia. We also include an analysis of habitat preference and suggest measures to be taken in managing *X. germanus* with respect to the production of forest products.

2. Spread of *Xylosandrus germanus* across Europe

In this chapter we provide the first records of. *X. germanus* within Europe (Figure 1a) with the emphasis on the two separate periods: before 2000 and after 2000.

2.1 Before 2000

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Germany

Within Europe, *X. germanus* was first recorded in Germany near Darmstadt on oak and beech [19], the oldest record of a single female near Darmstadt (Kranichsteiner Wald) being dated 27th October 1951 [20,23]. Further records followed over the next several years, mostly from regions with mild climate. Wichmann [24] suggested that *X. germanus* was likely to arrive in Germany through the importation of oak lumber from Japan, mainly before and after World War I over the period 1907–1914 and 1919–1929. The unintentional introductions of *X. germanus* from North America after World War II could also contribute to its spread due to multiply deliveries of timber and wood products to western part of Germany [20,24]. Empirical data support that *X. germanus* is established in Germany.

Switzerland

Maksymov [25] reported the first occurrence of *X. germanus* in Switzerland (near Basel) on a beech trunk in 1984. Germany could have been the source of invading specimens since the distance between Darmstadt, Germany and Basel, Switzerland is circa 300 km. The first mass attack was recorded two years later on beech, oak, and spruce in June. Empirical data support that *X. germanus* is established in Switzerland.

France

In France, *X. germanus* was first reported in 1984 [26,27] and additional records followed later [28]. Empirical data support that *X. germanus* is established in France.

Austria

Holzschuh [29] reported *X. germanus* in Austria (at two sites in western part of this country) in 1992. In 1994, the beetle was found at two more sites near Salzburg [30]. Holzinger et al. [31] describe this species as the most abundant ambrosia beetle collected in 2012. Empirical data support that *X. germanus* is established in Austria.

Belgium

X. germanus was incidentally recorded in Belgium near Brussels in 1994 [32]. Later studies describe this species as the most abundant scolytine [17]. Henin and Versteirt [33] reported it from 29 additional sites in Belgium. Empirical data support that *X. germanus* is established in Belgium.

Poland

The first record of *X. germanus* from Poland was made in 1998, followed by many other records after 2005 [34,35]. Empirical data support that *X. germanus* is established in Poland.

Italy

In Italy, *X. germanus* was first recorded in a walnut plantation in 1998 [36,37]. Later, in north-eastern Italy, Rassati et al. [1] collected *X. germanus* at 24 out of 25 sites. *X. germanus* has two generations per year in Italy [1,38] compared to one generation in more northerly situated areas or countries, respectively. Empirical data support that *X. germanus* is established in Italy.

