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ORIGINAL PAPER

Forest ecosystem disturbance affects tree dieback from *Ips* engraver beetles, evidence from UAV multispectral mapping

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ABSTRACT

Engraver beetles *Ips* spp. (Coleoptera: Curculionidae: Scolytinae) are one of the main factors causing tree dieback in European forests. During the last 50 years, *Ips* beetles killed more than 150 million m^3 of forest in Europe, affecting ecosystems on a large scale and causing significant economic losses. In this paper, we investigated the relationship between the habitat disturbance of pine tree stands and the effects of pine engraver beetles infestation resulting in tree crown dieback. We utilized a UAV equipped with a SENOP multispectral camera, which captured images at a resolution of 10 cm, to accurately ascertain the extent of pest infestation. We mapped the tree stands in the Miradz Forest District (Poland) planted on sites formerly drained by the Konin lignite mines. We examined the undergrowth vegetation in varying habitat conditions to assess the habitat degradation level. In transects 50 meters wide we identified clusters of trees infested by the engraver beetles. We found the fertile oak-hornbeam forests to be most sensitive to the infestation of *Ips* engraver beetles. The probability of expansion in those habitats is 2-3 times higher than in a nutrient-poor pine forest. Susceptibility to the expansion of the *Ips* beetles increases with the disturbance level of the undergrowth and the presence of non-forest plant species, mainly from the *Epilobietea* class, followed by the disappearance of species associated with preserved habitat continuity – ancient forest species. UAV monitoring and vegetation data indicating habitat degradation level can be helpful tools for successful monitoring and prevention of infestations by *Ips* beetles.

KEY WORDS

biodiversity, forest degradation, insect pest monitoring, *Ips* outbreak, unmanned aerial vehicles

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Introduction

Ips (De Geer) engraver beetles (Coleoptera: Curculionidae: Scolytinae) are one of the main factors causing tree dieback in European forests. During the last 50 years, engraver beetles killed more than 150 million m^3 of forest in Europe (Huo *et al.*, 2021), affecting ecosystems on a large scale and causing significant economic losses. Their expansion has constantly increased over the last decades (Økland *et al.*, 2019; Stereńczak *et al.*, 2020). Therefore, identifying the potential feeding sites of *Ips* engraver beetles is essential to prevent losses in forestry. The more so that *Ips* beetles can spread quickly over large areas (Wichmann and Ravn, 2001; Holuša *et al.*, 2010). Trees are often attacked in small clumps, usually 1-12 trees (Siitonen, 2014), and across large areas (Wermelinger, 200), creating a spatial mosaic in which the expansion foci are challenging to spot at an early stage of *Ips* beetle infestation. Remote sensing techniques with high spatial and spectral resolution have become an effective monitoring tool which allows the differentiation of canopy-infected areas. These are often data in the form of colour infrared aerial photography (Lausch *et al.*, 2011). However, they are not very precise, and the most appropriate technique is still being searched for, allowing precise canopy damage identification in the early stages of expansion (Iracka, 1987; Stereńczak *et al.*, 2020). Therefore, there is a need to identify the factors that allow better forecasting of the outbreak phenomenon (Stereńczak *et al.*, 2020). The appearance of the *Ips* engraver beetle in the previous year is the main trigger of the outbreak (Jurc and Bojović, 2004).

On the other hand, the probability of expansion is a function of the distance of the old deadwood from the sites of infestation from the previous year (Lausch *et al.*, 2011; Stereńczak *et al.*, 2020). The weakening of the condition of the stand is a factor increasing the susceptibility to outbreaks of *Ips* beetles (Grodzki, 2013). Most studies have identified the habitat factors favouring the infestation of the beetles (Stereńczak *et al.*, 2020; Kamińska *et al.*, 2021). For example, drought is a factor that significantly contributes to the increased risk of tree stand infestation by beetles (Siitonen, 2014). Pest outbreaks are also more likely to occur due to climate change (MacDougall *et al.*, 2013; Steffen *et al.*, 2015). For effective pest management rapid and cost-effective monitoring methods are necessary. Remote sensing techniques have become more frequently used to assess the extent of *Ips* engraver beetles outbreak in an effective and profitable way (Pyšek and Richardson, 2010). Even more, unmanned aerial vehicles (UAVs), allow to achieve high resolution and identification of early stages of outbreaks. Combining UAVs, equipped with multispectral sensors and response time can be minimized with minimal costs of monitoring (Duarte *et al.*, 2022). UAV systems provide images of high spatial resolution and can obtain updated and timely data with different sensors (Guimarães *et al.*, 2020; Poley and McDermid, 2020).

In this study, we aim to identify factors related to habitat degradation with UAV and vegetation mapping to assess tree stand susceptibility to *Ips* engraver beetle infestation.

