

ORIGINAL PAPER

Ten years (2012-2021) of spruce bark beetle *Ips typographus* (L.) activity in the Białowieża Forest District of the Białowieża Primeval Forest

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ABSTRACT

The Białowieża Forest District is one of the three forest districts managing the Białowieża Primeval Forest. With an area of 12,586 ha, this district accounts for approximately 20% of the entire Polish area of the Białowieża Primeval Forest. The forest district also includes many forms of nature protection that appear in Polish legislation, including Natura 2000, nature reserves and species protection zones. Additionally, the district is protected under international agreements as part of the UNESCO World Heritage Site 'Białowieża Forest'. Over the last 100 years, the forest stands of the Białowieża Primeval Forest have experienced numerous changes in the population dynamics of the spruce bark beetle, where outbreaks resulted in the insects colonizing live trees – mainly spruces. In the last decade (2012-2021), the spruce bark beetle outbreak also occurred in the Białowieża Forest District between 2013-2017. In this case, the size of the outbreak was largely influenced by introduced formal and legal restrictions which made it impossible to take active measures to prevent the reproduction of the spruce bark beetle. This led to a catastrophic development of the outbreak, resulting in about 2 million m³ of trees being infested in the forest districts – including over 0.7 million m³ of spruces and pines in the Białowieża Forest District. The aim of this study was to describe the activity of the spruce bark beetle between 2012-2021 in the Białowieża Forest District, and to analyse the collected data in relation to nature reserves, stands over 100 years old (based on Prof. Tomasz Wesołowski's criterion) and stands up to 100 years old. In the analysed 10-year period, the greatest volume of infested trees occurred in stands over 100 years old (395,761 m³), then in stands up to 100 years old (195,059 m³) and lastly in nature reserves (141,526 m³). The peak of the outbreak in the forest district occurred in 2016, when 200,761 infested trees with a volume of 224,674 m³ were registered. Using the collected data, the volume of infested trees was also characterized according to forest habitat types, age classes of stands and any changes that took place in this respect during the 10-year period. The highest volume of trees infested in 2012-2021 was found in the habitats of fresh mixed broadleaved forest (LMśw), fresh mixed coniferous forest (BMśw) and fresh broadleaved forest (Lśw), where the values were 229,143 m³, 186,276 m³ and 176,455 m³, respectively. In the initial phase of the outbreak, the spruce bark beetle mainly infested old spruce forests in the

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6th and older age classes. At a later stage, from 2016 onwards, the mass of the infested younger stands, *i.e.*, age classes II, III and IV, clearly increased. Giving up the practice-proven methods of reducing the bark beetle population led to the breakdown of tree stands over thousands of hectares. This resulted in threats to the existence of many species of plants, animals and fungi along with their habitats. Forest fire risk also increased, increasing the need to periodically prohibit access to the forest to implement work in the field of public safety. Management of such a valuable entity as the Białowieża Primeval Forest requires great caution and prudence in making decisions on protection methods. This should consider both the aspects related to passive protection, *i.e.*, the protection of natural processes, as well as active protective measures for the protection of habitats and species.

KEY WORDS

infested tree, Norway spruce, habitat type, protection form

Introduction

The Białowieża Forest District is one of the three forest districts managing a unique and greatly important natural area in Poland, namely the Białowieża Primeval Forest. In addition to the Białowieża Forest District, the Polish part of the Białowieża Forest is administered by two more forest districts (Browski and Hajnówka) which together form the Puszcza Białowieska Forest Promotional Complex. Additionally, 1/6 of the Polish part of the Białowieża Primeval Forest is constituted by the Białowieża National Park. In total, the area of the Polish part of the Białowieża Forest is about 63,000 ha. On the Belarusian side, the Belovežska Pusa National Park is the forest manager. Since 2014, the Białowieża Primeval Forest, both on the Polish and Belarusian sides, forms a joint UNESCO World Heritage Site 'Białowieża Forest'.

The Białowieża Forest District is the smallest forest district with an area of 12,586 ha, which is about 20% of the entire area of the Polish part of the Białowieża Primeval Forest. The whole area of the forest district is covered by the European Ecological Network Natura 2000, and more than 1/3 of the area of the forest district (4,305 ha) is made up of 7 nature reserves. Additionally, there are ten ecological sites (54.32 ha), 493 nature monuments and 54 species protection zones in the area of the forest district.

