

Mass outbreaks of the spruce bark beetle *Ips typographus* in the context of the controversies around the Białowieża Primeval Forest

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Abstract. Spruce bark beetle *Ips typographus* (L.) (Col.: Curculionidae, Scolytinae) outbreaks occur in managed and protected forests alike, but although known of for a long time, management and control of this insect is a controversial subject due to the forests' diverse nature and protection status. In this paper, an overview of the bark beetle, conditions leading to outbreaks, natural enemies and the efficiency of control measures is presented and put into perspective with regards to the current controversies concerning outbreak management. The Białowieża Primeval Forest is central to this discussion, because the area remains divided into parts with different nature protection statuses. Ideas concerning the current but also future outbreak progress and possible issues with the management of natural resources in this area are presented.

Keywords: bark beetle, Norway spruce, nature protection, Białowieża Forest

1. Introduction

The European spruce bark beetle *Ips typographus* (L.) is a species of small beetle in the weevil family (Curculionidae) and the bark beetle subfamily (Scolytinae), who has aroused extreme emotions – especially, in the recent years – on account of the ongoing heated discussion on the Białowieża Primeval Forest. The species is inherently associated with Norway spruce *Picea abies* (L.) Karst. and occurs in all places where this tree species is present, as well as it plays a decisive role in growth dynamics of Norway spruce stands. *I. typographus* is recognized not only as the most important insect pest of Norway spruce (e.g. Michalski et al. 2004; Grodzki, Kolk 2013), but also as a key species with main effects on the proper functioning of ecosystems (Gutowski 2004). It follows that opposing views are held with regard to the importance of *I. typographus* in forest ecosystems, even though its role stays the same and comes down to the elimination of alive Norway spruce trees killed after infestation by this species.

The European spruce bark beetle is one of the best investigated insect species. The list of works dedicated to various aspects of species biology and ecology comprises thousands of articles published in numerous countries (Skuhřavý 2002;

Grodzki 2013). Extensive knowledge on this species results from its abundance in forest stands with Norway spruce as well as specific species features that determine its predisposition for rapid reproduction, followed by certain ecological and economic effects. Hence, also in Poland, *I. typographus* has drawn attention for decades, both as the subject of scientific analyses (Karpiński 1935) and practical guidelines (Kozikowski 1922).

2. Reasons and mechanism of *I. typographus* outbreaks

As mentioned above, the European spruce bark beetle is a species with particularly high capability to rapidly increase its population numbers (mass reproduction). This is due to several factors, of which the most important are: polygamy and resultant high reproduction ability, very well developed chemical communication among specimens of the same or different sex, considerably high ability to disperse, and ability (under suitable climatic conditions) to produce several adult generations annually. Another significant feature of the species is quite recently discovered ability to play different roles in the ecosystem, depending on the stage of population development (latency or outbreak). Whatever the case may be, the described above

Submitted: 1.09.2016, reviewed: 14.09.2016, accepted after revision: 10.10.2016

features cause that under favorable reproduction and development conditions, European spruce bark beetle population numbers rapidly increase toward an invasive outbreak.

Every insect outbreak has a characteristic course, reflected in subsequent phases, i.e.: early outbreak stage (rapid increase of insect population numbers), outbreak culmination ('oversaturation' and breakdown of reproduction dynamics) and outbreak termination (gradual decrease of population numbers) (Köhler 1978). During the early stages, there are distinguished the following phases: preliminary (incubation), warning (prodromal) and explosive (eruptive), whereas outbreak termination comprises the post-crisis phase that moves towards the latency phase. During the outbreak early stage, among others, there increase population numbers and density, attributable to increased female fecundity, and at the warning phase, there are observed, among others: a dramatic increase of insect population numbers, more females than males, enhanced insect resistance to pathogens and parasitoids and greater than before colonization of neighboring host plants. A rapid increase of population numbers and density is observed in the eruptive phase, that after some time, leads to worsening life conditions of progeny, decreasing female fecundity, rising male numbers and further spreading of invasive populations. At the stage of outbreak termination, during the post-crisis phase, there are observed increased male numbers, decreased female fecundity and enhancement of pathogen and parasitoid efficiency (Szujecki 1995). The duration of outbreak stages and phases varies and depends on broadly understood environmental conditions in ecosystems affected by insect outbreak

