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 timber pest 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 habitat preference and distribution and 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 to 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

1. Introduction

Invasive ambrosia beetles (Coleoptera: Curculionidae, Scolytinae) can cause severe damage in forest systems [Rassati et al. 2016, Hulcr, Stelinski 2017]. In particular, ambrosia beetles in the tribe Xyleborini are among the most successful insect invader worldwide [Hulcr, Stelinski 2017, Haack 2006, Kirkendall, Faccoli 2010, Haack et al. 2013, Gomez et al. 2018]. Key traits likely contribute to their establishment and proliferation success, including a cryptic lifestyle, fungivory, broad host tree range, haplodiploid reproduction, and sibling mating [Gomez et al. 2018, Smith, Hulcr 2015]. Notably, ambrosia beetles are among the true fungus farming insects, whereby the adults and larvae live within wood in symbiosis with their ambrosia fungi [Batra 1985]. Consuming the fungal symbiont is the sole source of nourishment for the adults and larvae, and is required for proper development [Webwr, McPherson 1983a, Křístek, Urban 2004, Peer, Taborsky 2005].

*Xylosandrus germanus* (Blandford), also known as the black stem borer or black timber bark beetle [CABI 2017], 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. [Mayers et al. 2015]. A variety of secondary microorganisms have also been isolated from galleries of *X. germanus*, including bacteria, yeasts, and filamentous fungi [Dute et al. 2002, Hulcr et al. 2012]. Ranger et al. [2016] reviews additional important aspects related to the biology and ecology of *X. germanus* in detail.

*X. germanus* is native to Eastern Asia [Kirkendall, Faccoli 2010, CABI 2017], but has become established in Europe and North America [Gomez et al. 2018, CABI 2017, Grégoire et al. 2001]. In North America, *X. germanus* was first recorded in New York in 1932 [Felt 1932], and is now established in 28 US states and three Canadian provinces [Gomez et al. 2018]. The first record of *X. germanus* in Europe was in Germany in 1951 [Groschke 1953, Kamp 1968]. 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 [CABI 2017, Björklund, Boberg 2017] (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 [CABI 2017, Björklund, Boberg 2017]. The main pathways are human assisted movement via infested wood and wood products, along with natural dispersal [Björklund, Boberg 2017].

A Rapid Pest Risk Analysis was prepared for *X. germanus* in the United Kingdom [Inward 2015] and Sweden [Björklund, Boberg 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 [Inward 2015]. 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

Across Europe, *X. germanus* was first recorded in Germany and since then in 21 European countries (and 4 countries with assumed occurrence) along with Russia (Figure 1). In this chapter we describe the first records of *X. germanus* in European countries in detail with emphasis before 2000 and after 2000.

2.1 Before 2000

**Germany**

Within Europe, *X. germanus* was first recorded in Germany near Darmstadt in 1951 on oak and beech [Groscheke 1953], the oldest record near Darmstadt (Kranichsteiner Wald) being dated 27th October 1951 [Kamp, 1968]. Further records followed over the next several years, mostly from regions with mild climate. Wichmann [1957] 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. According to Kamp (1968) unintentional introductions of *X. germanus* from North America after World War II could also contribute to its spread due to multiply deliveries of wood and wood products to western part of Germany at that time. Empirical data support that *X. germanus* is established in Germany.

**Switzerland**

Maksymov [1987] 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 [Schott 1994, Bouget, Noblecourt 2005] and additional records followed later [Wood, Bright 1992]. Empirical data support that *X. germanus* is established in France.

**Austria**

Holzschuh [1993] 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 [Geiser, Geiser 2000]. Holzinger et al. [2014] 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 [Bruge 1995]. Later studies describe this species as the most abundant scolytine [Grégoire et al. 2001]. Henin and Versteirt [2004] reported it from 29 additional sites in Belgium. Empirical data support that *X. germanus* is established in Belgium.