In addition to the above-mentioned forms of nature protection resulting from Polish legislation (Ustawa, 2004) and international obligations, the Forest Management Plan for the Białowieża Forest District, between 2012-2021 (Decision, 2012), also imposed additional restrictions related to the conduction of active protective measures. This included the exclusion of certain stands from economic activity: where at least 10% of the trees were over 100 years old (based on Prof. Tomasz Wesołowski's criterion), stands in wet and marshy habitats, and pioneering stands (dominated by birch and aspen).

These management factors in the analysed period definitely favoured the spruce bark beetle, *Ips typographus* (L.) (Curculionidae, Scolytinae) – one of the most well-known insect species (Kolk and Grodzki, 2013) associated with the Norway spruce *Picea abies* (L.) H. Karst. This insect is the most dangerous pest of spruce (Michalski *et al.*, 2004; Kolk and Grodzki, 2013; Grodzki, 2016) which can rapidly increase population numbers, referred to as an 'outbreak', with specific environmental and economic consequences. It is also considered a key species, on which the course of proper processes in the ecosystem depends. The assessment of the role of the spruce bark beetle may be different, but in both cases, it refers to the elimination of living trees infested by insects (Grodzki, 2016).

It should also be noted that the development of the spruce bark beetle population is stimulated by factors such as high temperature, lack of precipitation, unfavourable soil conditions, root infection by pathogens, and damage to forest stands by wind and snow. In the Białowieża Primeval Forest, issues related to a water deficit resulting in an increase in the number of weakened trees with a low defence potential, are particularly acute. All these factors, acting synergistically, cause rapid changes in the population of the spruce bark beetle and other accompanying species (Starzyk, 2013).

Due to all the above-mentioned conditions, the spruce bark beetle repeatedly showed a tendency towards mass outbreaks in the Białowieża Forest, which were documented at least 9 times from the end of the 19th century: 1882-1883, 1919-1922, 1950-1957, 1960-1966, 1983-1988, 1994-1997, 2001-2004, 2006-2009, 2013-2017 (Michalski *et al.*, 2004). In the analysed 10-year period (2012-2021), the bark beetle infested an increasing number of trees in the stands of forest districts every year, but the outbreak should be assumed for the years 2013-2017. In the earlier years (1992-2011) of the bark beetle activity, most of the trees that were infested were removed as part of the protective measures, and their volume was on average around 20,000 m³ during one growing season (Brzeziecki *et al.*, 2018).

The last analysed activity of the bark beetle in the Białowieża Forest, between 2012-2021, was unprecedented. It resulted in the death of about 2 million m³ of trees in forest districts, including over 730,000 m³ of spruce and pine trees in the Białowieża Forest District. This has become the motivation and reason to present the summary information in this article.

Materials and methods

The data for this study come from the database of the Information System of the State Forests of the Białowieża Forest District. The information available in the forest district about the number of infested trees and estimated volume (based on measurements by forest staff) was also used. The data is divided into 3 groups of stands (Fig. 1), which as of December 31, 2021, cover the following area in the forest district: nature reserves (4,122 ha), stands over 100 years old (based on Prof. Tomasz Wesołowski's criterion) (4,246 ha) and stands up to 100 years (3,595 ha). The information collected in the Białowieża Forest District in the years 2015-2021 on the quantity of the spruce bark beetle and pheromone traps was also presented. When determining the number of caught insects, a conversion factor was adopted which indicates that in 1 cm³ of caught insects, there are 40 specimens of spruce bark beetle. The analysis was carried out on data from the Białowieża Forest District, because this is the only forest district with detailed data on the number and volume of infested trees, which allows for analysis in terms of age classes and forest habitat types.

Results

As a result of the activity of the spruce bark beetle in the years between 2012-2021, in a total of 576,831 trees with a total volume of 732,345 m³ (spruces and pines) in the Białowieża Forest District were registered to be infested by the spruce bark beetle. In the total number of infested trees, there were only 2,320 pines with a total volume of 2,446 m³.

