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ORIGINAL PAPER

Mistletoe and crown defoliation in pine stands

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ABSTRACT

The extensive infestation of pine stands by mistletoe, especially *Viscum album* ssp. *austriacum*, has increasingly become a severe problem for forest management in recent years. In Europe, periodic droughts contribute to the trees' susceptibility to infestation by this semi-parasite. *Viscum album* can restrict the secondary growth of *Pinus sylvestris* to an extent that is relevant to forestry. The objective of this study was to assess the correlation between the degree of mistletoe infestation in pine stands and the prediction of damage. A total of 780 pine trees were surveyed, with 53.8% of all trees being infected by mistletoe. The present study demonstrates that the likelihood of a significant loss of needles rises with an increase in mistletoe numbers, irrespective of the tree's age. The progressively declining condition of pine stands infested by mistletoe presents a fresh challenge to forest management, foresters, and scientists. They are confronted with the task of developing effective methods to control this semi-parasite.

KEY WORDS

defoliation, forest, needles, prediction, semi-parasite, *Viscum* spp.

Introduction

In recent years, mistletoe infestation has escalated into an increasingly severe issue for both stands of trees and individual trees. The genus *Viscum* encompasses around 100 evergreen perennial semi-parasitic plants, most of which are found in southern Asia, Africa, eastern Australia, and Europe. It displays adaptability to a wide range of habitat conditions, as demonstrated by its capability to thrive on numerous host plant species (Jäger *et al*., 2021). This phenomenon occurs in over 450 species and varieties of trees (Barney *et al*., 1998; Zuber, 2004). In Europe, there are four subspecies of *Viscum album* (L.) identified: the common mistletoe *V. album* ssp. *album*, which infests deciduous trees and shrubs; the downy mistletoe *V. album* ssp. *austriacum*, predominantly found on *Pinus* spp., and occasionally on *Picea* spp. or *Larix* spp.; *V. album* ssp. *abietis*, which targets *Abies alba* Mill.; and *V. album* ssp. *creticum*, associated with *Pinus brutia* Ten. on Crete (Böhling *et al*., 2002; Zuber, 2004). In Poland, *V. album* ssp. *album*, *V. album* ssp. *austriacum*, and *V. album* ssp. *abietis* are present (Bukowiec and Bednarz, 2017). While this plant possesses needles (Mutlu *et al*.,

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2016), it acquires carbon alongside water and mineral salts from its host (Zweifel *et al.*, 2012). Consequently, it contributes to the weakening of the host plant by diminishing annual growth, impeding cone development and seed quality, reducing the photosynthetic apparatus and mycorrhizal status of roots, heightening vulnerability to infectious diseases and pest attacks, and even potentially leading to tree death (Rigling *et al.*, 2010; Pilichowski *et al.*, 2018). This species, previously regarded only as an interesting element enhancing the biodiversity of forest ecosystems, has begun to be perceived as a real threat to the stability of pine and fir stands (Iszkuło *et al.*, 2020).

Mistletoe spreads through ornithochory, facilitated by common birds such as *Bombycilla garrulus* L., *Turdus viscivorus* L., *Turdus pilaris* L., or *Sylvia atricapilla* L. (Becker, 1986; Martínez del Rio *et al.*, 1996; Zuber, 2004; Rybalka and Vergeles, 2017). *Viscum album*, characterized by an extensive genome, follows a distinct life cycle compared to other flowering plants (Schröder *et al.*, 2022). Its morphological structure, including its leaves and white berries that mature during the European winter, enables year-round thriving (Jäger *et al.*, 2021). The mistletoe attaches itself to the host plant using haustoria, drawing water, nitrogen, carbon, and metabolites from the host. The acids and hydrocarbons found in the hemiparasite's tissues differ from those of the host and display medicinal properties (Rubiales, 2011; Lim *et al.*, 2016). The effective long-distance spread of this plant is positively influenced by wiscin, a sticky substance found in the fruit's flesh. Seeds typically adhere to bird beaks, legs, or feathers and are then transferred by birds as they rub against the host plant's bark (Yan and Reid, 1995; Mathiasen *et al.*, 2008). Subsequently, the seeds, with the assistance of wiscin, adhere to branches, marking the beginning of a new infection (Zuber, 2004). Observations have indicated shifts in the prevalence of mistletoe. In Eastern Germany, specifically in Brandenburg, the occurrence rate of mistletoe on pine trees surged from 1% in 2009 to 11% in 2015 (Kollas *et al.*, 2018). Dobbertin revealed that the upper limit of *Viscum* spp. occurrence in the Alps has elevated by 200 meters in recent decades, most likely attributed to climate warming (Dobbertin *et al.*, 2005).

Due to the substantial infestation of pine stands by mistletoe in recent years, notably *V. album* ssp. *austriacum* (Szmidla *et al.*, 2019; Lech *et al.*, 2020). Forest management is confronted with a significant challenge. The infestation of *P. sylvestris* by mistletoe can result in noteworthy economic losses (Pilichowski *et al.*, 2018). Periodic droughts contribute more to trees' susceptibility to infection by this semi-parasitic organism than the distance from the infected tree.

Mistletoe is prevalent in Poland, but the expansion of *Viscum album* ssp. *austriacum* within forests is concerning. In 2018, as a result of drought, the transparency of tree crowns heightened, rendering mistletoe on trees more visible. This led to a rise in the expanse of mistletoe-infested forests, escalating from 1.4 thousand hectares in 2017 to nearly 23 thousand hectares in 2018.