Methods

Study area. We conducted the research in central Poland in the Miradz Forest District. The area remains under a strong influence of a cone of depression due to the close vicinity of the Konin S.A. lignite mines (Krotoska *et al.*, 1985; Krotoska, 1991; Przybyłek, 2018), which results in water scarcity. The study sites consisted of forested plots in Miradz Forest District. The research area consisted of pine forest stands with trees aged 32-102 years old and used for forestry. We selected study plots in varying habitat types, ranging from nutrient-poor pine forests to degraded oak-hornbeam habitats, representing different substrates subjected to the long-term effect of decreasing groundwater levels (Fig. 1).

The Miradz Forest District has been monitoring the occurrence of the engraver beetle in the study area for many years, systematically examining the sanitary condition of pine stands and monitoring the abundance of *Ips* engraver beetles. Together with foresters, we selected tree stands with *Ips* beetle occurrence recorded for several years as leading to the decline of pine stands. Pine tree stands were attacked mainly by *I. acuminatus* (Gyll.), but other species also occurred, such as *I. sexdentatus* (Boern.) (rarely) and *I. typographus* (L). (rarely), which took advantage of the deteriorating condition of the trees. Therefore, it was ideal for studying forest habitats exposed to *Ips* attacks in drought conditions.

Application of UAV for tree canopy dieback mapping. In May and August 2022 we performed a detailed tree canopy inventory with UAV equipped with a multispectral camera – SENOP. SENOP camera can be programed to measure reflectance in range from 400 nm to 1000 nm. In this study reflectance was measured in 19 bands (central wavelengths: 510 nm, 535 nm, 545 nm, 560 nm, 575 nm, 585 nm ,605 nm, 645 nm, 665 nm, 685 nm, 705 nm, 715 nm, 740 nm, 785 nm, 805 nm, 815 nm, 835 nm, 845 nm and 865 nm with 10 nm resolution). Based on data from the SENOP camera (10 cm resolution), RGB camera and field observations, we identified trees entirely infested by the *Ips* engraver beetle (Fig. 1). Firstly we identified the areas, based on previous monitoring data to be infested by *Ips* engraver beetle outbreaks. Secondly we used data on habitat properties retrieved from Forest Data Bank (BDL, 2022) to create 5 transects representing changes in properties from 2 adjacent habitat types (Fig. 2). The habitat types occurring in the investigated area along the established transects were:

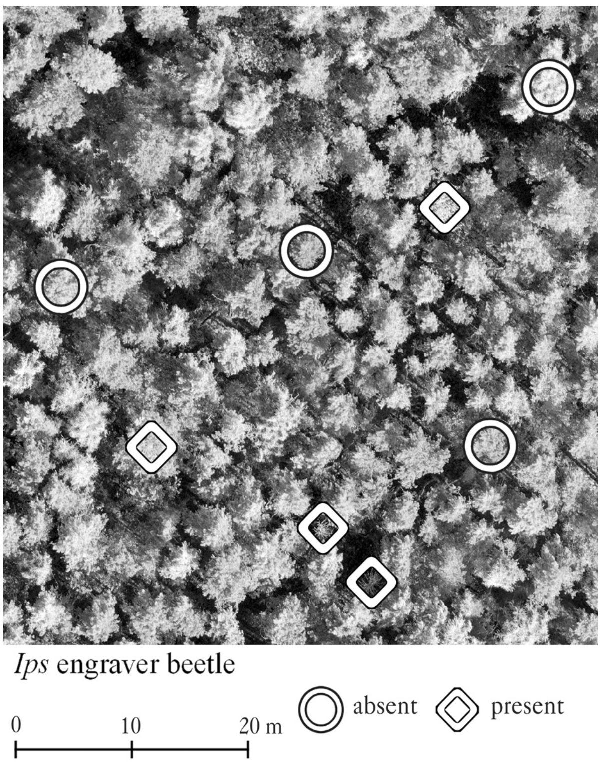

Fig. 1.
Pines infested by *Ips* beetle identified based on RGB composition from multispectral camera