The data were analysed in terms of the possibility of active protective measures according to 3 types of areas: nature reserves, stands over 100 years old (based on Prof. Tomasz Wesołowski's criterion) and stands up to 100 years old. In the analysed period, the greatest number of infested trees was found in stands up to 100 years old (250,898), then in stands over 100 years old (244,997), and lastly in nature reserves (80,936). In terms of volume, the situation was slightly dif-

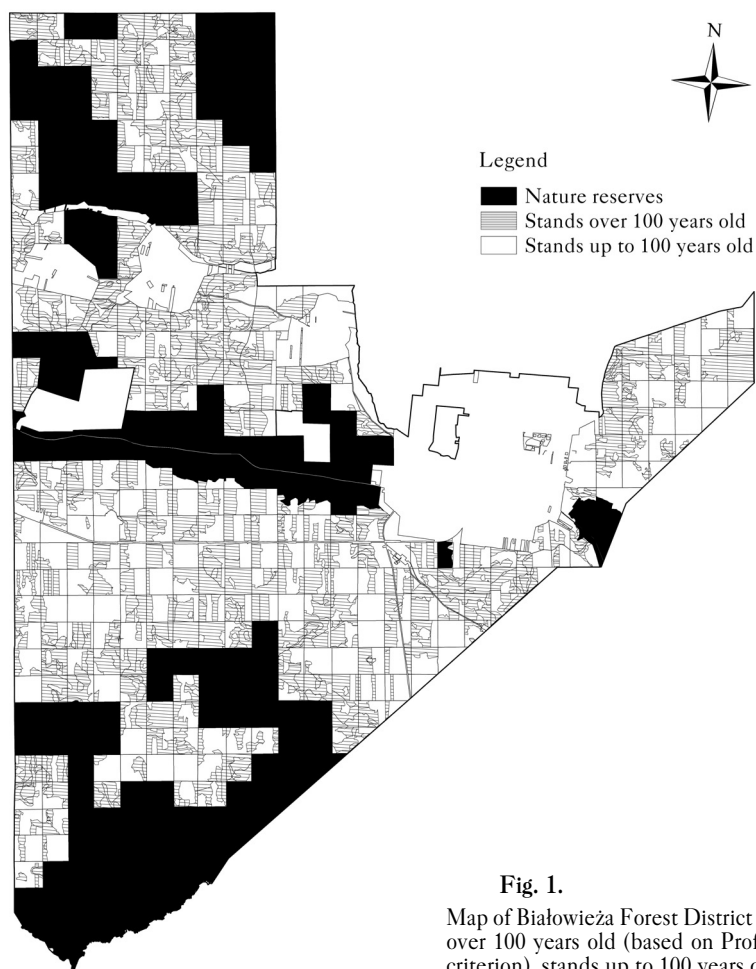


Fig. 1.

Map of Białowieża Forest District [nature reserves, stands over 100 years old (based on Prof. Tomasz Wesołowski's criterion), stands up to 100 years old]

ferent, as the greatest volume of infested trees occurred in stands over 100 years old (395,761 m³), then in stands up to 100 years old (195,059 m³) and lastly in nature reserves (141,526 m³) (Fig. 2).

In the 10-year data period, the spruce bark beetle outbreak occurred in 2013-2017. The peak was in 2016, when 200,761 infested trees with a total volume of 224,674 m³ were registered. A significant number of infested trees and tree volume were also classified in 2015 and 2017, with 123,474 trees / 153,566 m³ and 109,189 trees / 132,000 m³, respectively. In the first year of analysis (2012), 5,324 infested trees with a total volume of 7,595 m³ were recorded, and in the last year (2021) only 748 trees with a total volume of 982 m³ remained (Fig. 3).

Between 2012-2017, active measures were taken in the forest district to reduce the outbreak of the spruce bark beetle. In total, 78,597 m³ of infested trees were harvested, which constituted only about 11% of the total volume of trees affected in the above-mentioned period. Between 2012-2015, the volume of harvested wood infested by the spruce bark beetle systematically increased from 2,408 m³ to 17,272 m³. The largest number of infested trees, 36,735 m³, were harvested in 2017 (Fig. 4).

The spruce bark beetle activity in 2012-2021 was also analysed in terms of forest habitat types and stand age classes.