As per the 2019 Forestry Statistical Yearbook (CILP, 2020), pine stands encompass 60.1% of the total forest area in Poland, with almost 30% of these stands being afflicted by mistletoe. The semi-parasite *V. album* ssp. *austriacum* can curtail the growth of Scots pine to an extent of significance in forestry. Key information for forecasting overall wood losses includes the stand's age during initial parasitic infestation and the mistletoe population growth (Kollas *et al.*, 2018). The progressively deteriorating condition of pine stands infiltrated by mistletoe introduces a fresh challenge to forest management, foresters, and scientists as they strive to formulate effective techniques for controlling this semi-parasite.

The most common, direct methods of mistletoe reduction involve the removal of infected branches or whole trees (Hawksworth *et al.*, 1983). Another approach to mistletoe management is employing chemicals for this purpose, albeit this approach yields only partial success (Minko

and Fagg, 1989; Zuber, 2004; Hoyt *et al*., 2017). Only specific herbicides possess a selective impact on parasitic plants without endangering the host (Gressel *et al*., 2004). Systemic herbicides commonly used in agriculture, featuring active ingredients like ethephon, 2,4-5 T, 2,4-D, 2,4-MCPB, and dichloroethane (Geils and Hawksworth, 2002; Zuber, 2004), have primarily been employed to manage mistletoe. However, it's important to recognize that using chemical preparations entails risks such as host damage, environmental pollution, and adverse effects on animal and human health.

The effectiveness of treatment hinges on various factors including application technique and frequency, chemical type and concentration, or suitable weather conditions (Wood and Reilly, 2004; Hoyt *et al*., 2017). Currently, there are no economically feasible and efficient methods for controlling mistletoe on a large scale (Szmidla *et al*., 2019).

The investigated stands are situated near facilities linked to human industrial activities and display diversity in terms of water accessibility. The objective of this study was to proactively evaluate the correlation between the extent of mistletoe infestation in pine stands and the state of their assimilation apparatus. A comprehensive examination of three chosen stands was conducted in triplicate, wherein the count of mistletoe-infected trees was established, and the level of crown defoliation was appraised. Moreover, an analysis was conducted to identify the presence of pathogenic fungi and evidence of insect pest feeding on pine trunks.

Material and methods

An assessment of the health condition of pine stands infested by mistletoe was conducted within the Włocławek Forest District, under the Regional Directorate of State Forests in Toruń (RDLP in Toruń). Pine stands were selected randomly from three forest subdistricts: Lipiny (52.70N 18.90E), Poraza (52.65N 18.96E), and Szpetal (52.90N 18.70E). The Lipiny forest district is situated in close proximity to the 'Anwil' Nitrogen Factory, where Air Pollution Risk Zone 3 is applicable. The Poraza forest district is located 2 km away from the municipal landfill in Machnacz. The Szpetal forest district directly borders the Vistula River. The study area encompassed pine stands with ages ranging from 50 to 121 years.

Fieldwork was conducted three times within the same stands: in September 2019, March, and May 2020. Circular plots were randomly designated (15 per forest district), with a central tree characterized by a straight trunk and a diameter at breast height (DBH) exceeding 25 cm. The radius of each circular plot was set at 10 m. Due to the limited area of the surveyed stands, satellite imaging techniques were not employed. The diverse location of study plots across different subdivisions within the three forest districts facilitated an analysis of defoliation degree percentages in relation to subdivision location and other factors, such as stand age. During the assessment of the study plots, the methodology outlined by Iszkuło *et al*. (2020) was followed. This involved determining the count of mistletoe-infected trees, the quantity of mistletoe (in pieces), and its placement (branch or trunk) using traditional methods coupled with binoculars. The extent of defoliation was ascertained based on the loss of needles, represented as a percentage, utilizing the 'Atlas of the Loss of Assimilation Apparatus in Forest Trees' (Borecki and Keczyński, 1992) (Table 1). The study explored the relationship between crown defoliation, mistletoe colonization, stand age, and study area (subdivision). Analysis was exclusively conducted for the initial term, as this was the sole instance where data for individual trees was available, and differences in overall abundance in subsequent terms were insignificant.

Furthermore, the occurrence of macrofungal pathogenic fungi and signs of insect feeding on pine trunks was verified. The collected measurements were subjected to statistical analysis

using R Core Team 2021 (Oksanen *et al.*, 2013). Before proceeding to statistical analyses, all data were thoroughly checked to ensure their distribution and adherence to the assumptions of variance analysis.

Results

A comprehensive inventory of 780 live pine trees was conducted, revealing that 53.8% of the trees were infested with mistletoe, excluding those with downy characteristics. Through three rounds of assessments of pine stands, more than 1600 mistletoe specimens were documented, enabling a comparison of the average mistletoe count per tree across the analysed subdivisions in Lipiny, Poraza, and Szpetal subdistrict. The lowest count of mistletoes per pine (0) was noted in subdivision 229b in Poraza, where the surveyed pines were the youngest at 50 years of age. In contrast, the highest mean number of mistletoes per one tree (7) was observed in two subdivisions in Szpetal, specifically 23h and 23x, where the pines were 107 years old.