**Figure 1.** Occurrence and spread of *Xylosandrus germanus* in Europe (a) and in Slovakia (b). Years mean first recods.
Poland

The first record of *X. germanus* from Poland was made in 1998, followed by many other records after 2005 [Mokrzycki et al. 2011, 2014]. Empirical data support that *X. germanus* is established in Poland.

Italy

The first record from Italy came from a walnut plantation in 1998 [Frigimelica et al. 1999, Stergulc et al. 1999]. Later, in north-eastern Italy, Rassati et al. [2016] collected *X. germanus* at 24 out of 25 sites. *X. germanus* has two generations per year in Italy [Faccoli 2010, Rassati et al. 2016] compared to one generation in more northerly situated countries. Empirical data support that *X. germanus* is established in Italy.

2.2 After 2000

Slovenia

*X. germanus* was first recorded in Slovenia near Nova Gorica (on *Castanea sativa* Mill.) in 2000 [Jurc et al. 2011]. Since then it has been found at many other sites in various forest ecosystems mainly in south-eastern and central Slovenia [Jurc 2010, Jurc, Repe 2012]. The increased number of sites where *X. germanus* has been found recently, and the increased number of beetles caught in traps, suggest that the beetle has established in Slovenia [Jurc et al. 2011].

Russia

The first record of *X. germanus* in Russia was from Krasnodarsk Krai in the southwestern region in 2001 [Mandelstam 2001]. The occurrence of *X. germanus* in the Russian Far East near Vladivostok was later reported by Sweeney et al. [2016]. 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 [López et al. 2007]. Its spread continues, with additional records in the northern part of this country [Goldarazena et al. 2014]. 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 [Lakatos, Kajimura 2007]. According to CABI [2017] *X. germanus* is established in Hungary.

Czech Republic

A single *X. germanus* female was first found in Moravia (Czech Republic) in 2007 [Knížek 2009]. The record was from a mixed forest. *X. germanus* continues to spread across this country (M. Knížek, pers. comm.). Recently (2017-2018) in Moravia the beetle was obtained through ethanol-trapping in oak forests near Brno and Strážnice (E. Kula, pers. obs.) where it is (2018) less frequent and less abundant than in similar habitats i.e. in Central Slovakia (M. Dzurenko, J. Kulfan, P. Zach, pers. obs.). *X. germanus* is established in the Czech Republic.

Britain
X. germanus was first recorded in Britain during a saproxyltic beetle survey in 2008 [Allen et al. 2015]. Further records of this species came from a mixed pine forest in north Hampshire in 2012 and 2013 [Inward 2015] 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 (D. Inward, pers. comm.).

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

Croatia
Franjević et al. [2016] 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. X. germanus is established in Croatia [Franjević 2012].

Slovakia
X. germanus was first recorded in Slovakia in 2010 [Galko 2013] during testing ethanol lures in oak stands [Galko et al. 2014]. For more information see the section Spread 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 [Olenici et al. 2014, 2015]. 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 [Ak et al. 2011, Knížek 2011]. Later study [Tuncer et al. 2017] 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 [Nazarenko, Gontarenko 2014] bordering eastern Slovakia. According to Nikulina [2008] X. germanus could have been established in the southern territories of Ukraine as well. Empirical data support that X. germanus is established in Ukraine [Björklund, Boberg 2017].

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 [Hansen, Jørum 2014]. This species is believed to get 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 timbers from Germany was stored [Lundberg 2006]. The second record of one individual in a baited trap was from the...
Kalmar harbor in 2016 [Björklund, Boberg 2017]. There were no records of *X. germanus* females in 2017 (N. Björklund, pers. comm.). The likelihood that the beetle could spread to Sweden has increased since its recent establishment in Denmark [Björklund, Boberg 2017]. According to Björklund and Boberg [2017] 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 *X. germanus* 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 of *Xylosandrus germanus* in Slovakia

The first record of *X. germanus* in Slovakia was in 2010 (Figure 1) in an oak stand in Považský Inovec Mountains (Forest District Duchonka, western Slovakia) where in total 19 females were obtained through baited traps utilized for monitoring purposes [Galko 2013, Galko et al. 2014]. 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 detection is highly likely.