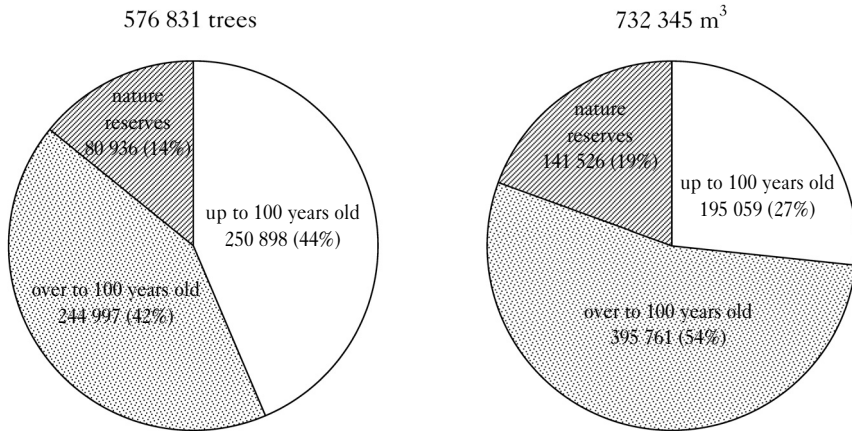


Fig. 2.

The number [count] and volume [m³] of trees (Norway spruces and Scots pines) killed by the European bark beetle (based on measurements by a forest staff) in the Białowieża Forest District in 2012-2021 according to nature reserves, forests stands up to 100 years old and forests stands over to 100 years old (based on Prof. Tomasz Wesółowski's criterion)

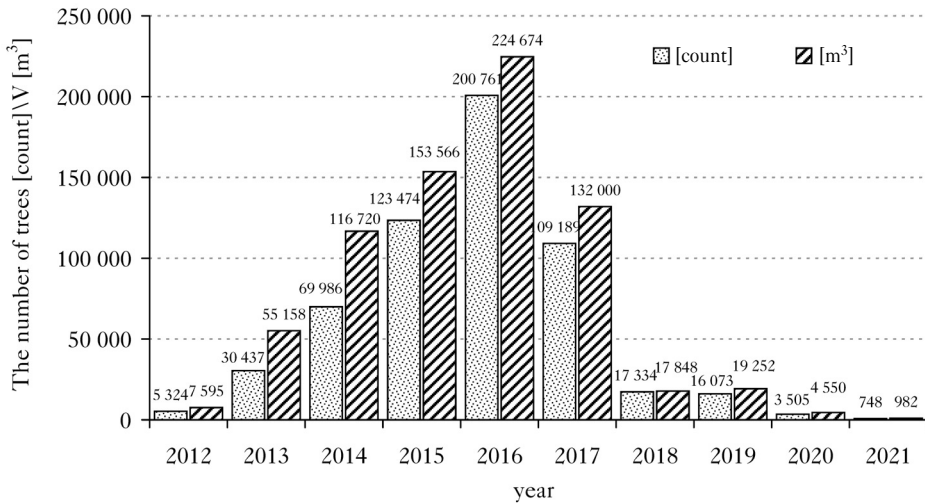


Fig. 3.

The number [count] and volume [m³] of trees (Norway spruces and Scots pines) killed by the European bark beetle (based on measurements by a forest staff) in the Białowieża Forest District in 2012-2021

The highest volume of infested trees in 2012-2021 was found in the habitats of fresh mixed broadleaved forest (LMśw), fresh mixed coniferous forest (BMśw) and fresh broadleaved forest (Lśw), where the values were 229,143 m³, 186,276 m³ and 176,455 m³, respectively. These forest habitat types covered a total area of about 6,943 ha, *i.e.*, about 58% of the forest area of the forest district. The smallest amounts of infested trees were found in wet and marshy habitats, except for moist broadleaved forest (Lw), moist mixed broadleaved forest (LMw) and moist mixed coniferous forest (BMw) habitats, where trees were identified in the following volumes: 47,540 m³, 41,555 m³ and 23,639 m³, respectively (Fig. 5). Despite the difference in the area covered between the moist broadleaved forest (Lw) and moist mixed broadleaved forest (LMw) amounting to