The varying observation dates provided insight into changes in the average mistletoe count per study plot across each of the analysed subdivisions. Among all assessment terms, trees in subdivision 23h exhibited the highest average number of mistletoe count, attributed to a low number of pines in that area (13). Conversely, the least number of mistletoes was observed in subdivision 229b, where the average number of pines per study plot was 46. During field observations, the majority of subdivisions experienced an average loss of needles exceeding 50%, except for subdivision 229b (Fig. 1). Defoliation of pine crowns ranged from 16.5% to 76.5%, with an average total defoliation of 53.3%. The distribution of individual degrees of crown defoliation varied based on the forest district's location (Fig. 2).

Table 1.

Degree of damage

Degree of damage	Percentage of the loss of the assimilation apparatus [%]
0 – no damage	0-10
1 – weak damage	11-25
2 – medium damage	26-60
3 – severe damage	>60

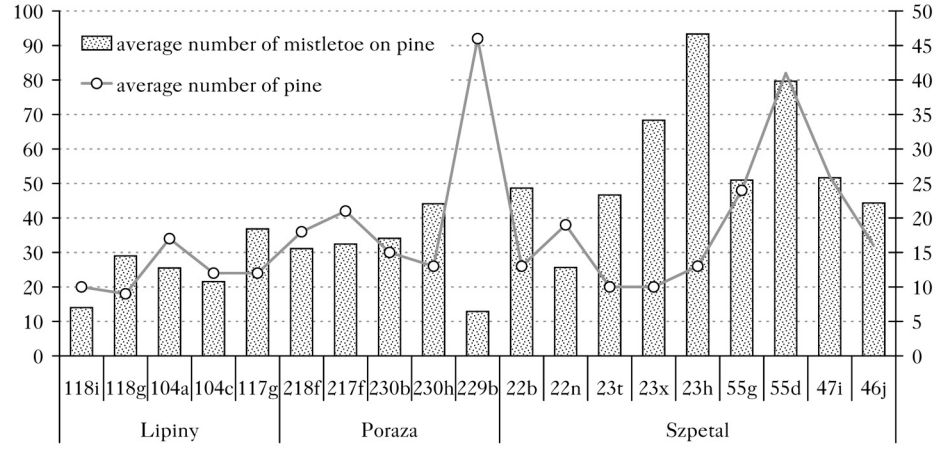

Fig. 1.

The average number of the mistletoe on Scots pine

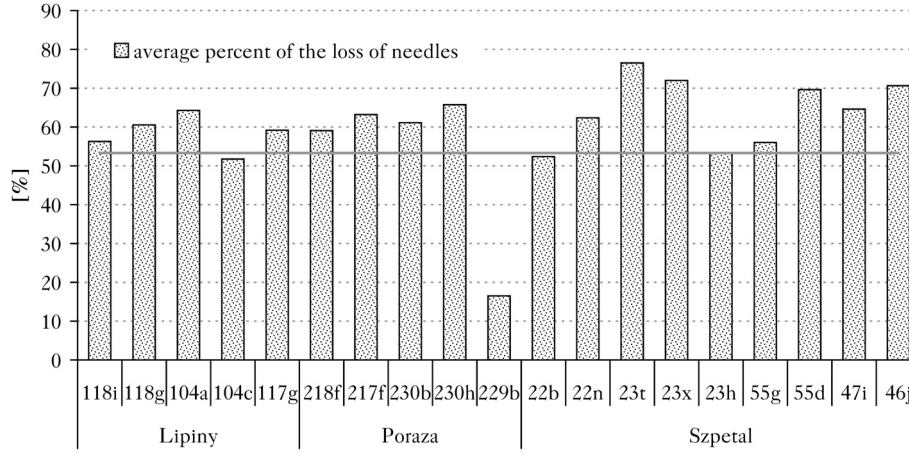

Fig. 2.
Average crown defoliation [%] for individual subdivisions compared to average

The four subdivisions showcasing the highest mean values of needles loss were situated in Szpetal, an area in close proximity to the Vistula River. In contrast, the lowest mean crown defoliation was observed in subdivision 229b (Poraza), which also had the lowest mean number of mistletoes per tree and study plot.

The examination of pine stands across different forest districts within the Włocławek Forest District revealed specific patterns. Most pine trees near the 'Anwil' Nitrogen Plant (Lipiny) exhibited grade 2 defoliation (55.8%). In the Poraza forestry, located near the municipal waste landfill in Machnacz, a similar degree of crown damage was prevalent (40.5%). The predominant degree of crown damage in Szpetal forestry was grade three (61.3%). Less than 10% of assessed trees experienced complete loss of the assimilation apparatus (degree 0), and none in Lipiny subdistrict were classified under this degree. Grade 1 defoliation was not significantly observed in any subdistrict. The highest count of dead trees (degree 4) was recorded in the Poraza subdistrict, which was heavily affected by bark beetle *Ips acuminatus* Gyll. activity, comprising 15 pieces (4.9%) of the inventoried trees.