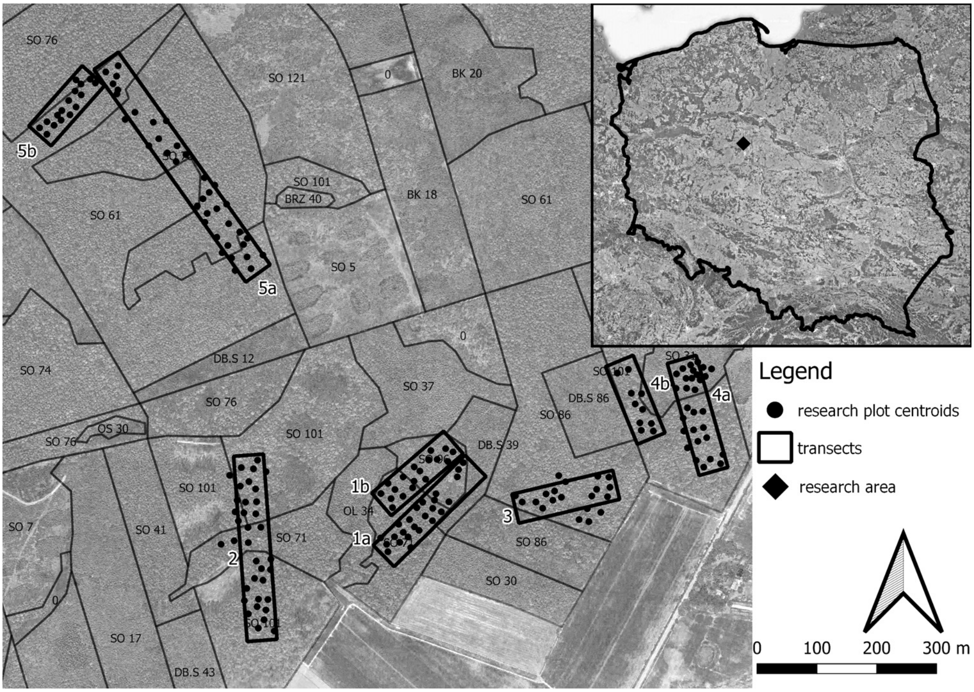

Fig. 2.
Map of the transects and study plots placement presented on an age of tree stands

- 1a and 1b (compartment 96) – vegetation of degraded *Leucobryo-Pinetum* forests (BMśw) changing into degraded mixed forests of *Querco roboris-Pinetum* (LMśw) (Fig. 3),
- 2 (compartment 96) – vegetation of degraded mixed forests with *Querco robori-Pinetum* (LMśw) turning into degraded oak-hornbeam forests with *Galio-Carpinetum* ferns (Lśw),
- 3 (compartment 95) – vegetation of degraded typical oak-hornbeam forests *Galio-Carpinetum* (Lśw) changing into wetter forms (Lśw),
- 4a (compartment 95) – vegetation of degraded mixed forests *Querco robori-Pinetum* (LMśw) changing into degraded *Galio-Carpinetum* (Lśw) oak-hornbeam forests,
- 4b (compartment 95) – vegetation of degraded *Galio-Carpinetum* (Lśw) oak-hornbeam forests,
- 5a and 5b (compartment 80) – vegetation of degraded typical oak-hornbeam forests *Galio-Carpinetum* (Lśw) changing into wetter forms (Lśw).

In a 25 m buffer from the transects, we identified visible tree dieback, where trees showed a typical discolouration in approx. 80-100% of the foliage area (Stereńczak *et al.*, 2020). In each of the transect, we randomly created plots for further analyses with the application of UAV. However if vegetation were homogenous in wider area, or there were local disturbances in vegetation structure, then the plots could be established outside the transect. We established 192 plots that represented the existing situation related to engraver beetle-infested and non-infested sites. We marked the plot location with GNSS receiver with a measurement accuracy of 0.2 m (Spectra Precision GPS Mobile Mapper 120; Spectra Geospatial, Westminster, CA, USA) to be further used as reference points.