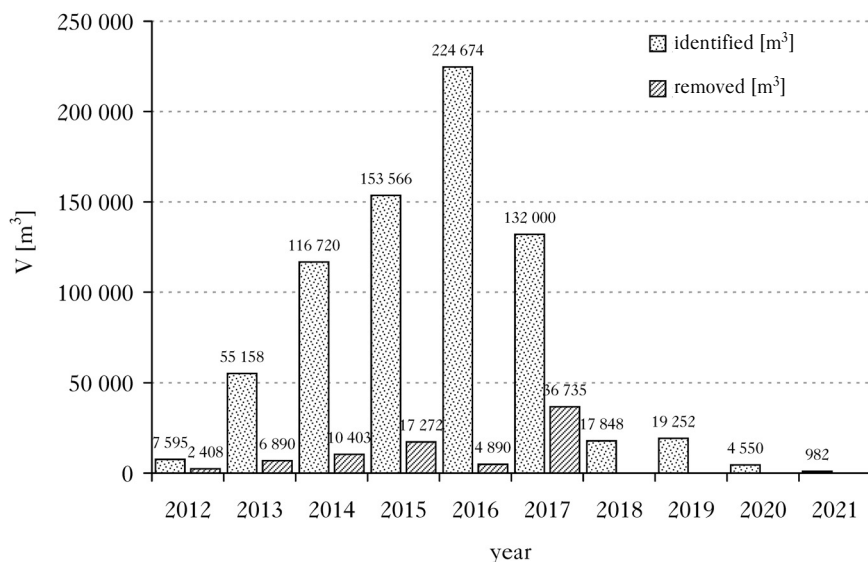


Fig. 4.

Volume of Norway spruces killed by European spruce bark beetle (based on measurements of trees marked by a forest staff) and removed in the salvation cuttings in the Polish managed part of the Białowieża Forest District within the period 2012-2021

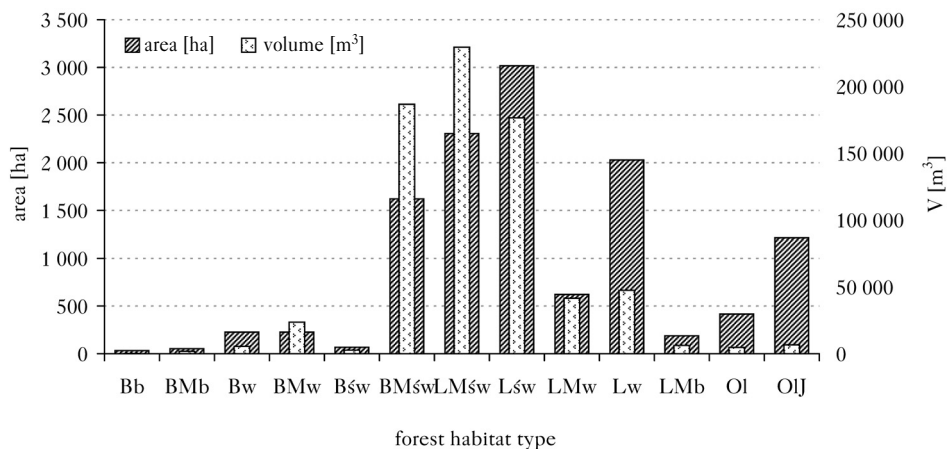


Fig. 5.

Volume [m³] of Norway spruces and Scots pines, according to the area forest habitat types [ha], killed by the European bark beetle (based on measurements by a forest staff) in the Białowieża Forest District in 2012-2021

approximately 1400 ha, the volume of infested trees was similar. The changes in tree colonisation by the bark beetle in individual forest habitat types over the 10-year period attracted attention. It is stated that the highest share of trees attacked by the spruce bark beetle in the initial period of outbreak occurred in fresh habitats, *i.e.*, fresh mixed coniferous forest (BMśw) and fresh mixed broadleaved forest (LMśw). Later, the number of trees infested by the spruce bark beetle in the above-mentioned forest habitat types decreased, and increased in fertile and moist habitats, *i.e.*, fresh broadleaved forest (Lśw), moist mixed broadleaved forest (LMw), moist

broadleaved forest (Lw) and wet moist mixed coniferous forest (BMw). The colonisation of trees by the spruce bark beetle in the forest habitat types of mixed broadleaved bog forest (LMb), mixed coniferous bog forest (BMb), alder forest (Ol) and alder-ash forest (OlJ) was also significant in 2016-2017 – areas where the bark beetle was essentially not active before. To summarise, in the years of 2012-2021, the largest number of infested trees in relation to the area of the habitat was seen in the fresh mixed coniferous forest (BMśw), *i.e.*, 115 m³/ha.