Among the subdivisions under observation in the Lipiny subdistrict, grade 2 defoliation was predominant. Furthermore, the percentage of grade 3 defoliation exceeded 30% in each of the analysed subdivisions in the discussed forest district. Despite its location near the 'Anwil' Nitric Works, the Lipiny forest district had the smallest number of dead trees, totaling only one tree (subdivision 104c). In the Poraza subdistrict, subdivisions 230b and 230h were characterised by the prevalence of grade 3 defoliation. Moreover, these subdivisions were situated closest to the landfill site in Machnacz (1.7-2 km). The youngest pine trees, aged 50 years, experienced the least damage, particularly in subdivision 229b, which was situated over 2 km from the landfill boundary. Grade 3 defoliation was prominent in seven out of the nine subdivisions in Szpetal forestry, which was positioned near the Vistula River. The percentage of dead trees did not surpass 10% in any of the studied sub-divisions of this forest district (Fig. 3).

The investigation delved into the relationship between crown defoliation, mistletoe colonization, stand age, and study area (subdivision). Analyses were exclusively conducted for the initial term, given that data for individual trees were only available at this point, and variations in total abundance in subsequent terms were not significant. The analysis included assessing

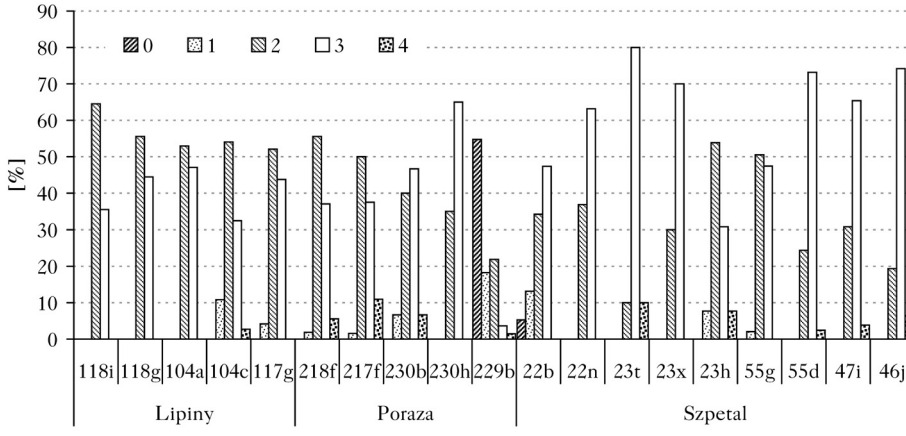

Fig. 3.
Percentage share of each degree of crown defoliation (0-4) in the analysed forest districts

Table 2.
Logistic regression results of defoliation degree on age and number of mistletoe on the tree

Variation coefficient		df	chi-squared test	p-value	Statistical significance
Number of mistletoes		1	96.631	<2.2e-16	***
Tree age		1	45.185	1.792e-11	***
Interaction	number of mistletoes × age	1	45.255	1.730e-11	***

the defoliation degree based on tree age and mistletoe count (Table 2). The probability of defoliation was examined in relation to the number of mistletoes present at a given age, as illustrated in Figure 4.

An estimation was made of the probability of defoliation, considering the number of mistletoes. It was noted that, irrespective of tree age, the probability of grade 3 defoliation increased with a higher mistletoe count. Trees with over ten mistletoes exhibited a high probability of grade 3 defoliation, with no trees experiencing lower defoliation at this mistletoe count. An exception was observed in 121-year-old trees, for which mistletoe count did not significantly affect the probability of grade 3 defoliation. The analysis further explored the relationship between defoliation, tree age, and mistletoe count (Table 3). These findings were confirmed by Figure 5, depicting a very high likelihood of grade 3 defoliation occurrence in each subdistrict surveyed with more than ten mistletoe pieces. An exception was observed in Szpetal subdistrict for trees aged 107 and 108. Generally, the probability of grade 3 defoliation occurrence remained consistently high and was not influenced by mistletoe count.

Another analysis was conducted to evaluate the impact of mistletoe count in a given subdistrict on the degree of defoliation (Table 4). The likelihood of grade 3 defoliation occurrence with more than ten mistletoe infestations was nearly certain, with a probability close to 1 in all forest districts (Fig. 6).

The dependence of the degree of defoliation on tree age and study site (subdistrict) was investigated. For this analysis, all defoliation degrees were considered (Table 5). Lipiny subdistrict was more likely to experience grade 2 defoliation, with this probability decreasing as the trees age. The occurrence of grade 3 defoliation was lower but exhibited a slight increase with age.

The probability of grade 4 defoliation occurrence was low and remained unchanged with age (Fig. 7). In Poraza subdistrict, the likelihood of experiencing a particular defoliation degree dynamically changed with age. Up until approximately 70 years of age, grade 2 defoliation