Not too long ago, the European spruce bark beetle was categorized as the so called secondary pest of Norway spruce (Bilczyński 1974; Mazur 1994), and this terminology is still used in forestry jargon. It stems from the belief that *I. typographus* attacks only weakened trees and eliminates them from a stand. To some extent, such view is justified, as this takes place in the periods when European spruce bark beetle numbers are low, as well as under the conditions when forest ecosystems functioning is relatively stable. However, in subject literature, there has been stated that at increasing population numbers, the European spruce bark beetle also infests alive and healthy trees, as its mass attack overcomes tree resistance mechanisms and allows successful colonization leading to tree death (Wermelinger 2004; Kausrud et al. 2011). Then a change of the status of the European spruce bark beetle is declared – it becomes a primary insect pest, because its attack on vigorous and healthy tree is the principal reason of host plant death. In view of the above, in literature concerning *I. typographus* and other beetle species, which simultaneously attack alive trees (*Ips amitinus* [Eichh.], *I. duplicatus* [Sahlb.], *Pityogenes chalcographus* [L.]), there has been more and more often used the term: 'cambiophagous insects' rather than: 'secondary insect pests'.

The abovementioned alteration of *I. typographus* status from the secondary into the primary pest is associated with the relationship between its population numbers and physiological status of infested host trees, i.e. the Threshold for Successful Attack (TSA) (Christiansen et al. 1987). The TSA model was a breakthrough in understanding the mechanisms involved in shaping the role of bark beetles (especially those 'aggressive', such as the European bark beetle) in forest ecosystems dominated by coniferous species. Without going too much into detail, TSA relationship can be outlined as follows: the stronger (more resistant) is the host tree, the more specimens are needed to overcome tree resistance mechanism. In balanced ecosystems and at low bark beetle population numbers, weaker trees will be colonized (and eliminated), however, with increasing bark beetle population numbers, stronger trees will be also infested, and pest selectivity as regards host tree physiological status (resistance ability) will be lessening. The European spruce bark beetle 'does not count losses' during advanced outbreak stages – regardless of host plant defence mechanism, bark beetle mass attack occurs, because at that time, the species biological imperative (need to reproduce) wins the instinct of self-preservation. Thus, in population dynamics during the eruptive outbreak phase, a decisive role is played by cambiophagous insect pressure on account of high population numbers as well as susceptibility of the host plant resulting from stand condition.

Susceptibility of Norway spruce to *I. typographus* is shaped by different factors, affecting both entire stands and individual trees. Norway spruce share and tree age significantly influence a degree of stand vulnerability, as well as the features, such as: site quality, and (under mountainous conditions) altitude of stand situation and slope exposure (Netherer, Nopp-Mayr 2005; Grodzki et al. 2014). Individual tree vulnerability depends principally on tree physiological status, e.g. weakening due to drought or epiphytoses caused by root pathogens (Grodzki 2010b). *I. typographus* population numbers can rapidly increase as a result of windthrow (uprooted or broken by wind trees provide suitable and easy to colonize breeding sites) or due to water stress that leads to an increase of the number of weakened trees with low defence potential in the forest stand (Gutowski, Kubisz 1995; Michalski et al. 2004; Grodzki, Guzik 2009; Grodzki 2010b). In each of the abovementioned cases, prerequisites for beetle mass reproduction are met, however, as a general rule the factors described above act in synergism.

3. The European spruce bark beetle in the Białowieża Primeval Forest

The Białowieża Primeval Forest is characterized by rich biodiversity that is reflected also in the species composition of forest tree stands. Among tree species forming the stands, Norway spruce plays an important part, and covers more than

25% of the forested area within three Forest Districts (Promotional Forest Complex ‘Białowieża Primeval Forest’). The highest Norway spruce proportion is recorded in the Forest District Białowieża (Table 1). Tree stands within the Promotional Forest Complex ‘Białowieża Primeval Forest’ are of high average age, including those with Norway spruce – 37% of trees of this species are 60–80 years or more old (IV age class or higher age classes). Then again, the highest share of Norway spruce of this age is recorded in the Forest District Białowieża (Table 1). Consistent with the described above factors affecting Norway spruce susceptibility to *I. typographus* invasion, the Białowieża stands are highly vulnerable to attacks of this pest. Stand resistance decreases periodically due to other factors directly affecting Norway spruces, such as water stress or wind damage (Gutowski, Kubisz 1995; Boczoń 2002; Pierzgałski et al. 2002; Michalski et al. 2004).