Considering the colonisation of spruce stands according to age classes, it was found that, in the initial phase of the outbreak, the spruce bark beetle infested mainly old spruce stands in the 6th and older age classes. In a further phase starting from 2016, the mass of infested younger stands, *i.e.*, age classes II, III and IV, clearly increased. The share of young stands in the total volume of infested trees increased from a few to almost 30% of the total volume in 2019. In the period from 2015 to 2021, a total of 39.5 million imagines of the bark beetle were caught in pheromone traps, of which the most was found in 2017 (15.9 million) (Table 1).

Referring to the effects of spruce bark beetle activity in 2012-2021 in the three forest districts of the Białowieża Primeval Forest, it should be noted that the proportion of areas where spruce was a dominant species decreased from 21.7% to 6.6%. This decrease was from an area of approx. 13.4 thousand ha to approx. 3 thousand ha, which proves the significant influence of the insect's activity in the last decade (Porowski, 2022). Analysing the data on the dynamics of spruce changes according to the actual share, it was found that the area decreased by approximately 7,300 ha. Currently, the area according to the share of actual spruce in the Białowieża Forest is approximately 6,500 ha (Porowski, 2022).

The effects of the spruce bark beetle outbreak and the related limited possibilities of active reduction and logging of broken, uprooted infested trees can be related to changes in the amount of available dead wood. The average volume of dead wood of all species in the forest districts of the Białowieża Forest increased from 24,7 m³/ha in 2012 to 85,6 m³/ha in 2021, with the highest average values exceeding 100 m³/ha in the forest habitat types of mixed coniferous bog forest (BMb), alder-ash forest (OlJ) and fresh mixed broadleaved forest (LMśw). The fresh mixed broadleaved forest (LMśw) habitat specifically had the highest increase in the average amount of dead wood, from the level of 16 m³/ha (2012) to 104 m³/ha (2021) (Porowski, 2022).

Table 1.

The number of pheromone traps and the number of bark beetles caught in pheromone traps in the Białowieża Forest District in 2012-2021

Year	The number of pheromone traps [count]	The amount and number of spruce bark beetles caught in pheromone traps	
		litres	count
2012	218	–	–
2013	175	–	–
2014	180	–	–
2015	180	155	6,192,000
2016	147	205	8,200,000
2017	170	398	15,916,000
2018	170	115	4,618,000
2019	120	62	2,492,000
2020	120	32	1,268,000
2021	120	23	908,000
Summary		990	39,594,000

Discussion

In the discussion around methods to reduce bark beetle population sizes and limit the damage that has been taking place for many years, there has been support for the idea that the standard methods of removing infested trees are ineffective and can lead to the decline of the entire stand (Brzeziecki *et al.*, 2018). However, many years of observations and experiences gathered in Poland and other European countries prove something completely different (Capecki *et al.*, 1998; Grodzki, 2016; Miścicki and Grodzki, 2021).

Referring to the 20-year observations (1992-2011) of the course of the outbreak in the Białowieża Forest District and the Białowieża Primeval Forest, when active measures were possible, the population of the spruce bark beetle was limited and controlled. This prevented a sudden and large-area decline of tree stands. The situation changed significantly in 2012-2021, when several restrictions led to the death of trees (spruces and pines) with a total volume of over 0.7 million m³.

