

Occurrence of *Ips typographus* (L.) after wind damage in the Kościeliska Valley of the Tatra National Park

Wojciech Grodzki^{1*} , Wojciech Gąsienica Froniek²

¹ Forest Research Institute, Department of Mountain Forestry, ul. Fredry 39, 30–605 Kraków, Poland;

² ul. Jana Pawła II 225A, 34–425 Biały Dunajec, Poland

Tel. +48 12 2528212, fax +48 12 2528202, e-mail: W.Grodzki@ibles.waw.pl

Abstract. At the end of 2013, Norway spruce stands in the area of the Tatra National Park were severely damaged by strong storms especially in the Kościeliska Valley region. In the following spring of 2014, a survey recording the occurrence of the spruce bark beetle *Ips typographus* (Coleoptera, Curculionidae, Scolytinae) was initiated in order to describe the dynamics of beetle reproduction in relation to protection measures executed in wind-damaged stands. Ten research plots with 20 trees each were established in a so-called active protection zone, where the broken and fallen trees had been processed and removed in 2014, and in a passive protection zone, where no actions were taken, and the dynamics of Norway spruce mortality due to bark beetle infestation including quantitative parameters (infestation density, sex ratio of beetle populations) were examined. The entomological analyses were performed on 25 × 25 cm large bark samples taken from four (active zone) or two (passive zone) tree sections.

In the first year of the survey, no infested standing trees were recorded on the plots and the colonisation of fallen and broken trees was very weak. In the second year (2015), infestations appeared in larger numbers on the plots with passive compared to active protection but the infestation density was 0.89 mating chambers per 1 dm² regardless of the protection status. In the third year (2016), most of the remaining living spruces had been infested with a mean density of 0.82 m.ch. per 1 dm². In 2015, the proportion of females in the beetle population was 65.8% being higher in the active (68.4%) than the passive (64.0%) protection zone, while in 2016 the proportion was 63.5% and in this case slightly higher in the passive protection zone (63.9% as compared to 63.2%).

These results are in accordance with patterns observed in wind-damaged Norway spruce stands of other areas in Poland and Europe and demonstrate the usefulness of forest management procedures in mitigating *I. typographus* outbreaks.

Keywords: bark beetles, Norway spruce, population dynamics, damage management

1. Introduction

Tree stands of the Tatra National Park (TNP) from many years have been repeatedly damaged due to windfall that has led to the development of cambiohagous insects, in particular bark beetle *Ips typographus* (L.) (Grodzki, Guzik 2009). So far, the conducted research in Tatra on these insects were mainly to determine the growth of its population and the mechanisms behind the start and development of outbreaks (Grodzki et al. 2003a, 2006a), as well as the role of these insects in the shaping of forest biocenosis (Ambroży 2000). The aim of national parks, that is different from managed forests, is to maintain the natural aspects in their entire complexity. Bark beetles and

other species that exist in it are immanent elements of the forest ecosystem (Karpiński 1935; Holeksa 1998; Grodzki 2002). In consequence to its activity, the changes within the structure of the tree stands and crop location can occur (spruce – rowan) in the conifer forest habitats but overall, it allows for higher rate of the biological diversity. Sixty percent of the TNP is under strict protection and any treatment such as silviculture, logging or forest protection is forbidden in order to preserve the natural processes. People who visit the park do not comprehend these functions. Rules governed in the park are usually seen as a sign of mismanagement and at the same time as a reason which favours excessive growth of the cambiohagous insects – especially bark beetles (Mączka 2012). Therefore, the foregoing

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research was mainly focused on identifying how the omission of forest protection treatments affects the development of bark beetle outbreaks (Grodzki et al. 2003a,b, 2006a; Grodzki 2007).