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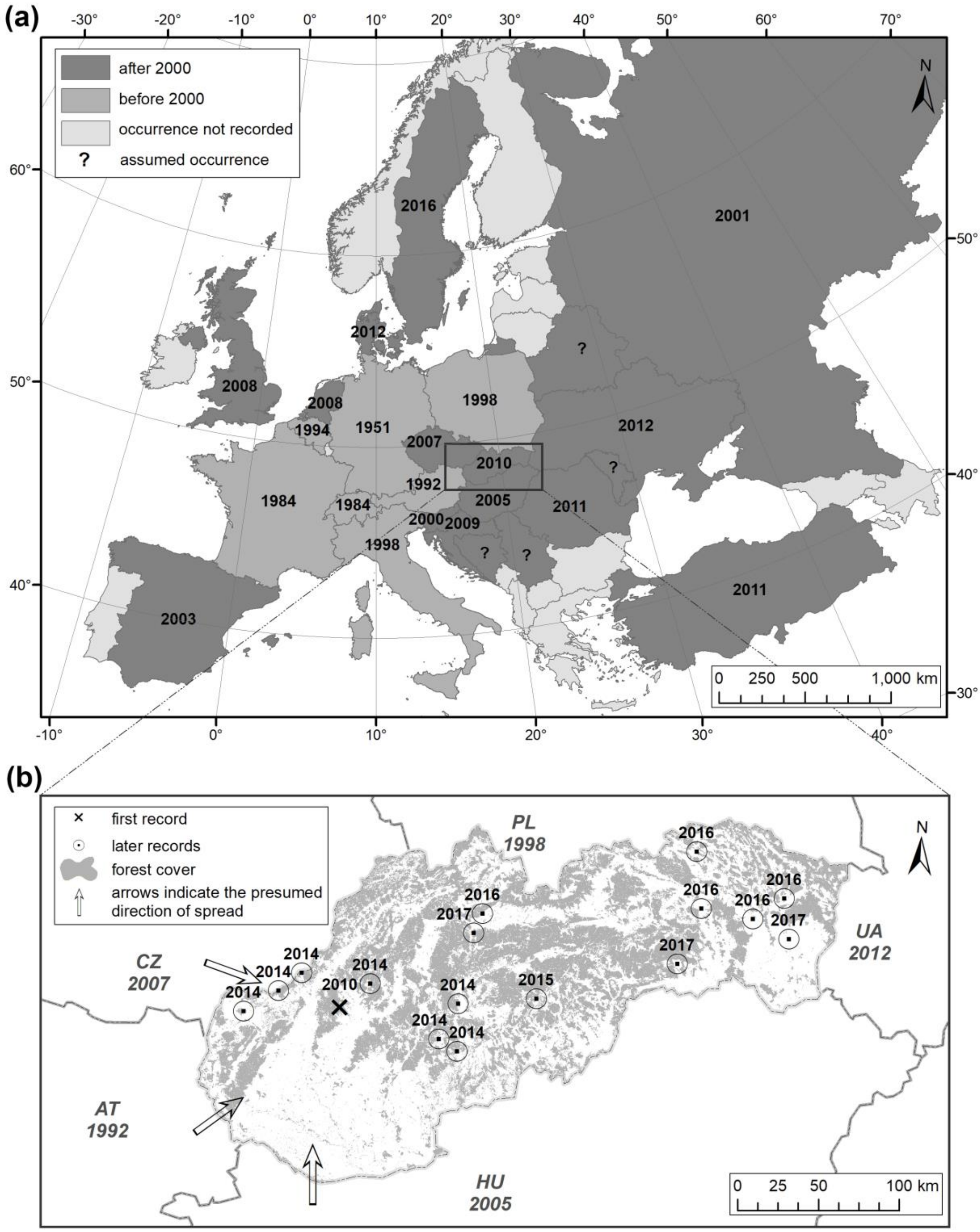

Figure 1. The occurrence and spread of *Xylosandrus germanus* across Europe (**a**) and in Slovakia (**b**). Records are indicated by years (AT-Austria, CZ-Czech Republic, PL-Poland, UA-Ukraine, HU-Hungary).

2.2 After 2000

Slovenia

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X. germanus was first recorded in Slovenia near Nova Gorica on *Castanea sativa* Mill. in 2000 [39]. Since then it has been found at many other sites in various forest ecosystems mainly in south-eastern and central Slovenia [40,41]. The increased number of sites where *X. gemanus* has been found recently, and the increased number of beetles caught in traps, suggest that the beetle has established in Slovenia [39].

Russia

The first record of *X. germanus* in Russia was from Krasnodarsk Krai in the southwestern region in 2001 [42]. The occurrence of *X. germanus* in the Russian Far East near Vladivostok was later reported by Sweeney et al. [43]. Empirical data support that *X. germanus* is likely established in the Russian Far East, but additional collection efforts are required from Krasnodarsk Krai in the southwestern region of Russia.

Spain

X. germanus was first recorded in northern Spain in 2003 [44]. Its spread continues, with additional records in the northern part of this country [45]. Empirical data support that *X. germanus* is established in Spain.

Hungary

Four specimens of *X. germanus* were recorded in Hungary in 2005. They were picked up from felled *Quercus* sp. and *Tilia* sp. logs [46]. According to CABI [12] *X. germanus* is established in Hungary.