In connection with the above, resignation from the use of preventive treatments resulting from the applicable regulations (Ustawa, 1991) and instructions (Instrukcja, 2012) on more than 3/4 of the area of the Białowieża Forest District, and the methods of reducing the bark beetle population that have been proven in practice (Hilszczański and Starzyk, 2017), has contributed to:

- decline of tree stands over thousands of hectares, which resulted in threats to the existence of some species of plants, animals and fungi along with their habitats (Brzeziecki *et al.*, 2018),
- abrupt increase in the amount of dead wood, mainly spruce, and the abundant development of grass cover, mainly rough small reed *Calamagrostis arundinacea* L. Roth., which contributed to an increase in forest fire risk – in particular in spring and autumn, and in long periods of summer drought (Szczygieł and Kwiatkowski, 2015),
- the need to introduce a periodic ban on access to the forest in a large area of the forest district due to the destruction and damage to forest stands (Ustawa, 1991),
- implementation of works in the field of public safety, including fire safety, on most roads, tourist routes and educational paths (Brzeziecki *et al.*, 2018),
- a social conflict that arose as a result of different approaches to the activity of the spruce bark beetle in forest stands.

In the example of the Białowieża Forest District, it was confirmed that the spruce bark beetle, in the first phase of the outbreak, was a secondary pest. It attacked only weakened trees, eliminating them from less resistant stands, and targeted trees suffering in the event of drought. At the time of the cascading increase in numbers, as was the case in the Białowieża Forest District, the bark beetle also attacked potentially healthy trees, regardless of their defence mechanisms (Grodzki, 2016). The phenomenon of changing the status from secondary to primary pest is related to the number of insects and the physiological condition of trees, described as TSA (Threshold for Successful Attack) (Christiansen *et al.*, 1987). This means that the stronger and more defensive a tree, the greater the number of bark beetles will be required to overcome its defensive abilities. It is estimated that about 5,000 bark beetles are required to kill one spruce.

To summarise, a question should be asked: Has anyone benefited from the development of this situation, from such a course of the spruce bark beetle outbreak in the Białowieża Forest District and the Białowieża Primeval Forest? It is difficult to find an unambiguous answer. Certainly, the outbreak of the spruce bark beetle highlighted many issues and problems that the

managers of this unique area had not dealt with before, as well as the local community and everyone for whom preserving the species diversity of the Białowieża Forest is important. The situation also showed that, for the proper management this UNESCO World Heritage Site 'Białowieża Forest', it is necessary to urgently prepare an integrated management plan which will take into account and reconcile various social needs and expectations with regard to this unique forest.

Conclusion

- ✦ The analysed outbreak of the spruce bark beetle *I. typographus* in the Białowieża Forest District and the Białowieża Primeval Forest assumed catastrophic dimensions, not recorded since the 1920s. In addition to several abiotic and biotic factors, which undoubtedly influenced its dynamics, one should also mention the introduction of formal restrictions, preventing the effective implementation of active measures aimed at limiting and mitigating the course of outbreak.
- ✦ The spruce bark beetle *I. typographus*, as a species with the special ability to rapidly increase its numbers, showed a number of behavioural mechanisms that were not observed in previous years in the Białowieża Forest District. These include mass colonisation of trees in younger age classes (I-II), as well as intensive colonisation of trees in fertile, moist and marshy habitats [fresh broadleaved forest (Lśw), moist broadleaved forest (Lw), moist mixed broadleaved forest (LMw), moist mixed coniferous forest (BMw), mixed broadleaved bog forest (LMB), mixed coniferous bog forest (BMB), alder forest (Ol) and alder-ash forest (OIJ)].
- ✦ The spruce bark beetle outbreak in Białowieża Forest District had several negative economic, natural and social consequences, and their effects will be felt by the local society and the area's managers for many years to come. The adopted concept of leaving such a large area as the Białowieża Forest to the 'forces of nature' was ill-considered.
- ✦ Management of such a valuable entity as the Białowieża Primeval Forest requires great caution and prudence in making decisions on protection methods, which should take into account aspects related to passive protection (the protection of natural processes), as well as protective measures in the field of active protection of habitats and species.

Authors' contributions

T.G. – research concept, methodology, data analyses, manuscript preparation, review and editing;
A.L.-G. – manuscript preparation, review and editing.

Conflict of interests

The authors declare no conflicts of interest.