In managed forests of the Białowieża Primeval Forest, mass European bark beetle outbreaks have been observed time and again – only in the period after the Second World War (starting from the 1950s) mass *I. typographus* reproduction was reported a number of times, and subsequent outbreaks were considered as more and more severe (Gutowski et al. 2003; Michalski et al. 2004). During the last two decades, four outbreaks of the European spruce beetle have been observed, of which three culminated in 1995, 2003 and 2008 (as determined based on the volume of infested trees). The fourth outbreak (extremely severe) has lasted since the year 2012. In view of the fact that mass reproduction of *I. typographus* has been yet observed, there has not been determined outbreak culmination. In the years 2012–2015, a rapidly increasing rate of infested trees’ volume was recorded, and data from 2016 indicate that the process of Norway spruce decline due to European spruce beetle invasion has not been limited. This is caused mainly by the hot and dry vegetation season and warm and dry fall in 2015, i.e. very favourable thermal conditions for *I. typographus* reproduction, which accelerate the development of pre-imaginal instars and also - increase the number of produced generations (Annala 1969; Wermelinger, Seifert 1998). For the periods of the above described 3 outbreaks, at their culminations, the maximum volume of

infested trees ranged from 40 thousand m³ (1995 and 2008) to 75 thousand m³ (2003), whereas in the year 2015 – it amounted to more 260 thousand m³ (Opinia... 2016). Noteworthy is the fact that until the year 2011, practically all the infested trees identified and selected for felling were removed from managed forest stands during sanitation harvest, while afterwards, such treatments were almost abandoned due to centrally introduced new regulations on, among others, admissibility of tree cutting in forests (Program... 2011; Aneks... 2016).

Taking into account the area now affected by *I. typographus* outbreak in the Białowieża Forest (comparable to that in 2001–2004), one can expect that the present outbreak shows similar patterns in the stands protected in the Białowieża National Park (Grodzki 2005), and these are excluded from active protection treatments under the national law.

4. The European spruce bark beetle and nature protection

Evidently, *I. typographus* outbreaks are intrinsically associated with growth dynamics of Norway spruce stands, as well as have an effect on the replacement of tree generations and subsistence of non-specific environments and habitats for numerous organisms. In this context, the European spruce bark beetle indeed can be perceived as the key species, playing a significant role in natural processes in the ecosystem (Gutowski 2004). This concerns especially natural or close-to-nature forests, with relatively well functioning mechanisms that shape ecological balance. The primeval protected part of the Białowieża Forest certainly represents one of such forests (Bałazy 1968; Okołów 1999; Gutowski, Kubisz 1995), likewise *Picea* forests of the montane to alpine levels in the Tatra Mts. as well as characteristic of high biodiversity forests in the Pieniny Mts. (Grodzki 2010a). However, the circumstances in managed forests are dissimilar, as due to certain silviculture treatments, there has been not only simplified the structure of stands but also their regulation mechanisms have grown weaker. The results of research carried out in forests with symbolic values, such as the Bavarian Forest (Germany) as well as in the Bia-

Table 1. Areal share of the Norway spruce stands and spruce stands above 100 years in the forest districts of the Forest Promotional Complex “Puszcza Białowieska” (Bank danych o lasach, 2016)

Forest District	Norway spruce areal share [%] ¹	Norway spruce stands aged above 120 years ²
Białowieża	31.4	47.8
Browsk	26.9	28.6
Hajnówka	28.4	36.2
Total 3 Forest Districts	25.3	37.0

¹ forest area according to dominant species, state as for 1.01.2015

² in relation to the total area of Norway spruce stands (according to dominant species)