Czech Republic

A single *X. germanus* female was first found in Moravia (Czech Republic) in 2007 [47]. The record was from a mixed forest. *X. germanus* continues to spread across this country [48]. In 2017 and 2018, this species was obtained through ethanol-trapping in oak forests near Brno and Straznice na Morave, Moravia [49]. Empirical data support that *X. germanus* is established in the Czech Republic.

Britain

X. germanus was first recorded in Britain during a saproxylic beetle survey in 2008 [50]. Further records of this species came from a mixed pine forest in north Hampshire in 2012 and 2013 [22] and at a site in southern Suffolk (East Anglia, UK) in 2017. While *X. germanus* is established in Britain, it seems to be restricted to the southern region [51].

The Netherlands

In the Netherlands, *X. germanus* was first noticed in 2008 and observed at 10 sites over a large part of the Netherlands [52]. Empirical data support that *X. germanus* is established in the Netherlands.

Croatia

Franjević et al. [53] stated that *X. germanus* has been collected in oak stands in Croatia since 2009. In 2011, it was the second most abundant scolytid species caught in pheromone traps. Empirical data support that *X. germanus* is established in Croatia [54].

Slovakia

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X. germanus was first recorded in Slovakia in 2010 [55,56]. For more information see the section "Spread and occurrence of *Xylosandrus germanus* in Slovakia". Empirical data support that *X. germanus* is established in Slovakia.

Romania

The first record of *X. germanus* in Romania was made in 2011 in an old beech forest in northern part of this country in the East Carpathians at altitudes between 760 and 900 m (a.s.l. in all review). The spread of this species continues so that further areas in Romania have already been colonized or are likely to be colonized soon [57,58]. Empirical data support that *X. germanus* is established in Romania.

Turkey

The first record of *X. germanus* in Turkey is from 2011 and was obtained by ethanol trapping in kiwi orchards [59,60]. A later study [61] confirmed occurrence of this species in hazelnut orchards. Empirical data support that *X. germanus* is established in Turkey.

Ukraine

In 2012, *X. germanus* (a single female) was first recorded in Ukraine, the Transcarpathian Region, the Uzhgorod District [62] bordering eastern Slovakia. Since *X. germanus* occurs in Hungary, Slovakia and Poland, its establishment in the Ukraine is likely.

Denmark

X. germanus was first recorded in Denmark (a female crawling on an ash tree trunk on Lolland island) in 2012. More records were gathered in 2013 [63]. This species is believed to be established in Denmark.

Sweden

In 1996, one specimen of *X. germanus* was caught in a window trap in Nybro inside the flooring manufacturer Kährs area where, for example, oak timber from Germany was stored [64]. The second record of one individual in a baited trap was from the Kalmar harbor in 2016 [21]. There were no records of *X. germanus* in 2017 [65]. The likelihood that the beetle could spread to Sweden has increased since its recent establishment in Denmark [21]. According to Björklund and Boberg [21] empirical data does not support the establishment of *X. germanus* or its wide distribution in Sweden, and additional trapping efforts are required to determine if this species is established in this country.

Hence, between 1951 and 1998 *X. germanus* established in 7 of 44 European countries. Since 2000, the beetle has rapidly spread across Europe where it has been detected in another 13 European countries. As of 2018, *X. germanus* is established at least in 21 European countries.

3. Spread and occurrence of *Xylosandrus germanus* in Slovakia

X. germanus was first recorded in Slovakia in 2010 (Figure 1b) in an oak stand in Považský Inovec Mountains, Forest District Duchonka, western Slovakia, where in total 19 females were

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obtained through ethanol-baited traps utilized for monitoring purposes [55,56]. Since all of the individuals have been collected deep in a close-canopy forest distant from main traffic routes, the spread of *X. germanus* several years prior to its first detection is highly likely.

The catches of *X. germanus* have been rising rapidly since 2010. For example, monitoring traps set in the same oak stand and the same site repeatedly over time yielded a total of 40 specimens in 2011, 77 specimens in 2012 [55], 322 specimens in 2013, and over 1,000 specimens per year in next years [66]. *X. germanus* has soon become the dominant species over other species of ambrosia beetle in Slovakia. A similar pattern has been observed in other European countries [1,17,27,31,33,67,68]. Hence, *X. germanus* may substantially alter diversity of scolytine assemblages in forests [21,27,33]. It could be assumed that native competitors do not substantially limit *X. germanus* in nature [33].