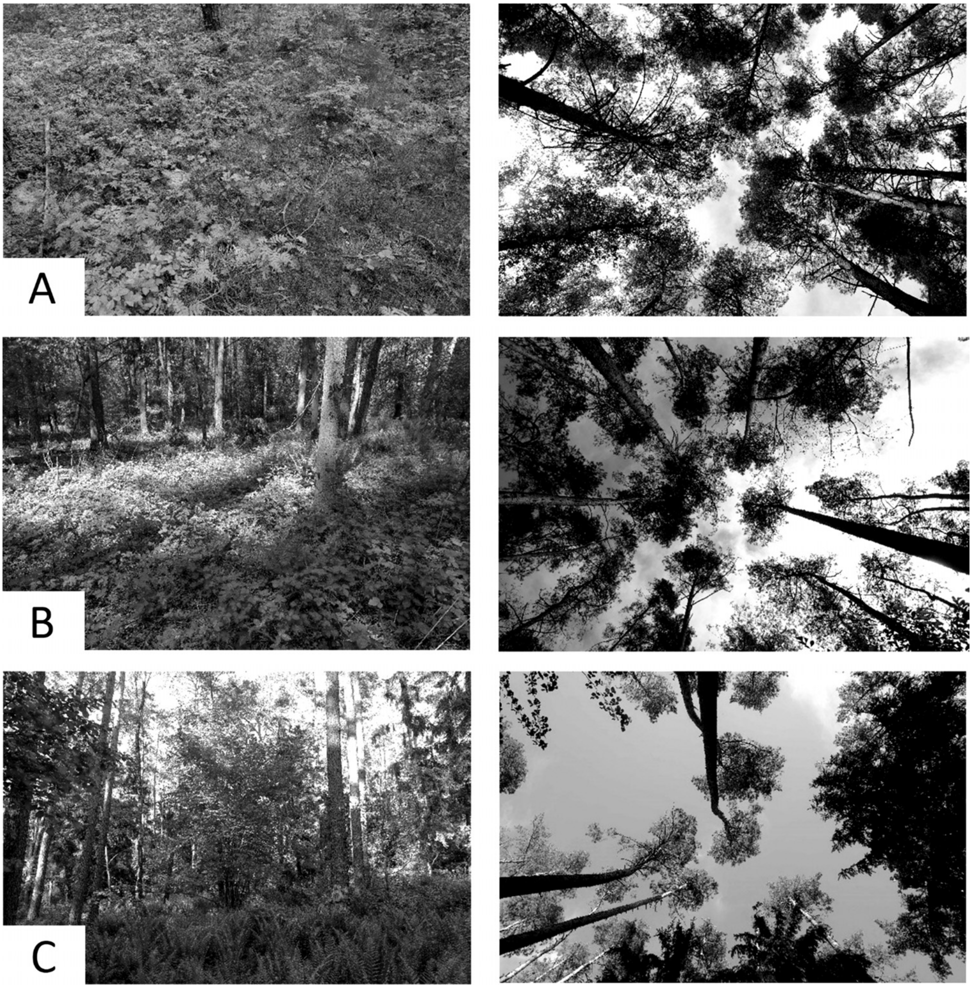

Fig. 3.

Pictures of undergrowth and canopy in the transect no. 1 of pine forest vegetation with typical species, relatively well-developed tree stand (A). Vegetation of mixed forests with undergrowth typical for the community, but with blackberry dominance, tree stand with less developed tree crowns (B). Vegetation of degraded oak-hornbeam forest, usually with the domination of broad buckler-fern, tree stand with the least developed tree crowns (C)

At the turn of May and June 2022, we conducted a series of botanical and habitat studies in research plots. In each of them, we identified all species of vascular plants in the undergrowth along with their percentage cover following the commonly accepted phytosociological methodology (Wysocki and Sikorski, 2014), using plant communities adopted after Matuszkiewicz (2017) and the species names after Mirek *et al.* (2002). In addition, we performed foliage measurements using a LiCOR LAI meter to assess the degree of leaf loss in the analyses.

DATA ANALYSIS. Based on the multispectral data analysis, we identified all trees in the study area with damage in 80-100% of their foliage. Then we calculated the average number of damaged trees in the buffer 10, 50, 100 and 200 m from all plots in each of the habitat.

For the analysis of the floristic diversity of ecosystems and their habitat indicators:

Taxa number – number of vascular plant species in the research plot,
Shannon index – Shannon-Wiener biodiversity index based on Magurran (2004),
Index ancient forest species – number of ancient forest species based on Dzwonko and Loster (2001),
LAI – leaf area index measured with LiCOR LAI-meter,
Ellenberg (L) – light index based on Ellenberg *et al.* (1992),
Ellenberg (T) – thermal index based on Ellenberg *et al.* (1992),
Ellenberg (F) – humidity index based on Ellenberg *et al.* (1992),
Ellenberg (R) – pH index based on Ellenberg *et al.* (1992),
Ellenberg (N) – nitrogen content index based on Ellenberg *et al.* (1992).

In addition, we calculated the indicators of the share of species from individual ecological groups related to specific types of degradation:

Epilobietea species [%] – percentage of *Epilobietea* species associated with forest clearings,
Artemisietea species [%] – percentage of species from the *Artemisietea* and *Stellarietea* class associated with the ruderalization of forest habitats,
Molinio-Arrhenatheretea species [%] – percentage of species from the *Molinio-Arrhenatheretea* class associated with open spaces,
Querco-Fagetea species [%] – percentage of *Querco-Fagetea* and *Vaccinio-Piceetea* species associated with typical forest areas.

Ecological groups were calculated based on phytosociological indicators adopted after Matuszkiewicz (2017).

Due to the fact that data is not normally distributed, we used non-parametric tests. We analyzed the influence of habitat type on the amount of trees infested by *Ips* engraver beetles in buffers through pairwise comparisons using the Wilcoxon rank sum test with continuity correction. We performed Spearman rank order correlations, to analyze the impact of habitat condition on the occurrence of *Ips* engraver beetles in buffers. All analyses were performed in R 3.4.4.