At the end of the 2013, in the western part of Tatra National Park (mostly in the Kościeliska Valley), a windfall affected spruce stands that were both in the active and passive protection zone. Accordingly to the rules regulated by the law, the fallen and broken trees in the area of the active protection zone were removed, whereas trees in the passive protection zone were left. This kind of situation created an opportunity to analyse the dynamics of the bark beetle population in the mountain environment encompassed by different protection regimes. So far, results obtained by the Polish and foreign researchers showed that since the second vegetation season after the wind damage, the bark beetle population density has been raising, which usually implies the beginning of its outbreak (Lindelöw, Schroeder 1998; Göthlin et al. 2000; Meier et al. 2003; Grodzki et al. 2007). Such a season took place in the year 2015.

The usefulness of protection treatments on the areas under nature protection is always a subject of controversies. Swiss and Scandinavian results showed that in the damaged, unmanaged stands, the number of trees infested by bark beetles was much (about two times) higher in the subsequent years than in those spruce stands that were subjected to forest protection activities (Forster 1998; Lindelöw, Schroeder 1999). The other publications, however, demonstrated that the omission of active protection procedures should not increase the threat to stands (Schlyter, Lundgren 1993; Weslien, Schroeder 1999), some tools for forest protection are not efficient in certain conditions (Grodzki et al. 2008), and the outbreak course in the stands encompassed by various protection statuses can be similar (Grodzki et al. 2006a). Although the no-intervention regime in the passive protection zones is unquestioned, in the stands damaged by abiotic factors and consequentially treated by cambiphagous insects in the areas encompassed by the active protection, the need of forest protection treatments is often questioned. Regardless of numerous investigations and experiments, this question has still not been solved.

2. Aim of research

The aim of the research was to determine the dynamics of bark beetle breeding in the western part of Tatra National Park, where the spruce trees have been damaged by the windfall and to evaluate the effect of protection regime (active or passive) on the pressure of cambiphagous insects on spruce tree stands.

3. Terrain and the methodology

Research was conducted in the area of Tatra National Park in the selected tree stands severely damaged by windfall in 2013;

these stands were located in the western part of the Park, in the area of Kościeliska Valley (Table 1). For the research purposes, a system of small plots was established in the exposed forest edges around the wind-damaged area. In order to ensure comparable results, the plots were located in both protection zones (active and passive) in equal number (i.e., 5), in similar forest edge exposure. In the active protection zone, the plots were located in the areas in which in 2014 all the broken and fallen trees had been removed. On the other hand, the plots in the area under passive protection were established in the stands where the broken and fallen trees have been left regardless of the formal zone status. A single plot consisted of a group of 20 numbered trees, which were examined during the growing season to determine the amount and period of time when the trees attacked (thoroughly successfully infested) by the spruce bark beetle appeared. Trees logged in the active protection zone within the active protection policy had been used to determine, by the standard and verified methodology, the density and structure of the bark beetle population, as the traits that can reflect its outbreak tendency (Lobinger 1996; Grodzki et al. 2006c, 2014).

For this purpose, entomological analyses have been conducted on the 25 × 25 cm large bark samples taken from four characteristic sections of the trunks of infested trees: 1. in the tree base, 2. in the midway between the tree and the crown base, 3. under the crown, 4. in the middle of the crown (Grodzki 2007). In the active protection zone, these sections have been assigned after tree felling, and then their diameter and height on the tree trunk was measured; whereas in the passive protection zone, bark samples from the first and second section have been collected on the standing trees. The following parameters characterizing the bark beetle population status and dynamics were registered:

Table 1. Basic characteristics of the experimental plots in the Kościeliska Valley

| Plot no | Protection | Forest comp. | Altitude m a.s.l. | Age of spruce ¹ |
|---------|------------|--------------|-------------------|----------------------------|
| 1 | passive | 274c | 980 | 109 |
| 2 | passive | 274f | 1130 | 125 |
| 3 | passive | 273n | 1050 | 100 |
| 4 | passive | 273m | 1130 | 124 |
| 5 | passive | 274k | 1200 | 109 |
| 6 | active | 270f | 1070 | 99 |
| 7 | active | 271c | 1120 | 125 |
| 8 | active | 273i | 1160 | 119 |
| 9 | active | 273m | 1040 | 124 |
| 10 | active | 236d | 994 | 104 |

¹ concerns analyzed trees

- The infestation density on the analysed trees (the number of gallery systems with one to four maternal galleries)
- Present development stages of the insect
- The sexual structure of the population infesting the studied trees; the number of mating chambers was used as the number of males, and the number of maternal galleries was used as the number of females.