X. germanus in Slovakia was spreading from the south/southwest to the north/northeast (Figure 1b). It has spread throughout the whole country (its length approximately 400 km) during 5-10 years. The rate of active spread of *X. germanus* has been described as tens of kilometers per year in Western Europe [33].

Not much is known about the vertical spread of *X. germanus* in European forests. Several works state that everywhere the species has established, it has permanent populations only at relatively low elevations [29,32,33]. Henin and Verstein [33] in Western Europe concluded that *X. germanus* does not appear to be able to settle and establish permanent populations above approximately 350 m. Similarly, Bruge [32] noted that *X. germanus* had not been observed above 500 m within Europe. For instance, 578–600 m is the highest elevation previously reported for a population of *X. germanus* [69,70]. However, Olenici et al. [57] stated that in the Voievodeasa Forest in the East Carpathians in Romania a permanent population was discovered at an altitude of 760–900 m on a slope with a south-easterly aspect. These accounts are considerably higher than the maximum altitudes described by other workers in Western Europe, and herein we provide the support for them from the West Carpathians.

The prevailing forest systems in the West Carpathians in Central Europe are composed of oak (*Quercus* spp.), European beech (*Fagus sylvatica*) and Norway spruce (*Picea abies*). These systems and their associated fauna show distinct zonation along altitudinal gradients [71]. A systematic ethanol-trapping carried out in the Kremnické vrchy Mountains, West Carpathians, Central Slovakia, yielded many *X. germanus* females (N = 37760) during their flight dispersal between May and August 2016. Analysis of these count data provided the first insights into the occurrence of *X. germanus* in the prevailing forest systems on southern slopes of volcanic hills with the variation of altitudes between 259 and 882 m, and with Norway spruce planted within this range of altitudes. A high measure of association between the factor forest type (levels: oak, beech and spruce) and the altitude (ANOVA, log-transformed altitudes, eta = 0.76) allowed separate analyses of the effects of these variables on the catches of *X. germanus* at randomly selected collecting sites or forest stands, respectively (n = 36).

Although approximately 51% of the collected beetles were obtained from beech stands, the factor forest type alone (irrespectively of elevation) did not influence the abundance of the beetle within the given range of altitudes (Kruskal-Wallis test, χ^2= 3.9204, df = 2, $n_1 = n_2 = n_3 = 12$, p = 0.141) (Figure 2a). In North America, abundance of *X. germanus* collected in ethanol-baited traps also did not differ between a hardwood habitat and coniferous habitat [72]. These results confirm broad ecological plasticity of this habitat generalist [9].

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The beetles were found along the entire altitudinal gradient. The significant effect of altitude on the abundance of *X. germanus* (negative binomial GAM, edf = 3.524, χ^2= 24.38, p < 0.0001) suggests the species optimum in the beech forest between approximately 500 and 700 m a.s.l. (Figure 2b). Moist climate in this forest is supposed to retain more stable microhabitats for *X. germanus* and its fungal symbiotic associates than warm and dry climate in oak forests in lower altitudes. Similarly, cool submontane forests in the altitudes of approximately 800 – 900 m and above could also suit much less to the beetle as indicated by the smoother (Figure 2b). Although *X. germanus* in Slovakia was observed to attack felled spruce logs as high as 1,020 m a.s.l. [73], it has not yet been found in cool mountain forests above 1100 m a.s.l. [74].

The model (Figure 2b) explains 38% of the deviance in the data. It could be extended by using more observations from the same and/or broader ranges of altitudes (depending on local topographies), slope aspects and variation in canopy openness. The extent to which the canopy openness could affect the occurrence of *X. germanus* in the prevailing forest systems in the West Carpathians has not yet been analyzed, however, the preference of this species for shady habitats or microhabitats in regions with both the oceanic [67] and continental climate [75] within Europe is evident. In the western part of Germany (Königsforst near Cologne), for example, *X. germanus* females produced approximately five times more entrance holes in spruce logs shaded by trees than in unshaded logs[67]. In the studied Carpathian forest the canopies of all stands were closed, and the breeding substrates attractive for the beetle were not scarce across all forest stands.