Results

Identification of damaged trees and influence of habitat type. Based on multispectral data analysis, pine trees with 80-100% crown damage were identified. The number of trees damaged in the 10, 50, 100 and 200 m buffer was 0.2, 2.2, 5.1 and 12.1 trees, respectively. Calculated per 100 m^2 of forest, it was 0.26, 0.11, 0.06, 0.03. Thus, the damage concerns individual trees, and the larger the buffer, the smaller the area of damage. The influence of the habitat type on the amount of damage is unequivocal and the probability of infestation is 2-3 times higher in the case of the most fertile *Pinus-Dryopteris* in the habitat of the *Galio-Carpinetum* (Lśw) oak-hornbeam forest. On the other hand, in the case of mixed forests – *Pinus-Rubus* in the habitat of *Querco roboris-Pinetum* (LMśw) and *Leucobryo-Pinetum* (BMśw) pine forest, no significant statistical differences were found for buffers 10, 100 and 200 meters (Table 1)

The impact of the habitat condition on the occurrence of the *Ips* beetles. The list of all habitat and vegetation quality indicators allows to identify factors most influencing the susceptibility of tree stands to engraver beetles. It is best explained by share of group of species not necessarily directly related to the habitat quality but resulting from disturbances in the stand. These are Ellenberg light indicators, which determine the level of light, coinciding with the LAI measurement, and the percentage of species from the *Epilobietea* class and *Molinio-Arrhenatheretea* class (Table 2). The researched factor explains the period vegetation – *Rubus idaeus* L., *R. fruticosus* L. *Calamagrostis epigejos* (L.) Roth, *Fragaria vesca* L. Its share explains up to 65% (Table 2) of the relationship with the number of infested trees.

The plant indices directly indicating the humidity in the form of Ellenberg numbers related to humidity (F), which was to be expected the most, poorly explain the probability of the appearance of the *Ips* beetles (28%, Table 2).

The pine stand growing in habitats characterized by high species diversity of vascular plants turned out to be slightly more resistant to the attack by the *Ips* beetles. This is indicated by significant but low negative correlations between the number of vascular plant species and the number of damaged trees in buffer (–0.24 for buffer 50 m and –0.26 for buffer 100 m, Table 2). The habitat continuity explained the presence of the *Ips* beetles. The higher the number of ancient forest species, the lower the share of trees with engraver beetles. The correlation was up to –0.49 (Table 2) for buffer 100 m.

When looking at the detailed breakdown of the factors most influencing the success of the beetles, its infestation tendencies can be noticed. The share of *Epilobietea* species at the level of over 40% is almost always accompanied by trees inhabited by the *Ips* beetles (Fig. 4). On the

Table 1.

Effect of the habitat type and buffer size on the average number of trees damaged by the engraver beetles, a, b, c – homogeneous groups (in columns) according to pairwise comparisons using Wilcoxon rank sum test, $p<0.05$

Habitat type	Buffer 10 m	Buffer 50 m	Buffer 100 m	Buffer 200 m
Degraded oak-hornbeam forest *Galio-Carpinetum* (Lśw) n=73	0.38b	3.89c	9.15b	19.2b
Degraded mixed forest *Querco roboris-Pinetum* (LMśw) n=77	0.08a	1.40b	2.92a	7.77a
Pine forest *Leucobryo-Pinetum* (BMśw) n=42	0.12a	0.79a	2.14a	8.14a

Table 2.

Correlation matrix of biodiversity and ecological indicators with the number of trees infested by the engraver beetles in various buffers, $p>0.05$, bold numbers are statistically significant

Biodiversity and ecological indicators	Buffer 10 m	Buffer 50 m	Buffer 100 m	Buffer 200 m
Taxa number	–0.118	**–0.243**	**–0.257**	–0.058
Shannon index	–0.028	–0.039	–0.123	**–0.160**
Index ancient forest species	**–0.243**	**–0.454**	**–0.488**	**–0.242**
LAI	**0.317**	**0.514**	**0.568**	**0.319**
Ellenberg (L)	**0.173**	**0.352**	**0.205**	0.085
Ellenberg (T)	–0.121	**–0.311**	**–0.175**	–0.134
Ellenberg (F)	–0.098	**–0.276**	**–0.240**	**–0.251**
Ellenberg (R)	–0.048	0.052	**0.156**	–0.001
Ellenberg (N)	–0.029	0.089	**0.171**	–0.014
Epilobietea species [%]	**0.245**	**0.646**	**0.564**	**0.462**
Artemisietea species [%]	–0.001	0.084	0.120	0.012
Molinio-Arrhenatheretea species [%]	0.121	**0.281**	**0.237**	**0.200**
Querco-Fagetea species [%]	0.097	–0.078	–0.020	0.138

other hand, a large share of ancient forest species in the undergrowth with a cover of over 60% is not synonymous with the absence of trees with *Ips* beetles. However, there was no high coverage of these species in the undergrowth and, at the same time, a large number of damaged trees in the 100 m buffer (Fig. 5).