łowieża Primeval Forest, did not indicate higher numbers of parasitoids and nearly all predators of *I. typographus* or their stronger effects on pest population dynamics in the protected forests, when compared to neighboring managed forests (Feicht 2006; Hilszczański et al. 2007). Furthermore, in forest stands where *I. typographus* infested trees were removed, the parasitic infestation degree was ‘surprisingly high’ (Feicht 2004), and in some cases, population numbers of the ant beetle *Thanasimus formicarius* (L.) were higher when compared to those in the protected forest (Schlyter, Lundgren 1993; Hilszczański et al. 2007). However, Weslien and Schroeder (1999) believe that predatory organisms are more sensitive to forest management activities when compared to their prey - the European spruce bark beetle. A study carried out in artificially planted Norway spruce stands in the Western Sudety Mts., after a wide-ranging outbreak of *I. typographus* and associated bark beetle species in the 1980s, showed that diversity of bark beetle parasitoids and predators was much lower when compared to Norway spruce stands protected in Pieniny and Bieszczady National Parks (Grodzki 1997). Nonetheless, it should be kept in mind that parasitoid and predator frequencies raise after populations of hosts/preys have increased, thus, their effectiveness is revealed during the post-outbreak stage. The results obtained by Schlyter and Lundgren (1993) as well as Gutowski and Krzysztofiak (2005) show that despite generally accepted opinions, the protected forests constitute no ‘hatchery’ for *I. typographus*. At the same time, a study carried out in the Gorce Mts., where Gorce National Park was established only in 1980, within the area of previously managed forests, showed that *I. typographus* threat to Norway spruce stands was determined by the provenance and structure of stands rather than their protection status.

5. Nature protection in the Białowieża Primeval Forest on the Polish side

Natural values of the Białowieża Primeval Forest in Poland are legally protected in: Białowieża National Park (zones of strict, active and landscape protection), nature reserves (active nature protection), Natura 2000 sites (following regulations of the Birds and Habitats Directives), landscape protection areas, zones of bird and lichen protection, as well as in ecological areas and as nature monuments. Another kind of natural resource management is the Forest Promotional Complex ‘The Białowieża Primeval Forest’, which comprises 3 Forest Districts (Białowieża, Browsk and Hajnówka) that administer all the Białowieża forests, except for those under the protection in Białowieża National Park. Evidently, the areas of nature protection forms overlap within a compact and territorially limited area, such as the Białowieża Primeval Forest, and their protection goals are not the same and every so often – in conflict. Now and then, some aspects of generally applicable legal regulations

are tightened, based on decisions taken in particular cases or at a local level (Aneks... 2016). At the same time, there lacks an overall concept concerning the protection of the Forest as a whole, whilst the plurality of nature protection forms and resultant restraints impede accomplishing the goals.

Giving up forest protection activities in the areas under strict protection in Białowieża National Park is out of question. According to Article 5, section 9 of the Nature Conservation Act (Dz.U. 2004 Nr 92 poz. 880 z późn. zm.), ‘strict protection’ shall mean: ‘permanent exclusion of direct human interference with the status of ecosystems, nature forms and elements, as well as with the course of natural processes within the areas under protection’. In view of the rule that the protection method taken on must result from protection objectives for a given object, no interference will merely assure the achievement of goals, such as conservation and surveillance of natural processes ongoing in the ecosystem. Furthermore, effectiveness of the conservation method can be assured by consistency in the proceedings, since only long-term permanent strict protection can guarantee possibilities to watch non-disturbed (or the least disturbed) natural processes. This condition has been met in the strict nature reserve designated in Białowieża National Park, which has sustained almost uninterruptedly since 1921.