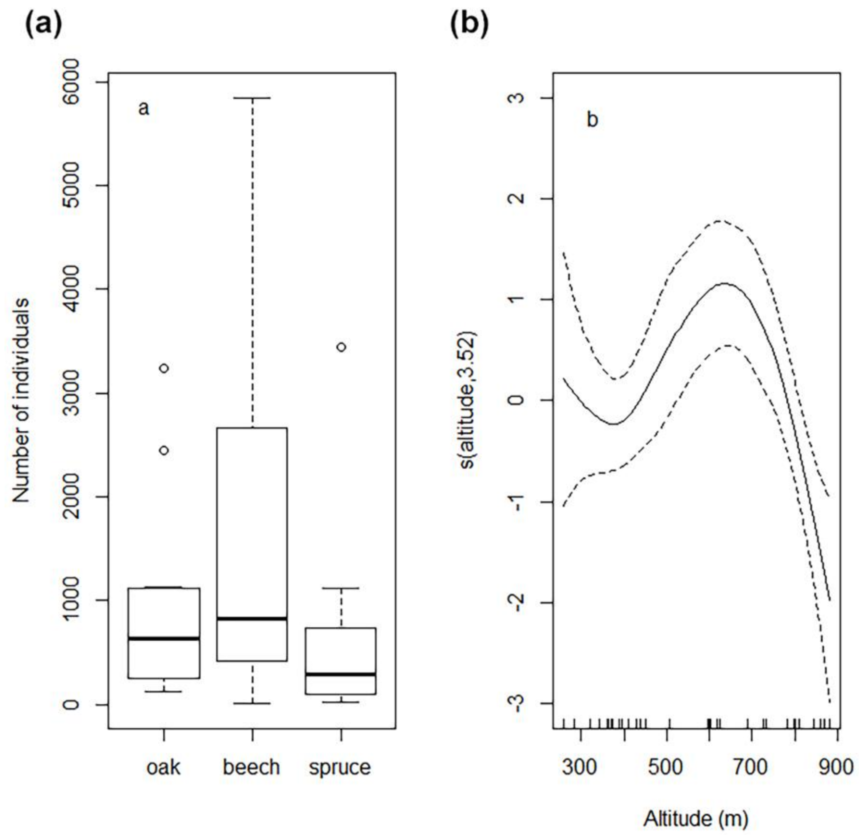

Figure 2. The number of dispersing *X. germanus* females caught in ethanol-baited flight interception traps (n = 36) set in the Kremnické vrchy Mountains, West Carpathians, Slovakia, during the whole dispersal period of the beetle in 2016. Plastic bottle traps were baited with 100 ml of 85% absolute ethanol and replaced in one-week intervals. Boxplots (median, IQR,

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minimum and maximum, outlying values as open circles) of the number of *X. germanus* for oak, beech and spruce forest stands as categorical explanatory variables (a). Estimated smoothing curves for the NB GAM model containing altitude as a solo explanatory variable; the solid line is the smoother, dotted lines are the 95% point-wise confidence intervals, 3.52 is effective degrees of freedom, the vertical lines along the x-axis are the altitude values of the observations (b). Statistical data analyses and graphics performed in R (76).

Minimum winter temperature has been proposed as a key parameter in limiting the survival of *X. germanus* [29,32,33]. The period 2010 – 2016 in Slovakia included successive mild winters, of which the winter of 2013/2014 and 2014/2015 were among the mildest since 1950 (data source: Slovak Hydrometeorological Institute). This could explain in part the rapid spread and establishment of *X. germanus* in this country. The expected effects of low freezing temperatures of several days under -20°C in January 2017 on the occurrence of *X. germanus* in Slovakia have not been analysed, but were probably not the principal parameter inhibiting survival and spread of this species. It is highly probable that the vertical spread of *X. germanus* is connected to a warming climate [69,70].