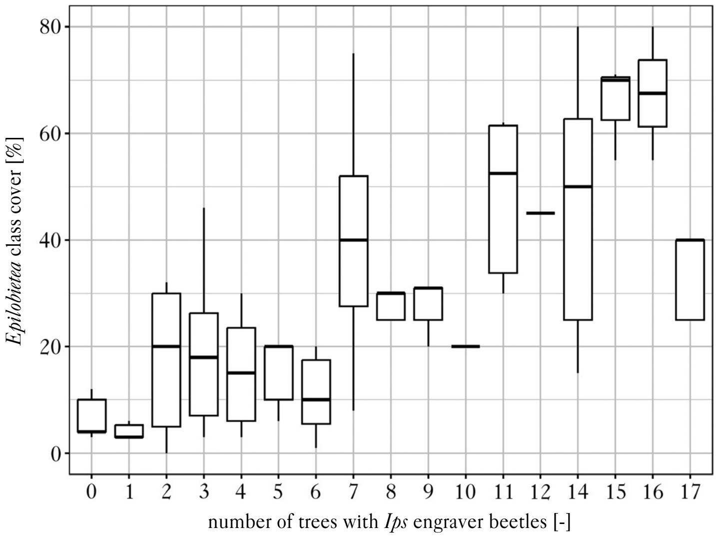

Fig. 4.
Relationship between the share of *Epilobietea* class species and the number of trees with engraver beetles in the 100 m buffer (boxes present the median, the lower and upper hinges correspond to the first and third quartiles, respectively, the upper and lower whiskers are the 1.5-interquartile range)

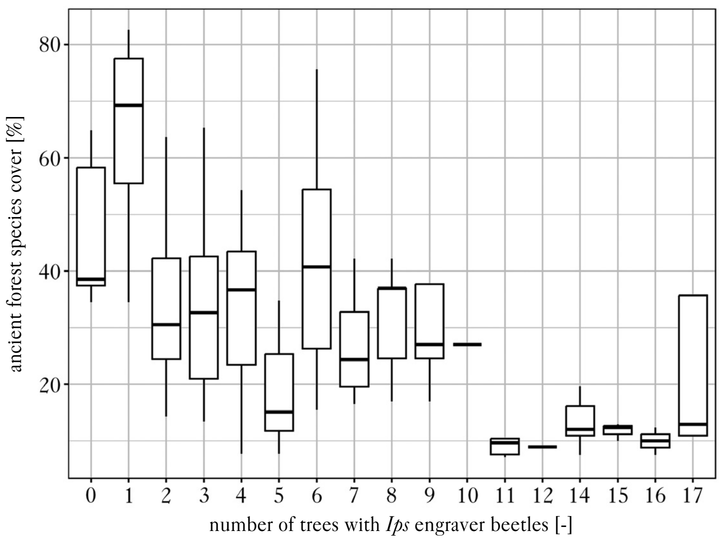

Fig. 5.
Relationship between the share of ancient forest species and the number of trees with engraver bee beetle in the 100 m buffer (boxes present the median, the lower and upper hinges correspond to the first and third quartiles, respectively, the upper and lower whiskers are the 1.5-interquartile range)

Discussion

The effects of mining activities related to large-area drainage significantly affect forest vegetation (Sawicki, 2010; Macdonald *et al.*, 2015; Polak *et al.*, 2015). Forests located in the vicinity of mining excavations react to dehydration only after several years (Kurowski, 1989). Such changes were observed in the Konin mines area 40 years ago (Krotoska *et al.*, 1985; Krotoska, 1991). Research conducted in forests subject to dehydration indicates analogous directions of degradation as in the case of the plots studied by us. Our research shows that the habitat type, in conditions of prolonged drought, is conducive to the occurrence and expansion of the *Ips* beetles. *Galio--Carpinetum* habitats are the most susceptible (Table 1).

Prediction models for the occurrence of the *Ips* beetles (Stereńczak *et al.*, 2020) take into account the structure of the forest stand, and habitat properties but omit the use of data on undergrowth vegetation. Forests, especially in national parks, own broad data on naturalness and their plant communities, allowing the authorities to manage these areas and to forecast the expansion of the *Ips* beetles. Our research shows that the concept of forest degradation by Olaczek (1972) and the phase referred to as fruticetization, *i.e.*, the large expansion of the shrub layer, may be one of the best predictors of tree stand susceptibility to *Ips* beetles' infestation, at least for *I. acuminatus*. It may also be useful to find out the cover of ancient forest species (Dzwonko and Loster, 2001).