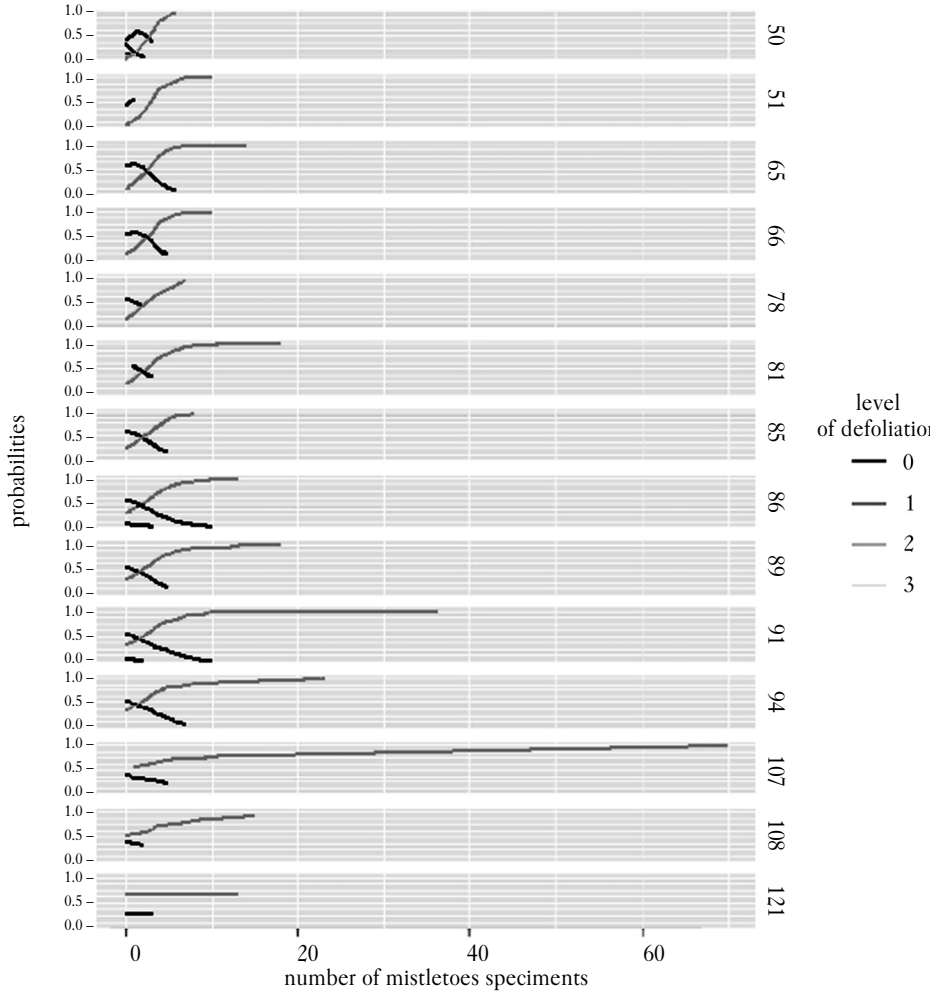

Fig. 4.
The probability of defoliation depends on the number of mistletoe in trees of a tree age

Table 3.
Logistic regression results of the degree of defoliation as a function of age and number of mistletoes on a tree in a given forestry

Variation coefficient		df	chi-squared test	p-value	Statistical significance
Number of mistletoes		1	142.059	<2.2e-16	***
Tree age		1	62.700	2.407e-15	***
Forest district		2	61.015	5.633e-14	***
Interaction	number of mistletoe × age	1	62.084	3.291e-15	***
	number of mistletoe × forest district	2	24.616	4.515e-06	***

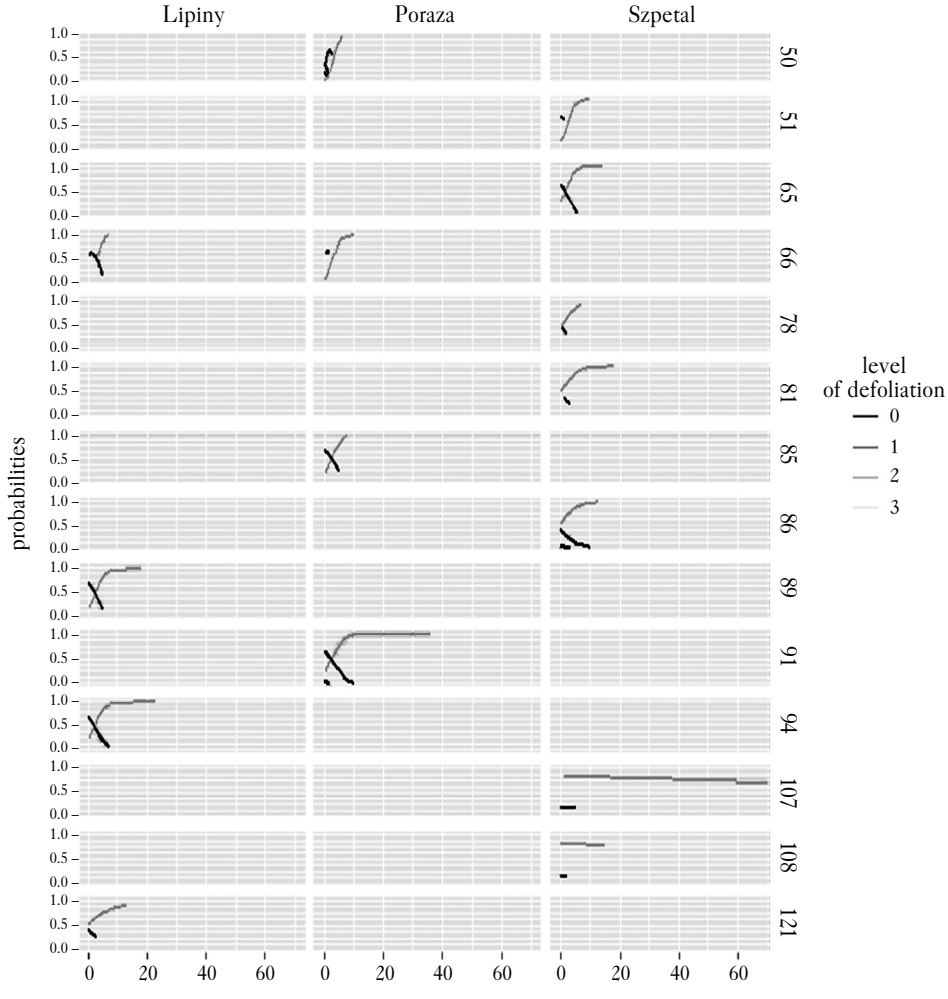

Fig. 5.