In the areas under active protection, the situation is mixed. According to Article 5, section 5 of the Nature Conservation Act, ‘active protection’ shall mean: ‘wherever appropriate, application of protection treatments with the aim to restore the natural status of ecosystems and nature elements or preserve habitats and sites of flora, fauna and fungi’. The part of Białowieża National Park referred to in the Nature Conservation Plan (Plan... 2014) is subject to active protection. Nonetheless, since *I. typographus* outbreaks have not been included in the Plan as the threat to nature of the Park, it may be expected that activities connected with forest protection against bark beetles will be disregarded also in the Park’s area designated for active protection treatments. Another issue is proceeding in the nature reserves with the active protection status that are situated in the Białowieża Forest, outside the Park’s borders. Most of these have no Nature Conservation Plans, and a degree of human interference is determined by the aforesaid decisions taken at a local level. Hence, the nature reserves of the total area more than 12 thousand ha may be considered as excluded from the treatments with the aim to reduce *I. typographus* population numbers.

The greatest part of the remaining area of the Białowieża Primeval Forest encompass tree stands with the status of managed forests, that have been in actual fact subject to forest silviculture and protection treatments for decades or centuries. Forest management has been the main factor shaping the present forest structure, and it included treatments connected with active protection against the European spruce bark beetle. This

obligation is defined in the Forest Act (Dz.U. 1991 Nr 101 poz. 444 z późn. zm.), in Article 10, section 1: ‘Under the conditions of harmful organism incidence threatening forest sustainability’ (1) the forest district manager (...) will perform control and protection treatments’ and ‘(3) if control and protection treatments are required in the area of two or more forest districts, the treatments denoted in section 1 point 1 are ordered by the regional director of the State Forests. Article 35.1. says: ‘The forest district manager is responsible for forest management carried out based on the Forest Management Plan and for the condition of forest in the district’. In the light of the Forest Act, in managed forests, there exists an obligation to actively protect these forests, including selection and removal of trees infested by cambiohagous insects, in line with the Guidelines on Forest Protection (Instrukcja ochrony lasu 2012), i.e. the legal instrument that provides a framework for forest protection activities. Then again, this is not the case, as active protection treatments have been given up as a result of specific decisions taken at a local level (Aneks... 2016), under pressure from bodies that formally have no responsibility for forest condition and the implementation of Forest Act regulations. Hence, duty-bound managers of forests can do nothing but watch and record dynamic expansion of *I. typographus* outbreak in the Białowieża Forest’s Norway spruce stands in their care.

6. The European spruce bark beetle and forest protection treatments

The problem of mass occurrence of *I. typographus* in Norway spruce forests has been faced for a long time, and experiences gained during numerous outbreaks supported elaboration of the strategy and methodology for protection activities toward reduction of excessive populations of this pest (Kolk, Grodzki 2013). The selection and timely (earlier than the emergence of the next adult generation) removal of infested trees (Niemeyer 1997) are considered as the most effective means among the methods used in the complex protection procedures. Other methods are applied as supportive measures (trap logs, pheromone traps) or interventionist measures (debarking, spraying infested trees with water, insecticide-treated nets, wood material left in forest and quickly removed after infestation [the so called ‘rotational method’]). However, the basic method requires that identified trees with ongoing development of bark beetle pre-imaginal stages under their bark are cut down and removed from forest early enough, so as to prevent emergence of young adults. Such treatment is included in the so called sanitation cuttings and is of selective nature – no more than infested trees are felled. This activity requires lots of efforts at all its stages, and does not turn into ‘logging’ which leads to clearcutting (only under the conditions of severe outbreak, the majority or almost all

infested trees have to be removed from an attacked stand). Elimination of such activities, especially under the conditions of expanding outbreak, encourages rapid increase of bark beetle population numbers, in the same way as newly fallen and broken trees, which form excellent breeding material for the European spruce bark beetle (Stadelmann et al. 2013; Grodzki et al. 2006b). In wind damaged stands excluded from forest protection treatments, the number of bark beetle infested trees is twice as high when compared to treated Norway spruce stands (Forster 1998; Lindelöw, Schroeder 2001). Therefore, in managed Norway spruce forests (and also - in those under active nature protection), there have been applied measures enabling reduction of *I. typographus* reproduction.