The number of gallery systems of *Pityogenes chalcographus* (L.), the other species co-occurring with the spruce bark beetle, was estimated on the infested trees. The collected data was noted in the sheets that included the following parameters: presence and the condition of the needles, tree height (after felling) and age, the height of the crown base and its maximal diameter, visible reasons for the tree weakening (abiotic, biotic, anthropogenic or natural), if any were present.

The field investigations started in the late spring of 2014. The plots were chosen and established in the break of May and June 2015 and the field analyses were conducted throughout July till the middle of September of 2015 and 2016.

4. Results

4.1 Mortality of infested trees in the study plots

In the first year after wind damage (2014), when the removal of fallen and broken trees in the active protection zone took place, no standing trees infested by the bark beetles were recorded on the surrounding stand edges, and the infestation of the fallen and broken trees was very low.

In the growing season of 2015, overall 59 spruces infested by the bark beetles were identified in the 10 study plots, which is 29.5% of the initial number of trees. In the study plots in the passive protection zone, bark beetles infested 39 trees in 3 plots, while in the active protection zone 20 trees in single plot were infested, which is 39% and 20% of the initially marked trees, respectively. In 2016, the rest of the trees in the passive protection zone were infested and another 60% of the trees from the active protection zone was also infested (Fig. 1). Only on the one of the study plots (i.e., no. 10), no infestation was detected throughout the duration of the two years.

In the first half of the growing season in 2015 (period when the first generation of the bark beetle develops), the mortality of the infested trees was very low until 26 July, when 9 trees in two plots (no. 2 and 4) in the passive protection zone were identified as attacked (Fig. 2). Starting from the beginning of August, the amount of infested trees began to grow, which indicates the infestation by swarming beetles establishing the second generation.

In 2016, the first trees infested by the bark beetle were identified in the middle of June (13 and 17 June) and in the following days of the vegetation season (till 4 August), their number remained more or less stable (Fig. 2)

During the analyses on infestation, which were conducted at the end of July 2015, all the development stages of bark beetle (with an emphasis on the beetles) were found in the galleries. At the end of August, all the development stages were still present, with remarkable share of pupae and young (yellow) beetles; while in September, the presence of larvae, pupae and single young beetles was recorded. On the other hand, in 2016, when the analyses were conducted at the beginning of August, larvae were present in the lower sections of trees, while in the higher ones (middle of the tree trunk, under the crown) – pupae as well as young beetles were found.

4.2 Selected traits of the *I. typographus* population inhabiting dead trees

The infestation analyses on 5 spruce trees were conducted during the vegetation season of 2015 in the active protection

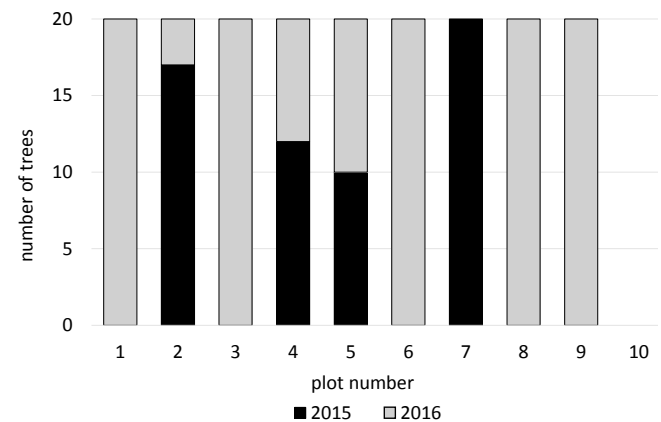


Figure 1. Number of infested trees registered on 10 experimental plots in the passive and active protection area during the growing season 2015 and 2016