On the basis of this we can assume that the spread of *X. germanus* in Europe does not occur only horizontally in individual countries but also vertically into higher altitudes where local topographies can play an important role. Yet, Ito et al. [77] hypothesized that *X. germanus* probably lacks enough dispersal ability to cross large geographical barriers such as oceans, high mountains, and grassland ecosystems due to an absence of woody hosts. Their study found that the Tsugaru Strait between Honshu and Hokkaido islands acts as a geographic barrier to *X. germanus*. It is unknown if the Carpathian mountain range will impact natural dispersal of *X. germanus*, especially in Slovakia, Ukraine, and Romania. Judged from the known altitudinal distribution of *X. germanus* and the topography of West Carpathians in Slovakia, this species would be able to cross this mountain range in many areas below 1000 m a.s.l. with ease.

4. Host Selection and Preference

The known host spectrum of *X. germanus* currently comprises over 200 shrub and tree species in 51 families [78], which includes trees growing in landscapes, woodlands, plantations, ornamental nurseries, tree fruit orchards, and forested stands, along with recently felled logs, stored timber, and stumps [16,17,33,46,67,79-87]. Thin-barked deciduous trees in ornamental nurseries are more commonly attacked than coniferous trees [16], but *X. germanus* attacks stored timber from both deciduous and coniferous trees [25,46,88].

Despite a broad host range, host quality plays an important role during host selection by *X. germanus* with weakened, dying, or stressed trees being preferentially attacked [16]. Healthy, non-stressed trees are not perceived as hosts. Ethanol is an important kairomone used during host-location and -selection by *X. germanus* that acts as a chemical indicator of suitable trees or host logs [89,90]. Ethanol also benefits the colonization success of ambrosia beetles by promoting the growth of their fungal symbiont and suppressing the growth of fungal garden competitors [91]. A variety of stressors can induce the emission of ethanol from living but weakened trees, including flood and drought stress, freeze stress, girdling, impaired root function, root and crown disturbance, pollutants, and pathogens [92-96]. In particular, flood stress and freeze stress have been demonstrated to induce the emission of ethanol and predispose trees to attack by ambrosia beetles

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[85,96-98]. The emission of ethanol from aging logs also attracts and induces attacks by *X. germanus* and other ambrosia beetles [46,67,99-102].

In North America, *X. germanus* is mainly a pest on a number of species of deciduous trees, particularly in ornamental nurseries [16,80,83,103] and tree fruit orchards [86,87]. For instance, *X. germanus* is the most abundant and problematic ambrosia beetle attacking trees in ornamental nurseries in Ohio [16,82,83]. Attacks have also been documented on logs in North America, especially deciduous species over coniferous species [104,105]. However, *X. germanus* is not currently considered an important pest of logs or lumber in the USA. Yet, new records of *X. germanus* were obtained during trapping surveys of high-risk sites in Oregon, for instance, businesses importing untreated solid wood packing material, raw wood products, port and industrial areas, and urban forests [106]. The intracontinental movement of untreated solid wood and raw wood products were proposed to be the basis for the introduction of *X. germanus* into Oregon [106].

In Europe, *X. germanus* is considered a secondary pest that attacks mostly felled tree logs [46] (Figure 3). While in North America *X. germanus* is most problematic in tree nurseries and orchards, in Europe most published records are from forests (see chapter "Spread of Xylosandrus germanus within Europe"), with the exception of an attack in a walnut (*Juglans regia*) plantation in Italy [37,107] and in kiwi and hazelnut orchards in Turkey [59,61]. Host reports from Europe include beech (*Fagus sylvatica*), oak (*Quercus* spp.) (Figure 3), spruce (*Picea abies*), pine (*Pinus sylvestris*), fir (*Abies alba*), elm (*Ulmus* spp.), lime (*Tilia* spp.), chestnut (*Castanea sativa*), and hornbeam (*Carpinus betulus*), especially on felled logs and stumps [1,22,25,32,46,50,84,88,108]. It is clear that, especially in the last 20 years, damage caused by *X. germanus* was reported on many tree species which are thus susceptible to be attacked by this beetle [33].