There is quite a lot of agreement on the issue of drought. Hot and dry summers increase the susceptibility of pines to infestation by these insects (Siitonen, 2014). High temperature recorded in the previous year increases tree mortality, as does more prolonged sun exposure (Trubin *et al.*, 2022). Considering climate change and changes in rainfall and temperature regimes worldwide, an in-depth research is needed to measure the damage and identify all factors causing *Ips* beetles' infestations in forests (McNichol *et al.*, 2022). According to Lexer (1997), one of the main factors is precisely the change in water access. Lasota (2016) mentioned, that the range of *I. acuminatus* basically coincides with the extreme drought area in the northern and central part of the Regional Directorate of State Forests in Lublin.

Several studies indicate that tree crown density and stand age are also predictors of engraver beetle expansion (Stereńczak *et al.*, 2020). The *Ips* engraver beetles significantly attack mature stands (Siitonen, 2014). The relationship between sunny stands, characterized by open spaces, and the expansion of the *Ips* beetles is not entirely clear (Siitonen, 2014). There are even detailed studies of lighting under the canopy of trees, which indicate that trunks exposed to light for longer periods were less exposed to the *Ips* beetles (Hayes *et al.*, 2008). It is also noted that a sudden increase in insolation is here more favored by the beetles (Turčáni and Čapek, 2000). For *I. acuminatus*, however, very attractive seem to be biogroups of old trees which are not directly connected to forest edges. This sudden exposure leads to changes in thermic conditions because of increased light supply (Plewa and Mokrzycki, 2017).

The naturalness of areas covered with pine stands, subjected to long-term drought, has not been associated so far with the susceptibility of trees to the infestation of the *Ips* beetles. There have been attempts to link habitat type with susceptibility to the infestation of the engraver beetles (Holuša, 2004), but in conditions of drought and climate change this factor may play an important role. Our research shows that in forests subjected to long-term drought, the relationship between the share of ancient forest species and the *Ips* beetles is statistically significant. This relationship requires further research and possible inclusion in engraver beetle prediction models.

Conclusion

- Different types of degraded habitats are differently susceptible to the engraver beetles. *Galio-Carpinetum* habitats are significantly more vulnerable than nutrient-poor pine tree stands.
- The consequence of pine defoliation is a slight decrease in plant species richness and a strong expansion of species from the *Epilobietea* class, referred to as fruticetization.
- A higher abundance of ancient forest species in the undergrowth is negatively correlated with the infestation of *Ips* beetle.
- With more and more frequent droughts and greater vulnerability of forests to the *Ips* beetle, protection of natural old forest fragments should be common practice.

Authors' contributions

P.S. – conceptualization, methodology, material collection, statistical analyses, investigation, writing – original draft preparations; P.A. – material collection, formal analysis, investigation, manuscript review and editing; W.C. – formal analysis, investigation; M.K. – material collection, formal analysis, investigation; A.K. – formal analysis, investigation; A.S. – conceptualization, methodology, material collection, manuscript review and editing.

Conflict of interest

The authors declare the absence of potential conflicts of interest.

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STRESZCZENIE

Zaburzenia ekosystemu leśnego wpływają na zamieranie drzew zasiedlonych przez korniki *Ips* spp., dowody z obrazowań multispektralnych UAV

Chrząszcze z podrodziny kornikowatych (Coleoptera, Curculionidae, Scolytinae) są jednym z głównych czynników powodujących zamieranie drzew w europejskich lasach. W ostatnich latach korniki spowodowały ogromne straty gospodarcze i wpłynęły na ekosystemy w dużej skali przestrzennej. Identyfikowanie potencjalnych miejsc żerowania kornika jest ważną częścią prewencji pozwalającej uniknąć strat w leśnictwie. Za pomocą technik teledetekcyjnych podejmowane są próby identyfikacji rozmiaru szkód wywołanych przez kornika, jednak są one mało dokładne i wciąż poszukuje się najwłaściwszej techniki pozwalającej precyzyjnie wskazywać wczesne fazy ekspansji owadów. Równolegle podejmuje się kroki, aby identyfikować czynniki pozwalające lepiej prognozować zjawisko inwazji korników. Osłabienie kondycji drzewostanu jest czynnikiem powodującym zwiększenie podatności na masowe wystąpienia korników. Do tej pory nie zidentyfikowano wszystkich czynników siedliskowych, które sprzyjają kornikowi, jednak panuje konsensus w kwestii wpływu suszy na podatność drzewostanu na zasiedlanie przez kornika, co jest szczególnie niepokojące w dobie zmian klimatu. Coraz więcej lasów, zwłaszcza na obszarach chronionych, jest poddawanych mapowaniu za pomocą technik teledetekcyjnych, umożliwiających lokalizację miejsca żerowania *Ips* spp. W połączeniu z danymi przyrodniczymi, pozwalającymi na określenie jakości ekosystemów, można byłoby je wykorzystać do badań przesiewowych, które w monitorowaniu zjawisk ekologicznych okazują się najbardziej skuteczne i opłacalne.