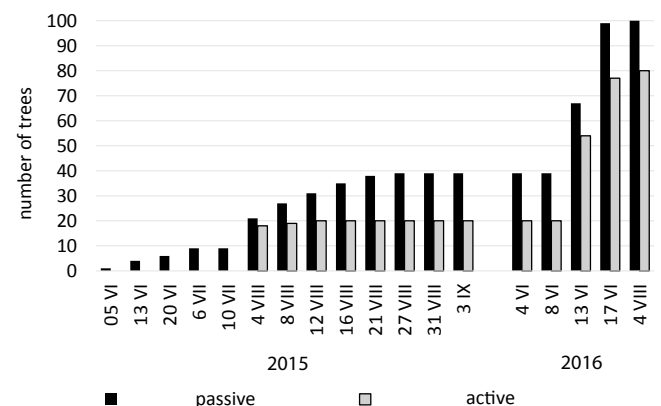


Figure 2. Number of infested trees registered on experimental plots in passive and active protection area in successive survey dates

zone (4 sections on the felled trees – 20 sections overall) and on 15 spruce trees in the passive protection zone (2 sections on standing trees – 30 sections overall). The average (\pm standard deviation) number of bark beetle gallery systems (treated as a number of mating chambers for 1 dm²) from all the examined tree trunk sections was estimated to be 0.86 (\pm 0.31) and reached the same value in both protection zones (\pm 0.29 and 0.33 respectively). On the trees felled in the active protection zone that were analysed in the four sections, the highest infestation density was found in the first section (1.02 ± 0.43) and steadily decreased in the higher parts till the value dropped to 0.61 ± 0.12 in section no. IV (Fig. 3). On the other hand, on trees in the passive protection zone, the infestation density in sections I and II was similar, but lower in the passive protection zone (0.86 ± 0.33) than in the analogical sections in the active protection zone (0.98 ± 0.32), without any statistically significant differences (Fig. 3). In the vegetation season of 2016 in the active protection zone, 15 spruce trees were examined (4 sections on the felled trees – overall 60 sections) and 21 spruces in the passive protection zone (2 sections on the standing trees – overall 42 sections). The average infestation density from all the examined sections was 0.85 (\pm 0.37) and was higher in the active protection zone (0.89 ± 0.34) than in the passive protection zone (0.78 ± 0.40). On the trees felled in the active protection zone that were analysed in the four sections, the infestation density was highest in section II (1.05 ± 0.17) and steadily decreased in the higher sections up to the value of 0.84 ± 0.12 in the section IV, although the lowest value was found in the section I (0.72 ± 0.40) (Fig. 3). On the other hand, in the passive protection zone, the density of feeding grounds in sections I and II was similar but slightly lower (0.60 ± 0.41 and 0.96 ± 0.31 , respectively) than in the analogical sections examined in the active protection zone. However, the average values for sections I and II in active and passive protection zones (0.88 ± 0.34 and 0.78 ± 0.40 , respectively) did not point out any statistically significant differences. (Fig. 3).

The average density of spruce bark beetle gallery systems in sections I and II was higher in 2015 (0.89 ± 0.33 vs. 0.82 ± 0.38 in 2016) with no statistical difference between those years. Instead, the average infestation density in sections I and II calculated from two years of observations altogether was higher in the active protection zone (0.91 ± 0.34) than in the passive protection zone (0.81 ± 0.37) without statistically significant differences.