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STRESZCZENIE

10 lat (2012-2021) aktywności kornika drukarza *Ips typographus* (L.) w Puszczy Białowiejskiej na przykładzie Nadleśnictwa Białowieża

W wyniku aktywności kornika drukarza w latach 2012-2021 w Nadleśnictwie Białowieża, która przyjęła charakter gradacyjny w latach 2013-2017, wyznaczono łącznie 576 831 zasiedlonych drzew (świerków i sosen) o łącznej miąższości 732 345 m³. W analizowanym okresie najwięcej drzew trocinkowych wyznaczono w drzewostanach do 100 lat – w liczbie 250 898, następnie 244 997 w drzewostanach powyżej 100 lat (kryterium prof. Tomasza Wesołowskiego) oraz w liczbie 80 936 w rezerwach przyrody (ryc. 1). W ujęciu miąższościowym sytuacja kształtowała się nieco odmiennie, gdyż największa miąższość drzew zasiedlonych wystąpiła w drzewostanach powyżej 100 lat – 395 761 m³, następnie 195 059 m³ w drzewostanach do 100 lat oraz 141 526 m³ w rezerwach przyrody (ryc. 2). Kulminacja gradacji kornika drukarza nastąpiła w 2016 roku, kiedy wyznaczono łącznie 200 761 drzew trocinkowych o łącznej masie 224 674 m³ (ryc. 3). Znaczące liczby

zasiedlonych drzew i miąższości wyznaczono w latach 2015 i 2017, odpowiednio – 123 474 szt./153 566 m³ oraz 109 189 szt./132 000 m³. W pierwszym roku analizy (2012 rok) wyznaczono 5324 zasiedlone drzewa o łącznej miąższości 7595 m³, a w ostatnim (2021 rok) jedynie 748, o łącznej miąższości 982 m³ (ryc. 2). W latach 2012-2017 prowadzono w nadleśnictwie czynne działania mające na celu ograniczanie gradacji kornika drukarza. Łącznie pozyskano 78 597 m³ zasiedlonych drzew, co stanowiło jedynie około 11% łącznej miąższości drzew trocinkowych wyznaczonych w tym okresie (ryc. 4). Największą miąższość zasiedlonych drzew w latach 2012-2021 stwierdzono na siedliskach LMśw, BMśw oraz Lśw, gdzie wartość ta wynosiła odpowiednio 229 143 m³, 186 276 m³ oraz 176 455 m³. Najmniejszą ilość zasiedlonych drzew stwierdzono na siedliskach wilgotnych i bagiennych, za wyjątkiem siedlisk Lw, LMw oraz BMw, gdzie wyznaczono drzewa trocinkowe o wielkości miąższości odpowiednio 47 540 m³, 41 555 m³ oraz 23 639 m³ (ryc. 5). Rozpatrując zasiedlanie drzewostanów świerkowych wg klas wieku, stwierdzono, że w początkowej fazie gradacji kornik drukarz zasiedlał głównie starodrzewy świerkowe, w VI i starszych klasach wieku. W dalszej fazie, poczynając od 2016 roku, wyraźnie wzrastała miąższość zasiedlonych drzewostanów młodszych, tj. II, III i IV klasy wieku, których udział w ogólnej miąższości zasiedlonych drzew wzrósł od kilku do niemalże 30% ogólnej zasiedlonej masy w 2019 roku. W okresie od 2015 do 2021 roku odłowiono łącznie w pułapkach feromonowych 39,5 mln szt. imago kornika drukarza, najwięcej w 2017 roku – 15,9 mln szt. (tab. 1). Gradacja kornika drukarza w Nadleśnictwie Białowieża spowodowała szereg negatywnych konsekwencji, które można rozpatrywać w ujęciu gospodarczym, przyrodniczym i społecznym, a ich skutki miejscowe społeczeństwo i zarządzający tym obszarem będą odczuwać jeszcze przez wiele lat. Przyjęta koncepcja pozostawienia tak wielkiego obszaru, jakim jest Puszcza Białowieża, „siłom natury” była nieprzemyślana. Zarządzanie tak cennym obiektem, jakim jest Puszcza Białowieża, wymaga dużej ostrożności i rozwagi w podejmowaniu decyzji dotyczących sposobów ochrony, które powinny uwzględniać zarówno aspekty związane z ochroną bierną, sprowadzającą się do ochrony procesów naturalnych, jak również działania ochronne w zakresie czynnej ochrony siedlisk i gatunków.