The probability of defoliation depends on the number of mistletoe in trees of a given age in the forest district

Table 4.

Logistic regression results of the effect of the number of mistletoe in a given forestry on the degree of defoliation

Variation coefficient		df	chi-squared test	p-value	Statistical significance
Number of mistletoes		1	115.253	<2.2e-16	***
Forest district		2	38.324	4.766e-09	***
Interaction	number of mistletoe × forest district	2	14.922	0.0005752	***

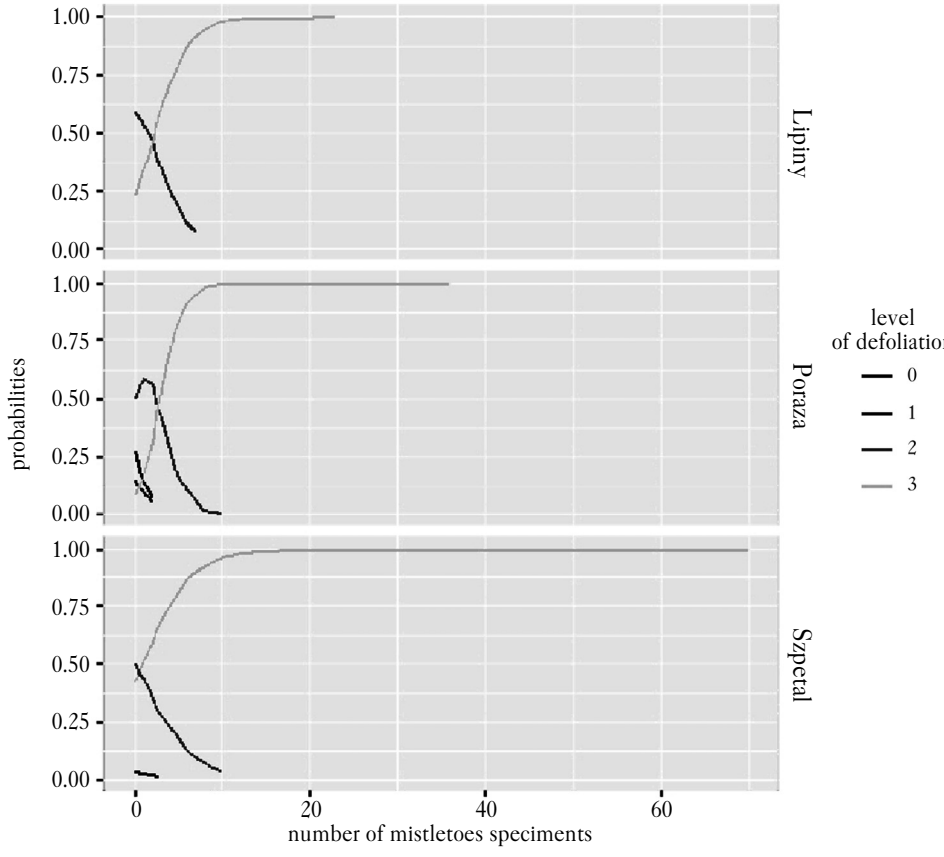

Fig. 6.
The probability of defoliation depends on the location

Table 5.
Logistic regression results of the effect of tree age and forest district on defoliation rates

Variation coefficient		df	chi-squared test	p-value	Statistical significance
Age		1	144.90	<2.2e-16	***
Forest district		2	106.31	<2.2e-16	***
Interaction	age × forest district	2	122.86	<2.2e-16	***

Discussion

Mistletoe carries significant significance for various reasons, as it can be viewed both as a threat to forest trees and as a valuable medicinal plant used in the pharmaceutical field. The shifting dynamics of mistletoe distribution allow for the formulation of effective strategies for forest management. It is projected that the potential range of mistletoe will shift towards the northeast, while mountainous regions in Europe will experience an upward shift in altitude. The presence of mistletoe could have adverse effects on forest ecosystems in Central and Eastern Europe, potentially hastening the decline of trees. Of particular concern is the subspecies *V. album* ssp. *austriacum*, which poses a specific threat to pine-dominated forest complexes (Walas *et al*., 2022).