In the sample of 516 *I. typographus* gallery systems analysed in 2015, those with two maternal galleries were dominating (57.0%), those with one (22.5%) and three (19.8%) maternal galleries were abundant, while those with four galleries were found rarely and only on the trees in the active protection zone (Fig. 4). The average share of females in the population, based on the analyses from 20 trees, reached 65.8% (\pm 0.05). It was higher in the active protection zone (68.4 ± 0.03) than in the passive protection zone (64.0 ± 0.05) (Fig. 5). Looking at the sections I and II exclusively, there are differences between the zones (65.8 ± 0.04 and 63.6 ± 0.04 , respectively), which indicate slightly higher share of females in the active protection zone, with statistically significant differences [ANOVA $F(1, 72) = 4.03$; $p < 0.05$].

In the sample of 1067 gallery systems of *I. typographus* analysed in 2016, those with two maternal galleries prevailed (64.5%), those with one maternal gallery were abundant (30.3%), but the systems with three and four maternal galleries were very rare (5.2% and 0.1%, respectively) (Fig. 4). The average share of females based on the results from 36 trees reached 63.5% (\pm 0.04) and was higher in the passive protection zone (63.9 ± 0.03) than in the active protection zone (63.2 ± 0.04) (Fig. 5). Taking under consideration sections I and II exclusively, there are still differences between the two zones (64.2 ± 0.04 and 64.0 ± 0.04 , respectively), which indicates slightly higher share of females in the passive protection zone, but the differences are not statistically significant.

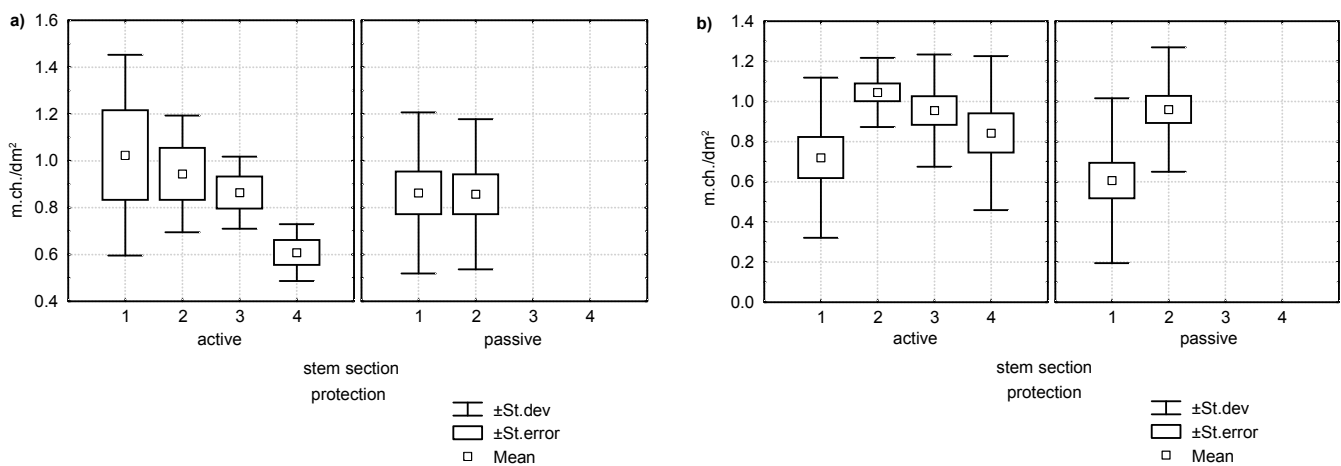


Figure 3. Density of *I. typographus* gallery systems in the sections of spruce stems analyzed on the plots in active (4 sections) and passive (2 sections) protection area in Kościeliska Valley in: a – 2015, b – 2016

4.3 Antagonistic and accompanying species

In 2015, the only bark beetle species accompanying the spruce bark beetle in the few examined tree trunk sections was *Pityogenes chalcographus*; the galleries of *P. chalcographus* were located in the upper parts of trunks (sections II–IV) on 2 infested trees in the active protection zone (plot no. 2) and on 1 tree (section II) in the passive protection zone (plot no. 7) with the density of 0.08–1.12 per dm². In 2016, the number of *P. chalcographus* increased as its galleries were found in 24.5% of all of the examined tree sections, mostly in the sections II and IV in which it was present with frequency 44% and 33%, respectively. The average infestation density in *P. chalcographus* evaluated basing on the infested sections was 0.25 per dm².