The catches of *X. germanus* have been rising rapidly since 2010. For example, monitoring traps placed in the same oak stand and the same site yielded a total of 40 specimens in 2011, 77 specimens in 2012 [Galko 2013], and then 322 specimens in 2013, and over 1,000 specimens per yaer in next years (Galko, unpub. data). *X. germanus* has soon become the dominant species over other species of ambrosia beetle caught as in many other European countries [Rassati et al. 2016, Grégoire et al. 2001, Bouget, Noblecourt 2005, Holzinger et al. 2014, Henin, Versteirt 2004, Zach et al. 2001, Haase et al. 1998].

Hence, *X. germanus* may substantially alter diversity of scolytine assemblages in traps and/or scolytine communities in forest stands [Björklund, Boberg 2017, Bouget, Noblecourt 2005, Henin, Versteirt 2004]. It could be assumed that native competitors do not substantially limit *X. germanus* in nature [Henin, Versteirt 2004].

*X. germanus* in Slovakia was spreading from the south/southwest to the north/northeast (Figure 1). It has spread throughout the whole country (the lengthh circa 400 km) during 5-10 years. The rate of active spread of *X. germanus* has been described as tens of kilometres per year in Western Europe [Henin, Versteirt 2004] but it may be much faster when assisted i.e. by timber transportation.

Indeed, 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 [Holzschuch 1993, Bruge 1995, Henin, Versteirt 2004]. Henin and Verstein [2004] concluded that *X. germanus* does not appear to be able to settle a permanent population above approximately 350 m. Similarly, Bruge [1995] 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* [Bussler et al. 2010, Blaschke, Bussler 2012]. However, Olenici et al. [2014]...
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 often show zonation along the altitudinal gradient [Zach et al. 1995]. A systematic ethanol-trapping in the spring and summer of 2016 yielded high numbers of *X. germanus* females (N = 37760) dispersing by flight in the Kremnické vrchy Mountains, West Carpathians, Central Slovakia. These data provided the first insights into the occurrence of *X. germanus* in prevailing forest systems on southern slopes of volcanic hills where suitable breeding substrates for the beetle are not rare and where altitudes show a distinct variation from approximately 260 to 890 m. A high measure of association between the factor forest type (levels: oak, beech and spruce, n = 12 observations per level) and the altitude (eta = 0.76) allowed separate analysis of the effects of these two variables on the catches of *X. germanus* at randomly selected collecting sites (n=32).

Although approximately 51% of the beetles were collected in beech stands, the factor forest type alone (irrespective of elevation) was not proved to be influencing the abundance of the beetle within the given range of altitudes (Kruskal-Wallis test, Chi.sq = 3.9204, df = 2, p = 0.141) (Figure 2). As evident, *X. germanus* occurs abundantly in managed spruce stands within the zone of oak and beech. In North America, for example, the seasonal trapping of *X. germanus* did not differ between a hardwood habitat and coniferous habitat (Ch. Ranger, unpub. data), in agreement with our results. This is providing further evidence of broad ecological plasticity of *X. germanus* which is considered a habitat generalist [Weber and McPherson, 1983a].