Previous studies from Europe indicate that *X. germanus* prefers to colonize logs that were debarked during logging and transport [25,66,67] (Figure 3). Beginning in 2014, *X. germanus* was first recognized as a pest since it started attacking freshly cut beech and oak logs (Figure 3) in many parts of western and even central Slovakia [84]. To our knowledge, attacks by ambrosia beetles to freshly cut logs had not been observed in Slovakia before. In 2016, we also recorded the first damage of oak and beech lumber by *X. germanus* in eastern Slovakia (109).

Currently, there have not been any reports of *X. germanus* attacking trees in plantations, orchards, or ornamental nurseries in Slovakia. Colonization of living trees was observed in Slovakia mostly on beech that were physiologically stressed by other adverse factors (wood-decay fungi, drought, bark burn, frost injury) (109). Colonization of live, albeit stressed beech trees was observed in Western Europe as well [17,33,97].

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Figure 3. Fresh attack (white sawdust) of *Xylosandrus germanus* on beech timber (**a**) and oak timber (**b**). After several weeks females expelled noodles of sawdust (**c**) from the gallery (**d**). Photo by Juraj Galko.

While *X. germanus* shows an apparent preference for thin-barked trees [16], it does not appear discriminate about the thickness (diameter) of host material [25]. Logging residues, as well as thick and highly valuable lumber are attacked [84]. For instance, Henin and Verstein [33] state that *X. germanus* was found in a 4,000 ha beech stand on all types of substrate: stumps, small branches, limbs, and logs. Presumably *X. germanus* can attack any sort of woody material from any species of woody plant, as long as key factors are met – the presence of ethanol in host tissues and sufficient humidity for the development of mutualistic ambrosia fungi [12,91].

Taking into account its broad host range, preference for weakened hosts, and capability to attack standing trees, recently felled logs, and lumber, we assume that many economically important species of woody plants, logs, and lumber could act as potential hosts and be vulnerable to attack.

5. Forest management and recommendations

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Due to its extreme inbreeding, haplodiploidy, fungiculture, and broad host range, *X. germanus* has become a very efficient invader [6,7]. It is probable that further spread of *X. germanus* will be difficult to stop, considering that a single fertilized female can found a population in a new region without any negative effects stemming from inbreeding depression [11]. However, it is possible to avoid considerable damage to timber using suitable management measures, as described below in greater detail.

For early detection of attacks, entrance holes with a 1 mm diameter and whitish, light colored sawdust (Figure 3) are typical signs of this species' presence [16,86]. At later stages, when sawdust is expelled from galleries in typical cylindrical formations (noodles) [16,23] (Figure 3), chemical treatment is ineffective. We assume that an effective preventive measure is early treatment of high quality lumber with an authorized insecticide. If the material is already attacked, a chemical treatment with a concentration at upper recommended limits may be used but is only effective during initial attack.

As previously noted, *X. germanus* mostly causes damage to felled lumber in Europe, [25], which can greatly reduce the value of timber products. The damage caused by attacking high quality oak timber can be especially costly because strict European standards do not allow for any timber infestation [53]. For instance, according to current pricing [111] the monetary value of high-end quality oak timber is about 500 EUR/m^3 up to 1,000 EUR/m^3 (depending on properties of the timber, this price can be up to 30% higher). After attacking such timber its price drops significantly under 200 EUR/m^3. The price of top quality beech timber is up to 350 EUR/m^3, when attacked it falls under 100 EUR/m^3. The resulting loss exaction between the procurer and purchaser may be very complicated, especially when damages manifest later in the purchaser's storage [110]. Thus, the greatest losses result from attacks on high quality lumber. For instance, in 1995 in Switzerland, *X. germanus* caused major mechanical damage on spruce and fir amounting to a loss of 1 million CHF [108].

Generally, it can be said that the purchaser can choose to purchase infested wood [110]. Yet, even though *X. germanus* does not drill deep into suitable material – only about 2–3 cm [25], the purchaser may not buy such infested lumber fearing the presence of other species (psychological effect on the purchaser) with similar infestation symptoms (such as holes and whitish sawdust) which drill much further into wood such as *Gnathotrichus materiarius* (Fitch) (Coleoptera: Curculionidae, Scolytinae) [67] and thus cause greater damage.