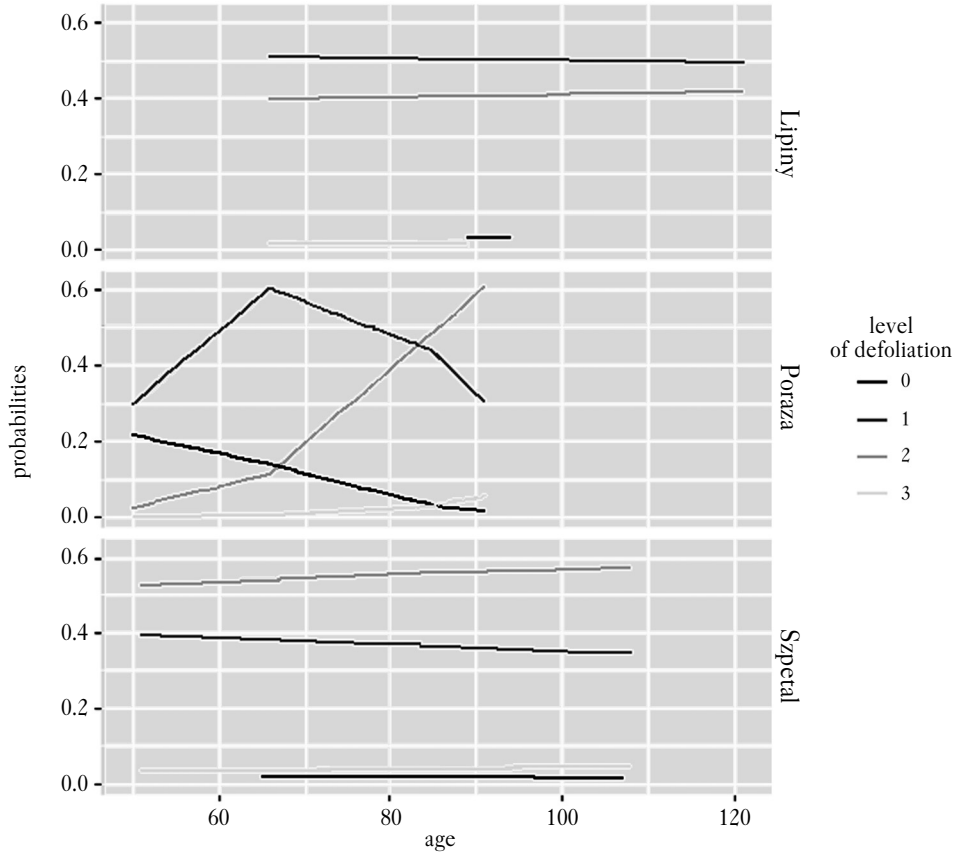

Fig. 7.
The probability of defoliation depends on the age of the stand in a given forest district

Kołodziejek and Kołodziejek (2013) studied the distribution of common mistletoe in pine stands in the village of Ewinów (Wielkopolskie Voivodeship), located 90 km from Włocławek. They employed the methodology outlined by Dobbertin and Rigling (2006) and Kołodziejek and Kołodziejek (2013). Their analysis revealed mistletoe infestation in 46% of the surveyed pines. Forest monitoring conducted in 2018 indicated that the average defoliation of pine trees in Poland reached 22.3% (defoliation degree 1) (Statistics Poland, 2019). Correspondingly, in RDLP Toruń, the average pine defoliation closely matched the national average at 21.6%. However, our study recorded a considerably higher average loss of the assimilation apparatus at 53.3%, predominantly categorized as defoliation degree two. The proportion of pines with an assimilation apparatus loss ranging from 0 to 10% (degree 0) stood at 8.3%, a result resembling the Poraza subdistrict analyzed in this study (11%). Notably deviating from these values were the other two inventoried plots, Lipiny (0%) and Szpetal (0.6%). Even greater discrepancies were evident in the case of the first degree of defoliation, which accounted for 74.8% in Poland. However, in the stands under study, defoliation degree two (Lipiny and Poraza) and defoliation degree three (Szpetal) predominated, constituting proportions of 15.4% and 1%, respectively. Trees classified as dead accounted for 0.5% nationally, almost mirroring the results from surveyed stands in Lipiny subdistrict at 0.54%. Other forest districts displayed higher proportions of grade four defoliation, with Poraza at 4.9% and Szpetal at 3.4%. Moreover, trees with men-

tioned mistletoe numbers did not display lower defoliation degrees. Dobbertin and Rigling (2006) investigated the presence of mistletoe and the health status of *P. sylvestris* in the Swiss Rhone Valley. Their study was prompted by the high and unexplained mortality of trees. The authors found that the probability of pine mortality increased with higher mistletoe numbers, defoliation degree, and dead branch count. Sangüesa-Barreda (2013) studied pine stands in the eastern part of Spain, indicating that heavily infected trees exhibited greater sensitivity to drought stress than uninfested trees. The combination of mistletoe infestation and drought led to reduced water uptake and management efficiency in infected pine trees. The researchers also noted an increased loss of needles with expanded mistletoe presence (Sangüesa-Barreda *et al*., 2013). Similar conclusions were drawn by Gea-Izquierdo (2019), who conducted a study on *Pinus pinaster* Ait. in Spain, revealing significant health decline (Gea-Izquierdo *et al*., 2019). The absence of prevalent fungal pathogens suggests their minor role in deteriorating tree health. Stress caused by abiotic factors, augmenting assimilation apparatus loss, heightens tree susceptibility to mistletoe infestation. Enhanced *P. sylvestris* mortality could be attributed to mistletoe-induced severe drought stress, with increased antioxidant enzyme capacity failing to shield the plant from oxidative damage during dry summers (Mutlu *et al*., 2016). Drought elevated the risk of death for mistletoe-infested trees by four times compared to uninfested ones. Age and relative humidity may constitute factors favoring mistletoe growth (Skrypnik, 2020; Geils and Hawksworth, 2002). The potential use of mistletoe as a bioindicator stems from its ability to selectively accumulate various heavy metals (Kolon *et al*., 2013). Mistletoe's enduring and comprehensive systemic effects transform the pine host from modular to unitary in terms of space and time. This metabolic alteration instigated by mistletoe can introduce a new metabolic identity for the host, enhancing the complexity and diversity of the forest canopy. This initiates a chain of ecological consequences detrimental to pine herbivores. However, a new identity might also entail a new niche and opportunities for tolerant and adapted herbivores. Elevating local and regional forest biodiversity at the ecosystem level could have practical implications for pine forest conservation and management (Lázaro-González *et al*., 2021).