The significant effect of altitude on the abundance of *X. germanus* (negative binomial GAM, edf = 3.524, Chi.sq = 24.38, p < 0.0001) suggests the ecological optimum for the beetle between approximately 500 and 700 m (Figure 2) within the zone of beech forest where wetter climate is supposed to retain more stable microhabitats for the beetle and its fungal symbiotic associates than much drier climate in oak forests where wood dessication could limit the occurrence of *X. germanus* during warm summer months. Cool submountain forests in the altitudes of approximately 900 m and above this height level could also suit less to the beetle as indicated by the smoother in the model (Figure 2). The model explaining 38% of the deviance in the data calls for extensions to broader range of altitudes and slope aspects. Although *X. germanus* in Slovakia was observed to attack felled spruce logs also at the altitude of 1,020 m (J. Galko, pers. obs., 2015), it seems to avoid cool mountain forests above 1100 m [Zach et al. 2017]. The extent to which the canopy closure affects the presence and spatial distribution of *X. germanus* in the prevailing forest systems in the West Carpathians has not yet been analysed, but the preference of the beetle for shady habitats/microhabitats in regions with both the oceanic [Zach et al. 2001] and continental climate within Europe is well known (M. Dzurenko, P. Zach, unpub. data). In Western Europe, for example, approximately five times more *X. germanus* females were stated that in the Voivodeasa Forest of 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 we provide the support for them below.
entering the log in the shade (shaded by trees) than the log exposed to direct solar radiation [Zach et al. 2001].

**Figure 2.** The number of dispersing *Xylosandrus germanus* females caught in ethanol-baited traps in the Kremnické vrchy Mountains, West Carpathians, Slovakia, during the whole dispersal period of the beetle in 2016. Boxplots (median, IQR, minimum and maximum, outliers as open circles) of the number of *Xylosandrus germanus* for oak, beech and spruce forest stands as categorical explanatory variables (a) and 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, and 3.52 is effective degrees of freedom, the short vertical lines along the x-axis are the altitude values of the 32 observations (b). The figure was drawn in R (R Core Team, 2018).

Minimum winter temperature has been proposed as a key parameter in limiting the survival of *X. germanus* [Holzschuh 1993, Bruge 1995, Henin, Versteirt 2004]. However, very low freezing temperatures of several days under -20°C in January 2017 did not seem to affect the survival of *X. germanus* in Slovakia (P. Zach, pers. obs.), however, further research is needed to clarify this in more detail. An ability to withstand low temperatures combined with a warming climate could explain in part the rapid spread and establishment of *X. germanus* in this country. Hence, low freezing temperatures (up to -20°C) are probably not the principal parameter inhibiting its spread. It is highly probable that the
vertical spread of *X. germanus* is connected to a warming climate [Bussler et al. 2010, Blaschke, Bussler 2012].

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. [2008] 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.

4. Host Selection and Preference


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 [Ranger et al. 2016]. 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 [Ranger et al. 2010, Ranger et al. 2012]. 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 [Ranger et al. 2018]. 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 [Kimmerer et al. 1982, Kimmerer et al. 1987, Kelsey, Joseph 2001, Kelsey et al. 2013, Ranger et al. 2015b]. In particular, flood stress and freeze stress have been demonstrated to induce the emission of ethanol and predispose trees to attack by ambrosia beetles [Ranger et al. 2015a, Ranger et al. 2015b, La Spina et al. 2013, Ranger et al. 2013, Ranger et al. 2016]. The emission of ethanol from aging logs also attracts and induces attacks by *X. germanus* and other ambrosia beetles [Lakatos, Kajimura 2007, zach et al. 2001, Kelsey 1994a, Kelsey 1994b, Kelsey, Joseph 1997, Kelsey, Joseph 1999].

In North America, *X. germanus* is mainly a pest on a number of species of deciduous trees, particularly in ornamental nurseries [Ranger et al. 2016, Oliver, Mannion 2001, Reding et al. 2015, Hale 2007] and tree fruit orchards [Agnello et al. 2015, Agnello et al.
In Europe, *X. germanus* is considered a secondary pest that attacks mostly felled tree logs [Lakatos, Kajimura 2007] (Figure 3). While in North America *X. germanus* is most problematic in orchards and plantations, 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 [Stergulc et al. 1999, Faccoli 2000] and in kiwi and hazelnut orchards in Turkey [Ak et al. 2011, Tuncer et al. 2017]. Host reports from Europe include beech (*Fagus sylvatica*), oak (*Quercus spp.*), 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 [Rassati et al. 2016, Inward 2015, Maksymov 1987, Brüge 1995, Lakatos, Kajimura 2007, Allen et al. 2015, Galko et al. 2015, Graf, Manser 2000, Graf, Manser 1996]. 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 [Henin, Versteir 2004].