We recommend the following management tactics to preserve the monetary value of quality lumber and minimize economic losses:

1. Logging, transport, storage, and processing of lumber should be carried out at periods without an increased abundance of technical pests. For instance, Franjević et al. [53] recommended the main felling period should be from October through March, harvesting should be prohibited during April and May, and thinning should take place from June through September.
2. We recommend that valuable, top quality lumber resulting from spring and winter logging stored at vulnerable sites from March to August is preventively treated with an authorized insecticide (chemical treatment) [25].
3. An alternative to chemical treatment is covering valuable lumber with protective nets infused with insecticides (Storanet®/Woodnet®, BASF®) [53,54]. According to Franjević et al.

[53] and our personal observations, the netting system provided excellent control against bark and wood-boring insects attacking fresh cut logs. The Forest Stewardship Council (FSC) and World Health Organization (WHO) have approved the use of these chemically treated reusable fabrics [Franjević et al. 2016].

4. Auctions of high quality products should not take place at sites and periods when wood-boring insects occur.
5. Inspection of attacked wood material is done visually (entrance holes, white piles of sawdust) (Figure 3). White sawdust is a typical sign of an infestation.
6. It is essential that personnel working with wood at vulnerable sites are aware of this species' symptoms, since chemical treatments are only effective at initial stages of attack.
7. For monitoring the presence of *X. germanus* is possible to use different types of traps [16,112] baited with ethanol. Traps provide information on the place, time, and numbers in which the monitored pest occurs [112]. However, mass trapping of *X. germanus* using ethanol-baited traps is not currently an effective management tactic [17,53].
8. Heavily infested material should also be chipped or burned to avoid population build up [2].
9. Wood products being imported into countries or regions where *X. germanus* has not yet reached should also be closely inspected and monitored.

There are other modern, albeit costly methods of protecting lumber such as treatment with heat, microwave [113] or other radiation, and special, direct injecting of insecticides into damaged spots [114]. Biocontrol measures, such as breeding and introduction of natural insect enemies (e.g. hymenopteran parasitoids), utilizing entomopathogenic fungi, or parasitic nematodes, still require additional research [114]. Promising results have been obtained using entomopathogenic fungi to control *X. germanus* and other ambrosia beetles [115-117], but the low threshold for attacks on ornamental and horticultural trees, logs, and lumber could hamper implementation.

7. Conclusions

In conclusion, we have summarized the known information on *X. germanus* and its significance in European forest ecosystems. It will be virtually impossible to stop the spread since a single female can found an entire new population. However, preventing the human-assisted movement of infested material will help to slow the spread. The spread of *X. germanus* in Europe has accelerated since 2000, and the species became established throughout Slovakia within 5–10 years. Our analyses indicate that *X. germanus* is also spreading vertically into higher altitudes. Climate change within Europe [118,119] and, specifically, mild winters could be assisting the spread of *X. germanus*. Similarly, freeze stress events following mild winters could also increase the availability of suitable host material and lead to an increased incidence of attacks [97]. Heavy precipitation and flood stress can also predispose trees to attack. The capability of *X. germanus* to attack a broad range of deciduous and coniferous trees, along with logs and lumber, also poses challenges to preventing its spread.

In Europe and especially Slovakia, *X. germanus* mainly causes damage to felled lumber and forested systems, and much less so in tree plantations, orchards, and ornamental nurseries. In the future, it may shift host preferences and become an important pest in European orchards, plantations, nurseries and vineyards as it is currently in North America. Notably, trees growing

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under controlled production systems that are weakened and emitting stress-induced ethanol are highly vulnerable to attack by *X. germanus*.

We recommend that forest management measures should be mainly focused on preventive treatment of high quality lumber. Insecticide-treated netting shows considerable promise for protecting logs and lumber. While ethanol-baited traps are very effective and important for detecting and monitoring *X. germanus*, a mass trapping strategy is not currently available. Like other Xyleborini ambrosia beetles, *X. germanus* is an excellent example of rapid spread by an alien species into new regions, therefore, its future movements and population changes should be watched carefully [17].

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