In the debates on the legitimacy and purposefulness of removing *I. typographus* infested trees from forests, there has been frequently raised the argument that such treatments are not effective. Quite a long time ago, in subject literature, there was pointed out that forest protection treatments could not stop *I. typographus* outbreak, however, they could contribute to decreasing rates of Norway spruce decline and premature tree mortality (Capecki 1978, 1982). In this context, there are also referred to the results of a study carried out in the 1990s in Polish-Slovakian borderland in the Tatra Mts. These showed the similar course of *I. typographus* outbreak in Tatra National Park - under strict protection in Poland, and in adjoining area of Slovakian Tatra National Park (TANAP) - periodically under active protection (sanitation cuttings) (Grodzki et al. 2006a). However, it needs to be noted that the stands on each side of the border differed, especially in terms of age structure characteristics (influencing natural processes of degradation). Also, *I. typographus* outbreak in TANAP rapidly ceased in 1997, whereas on the Polish side, the stage of outbreak termination lasted until 1999. Beside inevitable impacts of unfavourable weather, sooner outbreak termination in TANAP was caused by intensive (too rigorous?) active protection treatments. The results of studies showed that both the removal of available breeding material and already colonized trees contribute to considerable reduction of *I. typographus* threat to Norway spruce stands (Jönsson et al. 2012). Sanitation cuttings help reduce a rate of formation of new bark beetle invasion zones, and the removal of already infested trees is of most importance, especially in wind damaged stands (Stadelmann et al. 2013). Yet, decisions on removal of cut down trees should take into account reaching a compromise with regard to maintaining the balance between elimination of trees serving as bark beetle breeding sites and leaving behind adequate amounts of deadwood in order to protect forest biodiversity (Kausrud et al. 2012).

Successful control of *I. typographus* outbreaks in the Beskid Śląski and Beskid Żywiecki in 2007 proves the effectiveness of consistently pursued activities toward reduction of bark beetle population numbers (Szabla 2013). During three outbreaks in the Białowieża Primeval Forest, in the years 1994–1996,

2001–2004 and 2007–2009, all the selected trees infested by the European spruce bark beetle were eliminated and sanitation cutting volume did not exceed 75 thousand m³ in the year with the highest pest population numbers. On the other hand, after giving up forest protection activities (2012), there was observed a dramatic increase in the number and volume of *I. typographus* invaded trees: in 2013 – more than 3-fold increase when compared to 2012, in 2014 – about 2-fold when compared to 2013, and in 2015 – the volume of approximately 267 thousand m³ was assessed as infested by the European spruce bark beetle, of which only 42 thousand m³ were removed due to sanitation cuttings (Aneks... 2016). Continuous limiting of forest protection activities shall mean further progress of Norway spruce decline in the Białowieża Primeval Forest.

7. Conclusions

1. The Białowieża Primeval Forest is a natural site of exceptional importance, therefore, multidirectional protection tasks must be realized toward safeguarding all its natural values. In view of the fact that different nature conservation forms overlap within the Forest's area, there is a need to define an overall, comprehensive concept of the protection of the Forest taken as a whole. The protection method applied must be appropriate for a specific object (correctly determined) and compliant with its protection goals.

2. The European spruce bark beetle is an integral element of nature in the Białowieża Primeval Forest, and its outbreaks are instigated under reproduction favourable conditions (weather, abundance of breeding material). The Białowieża Forest's stands (especially those with Norway spruce) are vulnerable to *I. typographus* invasion, due to their specific characteristics (age structure, share of Norway spruce).

3. Under the conditions of the ongoing *I. typographus* outbreak, with unprecedented dynamics, and taking into account a relatively low level of environmental resistance, there can be expected further reproduction of this bark beetle species, followed by extensive mortality of infested Norway spruce trees.

4. The methods of reduction of excessive *I. typographus* population numbers – recognized and applied in forest management practice – have proven to be effective, which was confirmed in managed stands in the Białowieża Forest during earlier outbreaks, as well as in other Poland's and Europe's regions.

5. One of conditions to be met in order to hold back *I. typographus* outbreaks and Norway spruce dieback is regulation on the complex status of individual parts of the Białowieża Primeval Forest and consequential restrictions with regard to effective protection treatments in the Forest's parts with the status of managed forests. Forest management includes active protection of natural values of the Białowieża Primeval Forest.

Conflict of interest

The Author declares no potential conflict of interest.

Acknowledgements and source of funding

The study was financed from the Author's own funds

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