In 2015, the presence of *Coeloides bostrychorum* Gir. (Hym.: Braconidae) on the 2 spruces in the active protection zone was

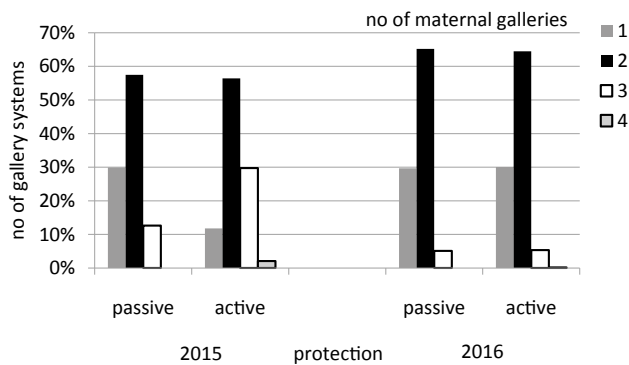


Figure 4. Number of *I. typographus* gallery systems with 1–4 maternal galleries found in the analyzed sections of spruce stems in the Kościeliska Valley in 2015 and 2016

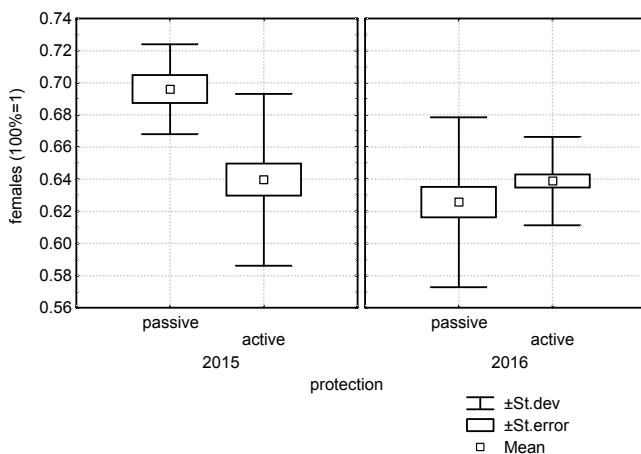


Figure 5. Percentage of females in *I. typographus* gallery systems in analysed sections of spruce stems in active and passive protection area in the Kościeliska Valley in 2015 and 2016

found in *I. typographus* galleries, estimated based on the number of cocoons, on 3–5%. In 2016, no signs of parasitism were noted.

5. Discussion

In the growing season of 2015, on three out of five research plots established in passively protected stands, over twice more trees were infested than on one out of five research plots established in the active protection zone. The infestation came late, in the second half of the growing season. It was a result of unfavourable weather in spring and in the first half of summer, which inhibited swarming and development of insects establishing their first generation. However, in the second hot and dry half of the growing season, the trees were attacked by a new generation of bark beetles that developed on still available breeding material offered by the broken and fallen trees left in the passive protection zone areas. In 2016, the rest of the trees were infested in all five plots in the passive protection zone and on four out of five in the active protection zone. No infestation of trees on one of the plots might have resulted from its location on the slope which exposure was different than the others, and not because of the protection status of the zone. The increased tree mortality in 2015 in the conditions of the passive protection zone fits in the patterns described from the eastern part of the Tatra National Park after the windfall of 2002 (Grodzki et al. 2006b). It is known that the trees broken and fallen by wind in the Tatra Mountains in the past were, in most of the cases, the key factor for eruption of the bark beetle outbreaks (Grodzki, Guzik 2009; Mezei et al. 2014). In the second season after the windfall, on the standing trees in the passive protection zone a fast reproduction of the bark beetles took place, which led to the infestation of the nearby spruce trees by bark beetles in the following year, regardless the protection regime applied.