Previous studies from Europe indicate that *X. germanus* prefers to colonize logs that were debarked during logging and transport [Maksymov 1987, Zach et al. 2001, J. Galko, pers. obs.] (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 [Galko et al. 2015]. 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 confirmed damage of oak and beech lumber by *X. germanus* in eastern Slovakia (J. Galko, pers. obs.) (Figure 1).

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) (J. Galko, pers. obs.). Colonization of live, albeit stressed beech trees was observed in Western Europe as well [Grégoire et al. 2001, Henin, Verstreit 2004, La Spina et al. 2013, J. Galko, pers. obs.).
Figure 3. Fresh attack (white sawdust) of *Xylosandrus germanus* on beech timber (a) and oak timer (b). After several weeks female expelled a noodles of sawdust (c) from the gallery (d). Photo by Juraj Galko.

While *X. germanus* shows an apparent preference for thin-barked trees [Ranger et al. 2016], it does not appear discriminate about the thickness of host material [Maksymov 1987]. Logging residues, as well as thick and highly valuable lumber are attacked [Galko et al. 2015]. For instance, Henin and Verstein [2004] 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 [CABI 2017, Ranger et al. 2018].

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

Due to its extreme inbreeding, haplodiploidy, fungiculture, and broad host range, *X. germanus* has become a very efficient invader [Gomez et al. 2018, Smith, Hulcr 2015]. 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 [Peer, Taborsky 2005]. 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 [Ranger et al. 2016, Agnello et al. 2015]. 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, [Maksymov 1987], 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 [Franjević et al. 2016]. For instance, according to current pricing (official pricelist of Slovakian State Forest, pers. comm.), 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 [Galko et al. 2016]. 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 [Graf, Manser 1996].

Generally, it can be said that the purchaser can choose to purchase infested wood [Galko et al. 2016]. Yet, even though *X. germanus* does not drill deep into suitable material – only about 2–3 cm [Maksymov 1987], 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: Cruculionidae, Scolytinae) [Zach et al. 2001] and other and thus cause greater damage.

We recommend the following management tactics to preserve the monetary value of quality lumber and minimize economic losses:
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. [2016] 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.

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) [Maksymov 1987].

An alternative to chemical treatment is covering valuable lumber with protective nets infused with insecticides (Storanet®/Woodnet®, BASF®) [Franjević et al. 2016 Franjević 2012]. According to Franjević et al. [2016] 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].

Auctions of high quality sortiments should not take place at sites and periods when wood-boring insects occur.

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.

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.

For monitoring the presence of *X. germanus* is possible to use different types of traps [Ranger et al. 2016, Galko et al. 2016] baited with ethanol. Traps provide information on the place, time, and numbers in which the monitored pest occurs [Galko et al. 2016]. However, mass trapping of *X. germanus* using ethanol-baited traps is not currently an effective management tactic [Grégoire et al. 2001, Franjević et al. 2016].

Heavily infested material should also be chipped or burned to avoid population build up [Hulcr, Stelinski 2017].

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 [Suh 2014] or other radiation, and special, direct injecting of insecticides into damaged spots [Galko et al. 2017]. Biocontrol measures, such as breeding and introduction of natural insect enemies (e.g. hymenopteran parasitoids), utilising entomopathogenic fungi, or parasitic nematodes, still require additional research [Galko et al. 2017]. Promising results have been obtained using entomopathogenic fungi to control *X. germanus* and other ambrosia beetles [Castrillo et al. 2011, 2013, Carrillo et al. 2015], but the low threshold for attacks on ornamental and horticultural trees, logs, and lumber could hamper implementation.
7. Conclusions

In conclusion, we have summarised 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 in the form of 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 [Ranger et al. 2016]. 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 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 [Grégoire et al. 2001].

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