Celem badań było określenie, jak odwodnienie w różnych typach ekosystemów leśnych wpłynie na podatność na inwazję kornika. Obszar badań stanowiły lasy Nadleśnictwa Miradz, położone w centralnej części Polski. Ze względu na bliskie sąsiedztwo kopalni węgla brunatnego

Konin SA lasy te znajdują się pod wpływem leja depresyjnego. Obejmują one różne typy siedliskowe: od ubogich borów po żyzne lasy świeże (ryc. 3). Powierzchnie są przy tym jednorodne, wszystkie obsadzone sosną w wieku 32-102 lat i użytkowane na potrzeby gospodarki leśnej. Lasy zostały zaatakowane kilkanaście lat temu przez korniki wykorzystujące pogarszającą się kondycję drzew. W maju i sierpniu 2022 r. wykonano nalot przy użyciu UAV wyposażonego w kamerę multispektralną – SENOP. Na podstawie danych spektralnych i obserwacji terenowych identyfikowano drzewa w całości opanowane przez kornika (ryc. 1). W transektach w pasie o szerokości około 50 m w odstępach co 10-20 m (ryc. 2) na przełomie maja i czerwca 2022 r. przeprowadzono serię badań botanicznych. W 192 punktach wykonano spisy roślin naczyniowych rosnących w runie wraz z ich pokryciem. Pozwoliło to na obliczenie wskaźników różnorodności biologicznej i kondycji siedliska. Na podstawie analizy danych multispektralnych zidentyfikowano drzewa z koroną uszkodzoną w 80-100%. Wpływ typu siedliska na ilość uszkodzeń jest jednoznaczny i prawdopodobieństwo inwazji kornika jest 2-3 razy większe w przypadku siedlisk najżyźniejszych *Pinus-Dryopteris* na siedlisku grądu *Galio-Carpinetum* (Lśw). W przypadku borów mieszanych – *Pinus-Rubus* na siedlisku *Querco roboris-Pinetum* (LMśw) i borów *Leucobryo-Pinetum* (BMśw) – nie stwierdzono różnic istotnych statystycznie (tab. 1). Zestawienie wszystkich wskaźników siedliskowych i dotyczących jakości roślinności pozwala uszeregować czynniki wpływające na podatność rosnących tam drzew na ich zasiedlenie przez korniki. Najlepiej wyjaśnia to udział grupy gatunków niekoniecznie związanych wprost z jakością siedliska, ale będących skutkiem zaburzeń drzewostanu (tab. 2). Udział roślinności porębowej wyjaśnia nawet w 65% (tab. 2) związek z liczbą zasiedlonych drzew. Wskaźniki roślinne bezpośrednio wskazujące na wilgotność, w postaci liczb Ellenberga dotyczących wilgotności (F), słabo wyjaśniają prawdopodobieństwo pojawu kornika (28%, tab. 2). Przyglądając się szczegółowym rozkładom czynników najbardziej wpływających na sukces kornika, można zauważyć jego tendencje do inwazji. Udziałowi gatunków porębowych z klasy *Epilobietea* na poziomie ponad 40% prawie zawsze towarzyszą drzewa zasiedlone przez kornika (ryc. 4). Z kolei duży udział gatunków starych lasów w runie o pokryciu ponad 60% nie jest równoznaczny z brakiem występowania drzew z kornikiem, ale nie zarejestrowano dużego pokrycia tych gatunków w runie i jednocześnie dużej liczby zasiedlonych drzew w buforze 100 m (ryc. 5). Skutki działalności górniczej związanej z wielkopowierzchniowymi odwodnieniami wpływają w dużym stopniu na roślinność lasów.

Z przeprowadzonych badań wynika, że postępująca długotrwała susza sprzyja występowaniu i ekspansji kornika. Koncepcja degradacji lasów Olaczka i faza określana fruticetyzacją, czyli duży rozrost warstwy krzewów, może być jednym z lepszych wskaźników podatności drzewostanu na inwazję kornika. Równie przydatne może być też stwierdzenie liczby gatunków starych lasów.