Infestation density by the bark beetle, evaluated on the attacked trees (0.86 m.ch./dm²) was not markedly high. Nonetheless, it was higher than the density noted in the Western Sudetes in the bark beetle retrogradation phase in the years 1988–1994 (Grodzki 1997) or in case of retrogradation in the spruce stands of Beskid Śląski in 2002 (Grodzki 2004). It was closer to the level noted in the Tatra Mountains in years 2000–2001, also in the phase of retrogradation (Grodzki et al. 2002). This can indicate a low resistance of the spruces weakened by the drought from 2015 on the bark beetle attack, as the number of beetles required to overcome the defensive reaction of such trees is much smaller than in the case of fully vital trees (Christiansen et al. 1987). Although, Christiansen and Bakke (1997) have not found the close impact of drought on the vulnerability of spruce trees to beetle infestation; but they found the effect of high temperatures stimulating the bark beetle reproduction. The phenomenon of increase of the bark beetle infestation density on the spruce trees damaged by wind in 2002 and 2004 was also described during progradation phase in years 2004 and 2006 in the Tatra Mts. (Grodzki

et al. 2007). The following pattern repeated in the surroundings of the Kościeliska Valley in the year 2016, when the numbers of beetles attacking more vital trees had to be higher, as reflected by the increased infestation density.

The sex structure in the bark beetle population changes depending on the stage of an outbreak. In the populations developing under the bark in endemic phase, the share of females was estimated to be around fifty percent and rose in progradation phase to about 72 percent (Lobinger 1996). The sex ratio in the bark beetle populations that infested spruces in Tatra, Gorce and Beskid Żywiecki during progradation and culmination was estimated to be around 64 to 69% of females (Grodzki et al. 2006c, 2007, 2014). Similarly, the high share of females observed in the Kościeliska Valley in years 2015 and 2016, indicates the bark beetles' tendency to outbreak that could develop in the next years. The high outbreak potential can be seen in very low frequency of parasitoids as well as the other bark beetle species (Grodzki 1997).

The presence of pupae and few young beetles in September indicates that significant part of bark beetle population is capable to overwinter underneath the bark, partially in the stage of adult beetles that will be ready for swarming at the beginning of the next spring (Onyśko, Starzyk 2011).

The results of investigations from the growing seasons of 2014–2016 indicate a very high probability for further dramatic development of the bark beetle outbreak, according to the patterns known from other areas (Forster 1998; Göthlin et al. 2000; Grodzki, Guzik 2009). It would be useful to continue field research in the Kościeliska Valley in the upcoming years, as per the methodology used until now, to verify the predictions based on the results from second growing season after the windfall occurred. In the active protection zone, it is also advisable to initialize the activities that would mitigate the bark beetle reproduction, adjusted to the existing local possibilities and conditions.

6. Conclusions

1. Observations conducted within three subsequent seasons after the windfall indicate that in the Kościeliska Valley, the bark beetle outbreak develops in a typical pattern known from other areas in Poland and Europe.

2. The bark beetle reproduction has higher dynamics in the stands under passive protection. This indicates the effectiveness of the protective measures in reducing the mortality level of infested spruces, which is the aim of the sanitary cuttings conducted in the active protection zones.

3. The sex structure of the bark beetle populations indicates its significant outbreak potential and high risk of its further reproduction in the tree stands surrounding the Kościeliska Valley.

4. Further observation of the bark beetle outbreak on the Tatra National Park areas with different protection status

will allow for better planning of protective procedures in the stands that survived the windfall.

Conflict of interests

Authors declare no potential conflicts.

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Authors’ contribution

W.G. – Concept and methodology of research, data treatment and manuscript preparation; W.G.F. – Fieldwork: selection and marking of the research plots, tree mortality survey, bark sampling and entomological analyses.