Organisms such as fungi and insects associated with mistletoe, while feeding on it, currently have limited impact on reducing the semi-parasite's abundance. A potential method for Integrated Plant Protection involves employing the fungus *Botryosphaeria visci* (Kalchbr.) Arx & E., which exhibits antagonistic behavior towards mistletoe. This mistletoe control approach offers numerous benefits, as biological control is eco-friendly and applicable in areas unsuitable for pesticide use, especially urban settings (Varga *et al*., 2012). An example of an insect associated with mistletoe (displaying a particular preference for *Viscum album* ssp. *austriacum*), as well as *Loranthus europaeus* Jacq., is *Synanthedon loranthi* (Kr.). The larvae of this butterfly exhibit a characteristic feeding pattern, which is shallow, occurring under the non-woody covering tissue. The development of *S. loranthi* takes one to two years, contingent on environmental conditions, and exclusively takes place within living mistletoe. *Viscum album* holds crucial medicinal value, with numerous studies exploring its pharmacological attributes, such as anti-cancer and anti-diabetic effects (Yousefvand *et al*., 2022). Given the therapeutic potential of mistletoe metabolites, mechanical removal and subsequent utilization in the pharmaceutical industry might serve as a prime method for reduction.

The expansion of *Viscum* ssp. will worsen the water stress experienced by trees, leading to decreased annual growth and accelerated crown dieback (Szmidla *et al*., 2019). Rapid changes in habitat due to environmental factors render trees more vulnerable to infection and infestation. The outcomes of surveys can offer insights into potential tree damage caused by semi-parasites, aiding in the development of appropriate management strategies for weakened stands. The

prevalence of mistletoe infestation was highest in the oldest and largest trees, especially those that were predominant or dominant in the area (Lech *et al*., 2020).

Conclusions

- None of the analysed subdivisions within the Włocławek Forest District exceeded 6% of the first degree of defoliation. This suggests that the proximity of nitrogen-rich plants or a landfill site did not contribute to an elevated degree of pine damage.
- When more than 10 specimens of mistletoe colonize a tree, the likelihood of experiencing third-degree defoliation in pine trees is notably high across all the studied stands.
- The degree of defoliation shows an upward trend with an increasing number of mistletoe occurrences, a trend that aligns with the findings of our current study.
- The results strongly indicate that the heightened mortality of pine trees is primarily linked to a combination of abiotic factors, particularly drought, and biotic factors like mistletoe.

Authors' contributions

All authors have contributed equally and declare no conflicts of interest.

Conflicts of interest

The authors declare no potential conflicts of interest.

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STRESZCZENIE

Jemioła a stopień defoliacji w drzewostanach sosnowych

W ostatnich latach porażenie przez jemiołę staje się coraz poważniejszym problemem zarówno dla całych drzewostanów, jak i pojedynczych drzew. Rodzaj *Viscum* obejmuje około 100 zimozielonych wieloletnich roślin półpasożytniczych, z których większość występuje w południowej Azji, Afryce, wschodniej Australii i Europie. Organizm ten potrafi dostosować się do szerokiego zakresu warunków siedliskowych, o czym świadczy jego zdolność do wzrostu na wielu roślinach żywicielskich (ponad 450 gatunków i odmian drzew). Masowe porażanie drzewostanów sosnowych przez jemiołę, zwłaszcza *Viscum album* ssp. *austriacum*, stanowi duże wyzwanie dla gospodarki leśnej, ponieważ może ograniczać wzrost wtórny *Pinus sylvestris* w stopniu istotnym dla leśnictwa. Jemioła ma aparat fotosyntetyczny, ale od swojego gospodarza – oprócz wody i soli mineralnych – pobiera także węgiel. Tym samym przyczynia się do osłabienia kondycji rośliny żywicielskiej poprzez ograniczenie przyrostów rocznych, pogorszenie rozwoju szyszek i jakości nasion, zmniejszenie aparatu asymilacyjnego, zwiększenie podatności na choroby zakaźne i ataki szkodników, a nawet obumieranie drzew. W Europie okresowe susze pozytywnie wpływają na podatność drzew na porażenie przez tego półpasożyta. Celem pracy była prognoza uszkodzeń drzewostanów sosnowych na podstawie stopnia porażenia jemiołą. Ocenę stanu zdrowotnego drzewostanów sosnowych porażonych przez jemiołę przeprowadzono w Nadleśnictwie Włocławek (RDLP Toruń). Badano drzewostany zlokalizowane w 3 leśnictwach: Lipiny (52,70 N, 18,90 E), Poraza (52,65 N, 18,96 E) i Szpetal (52,90 N, 18,70 E). Leśnictwo Lipiny położone jest w pobliżu Zakładów Azotowych „Anwil", gdzie obowiązuje 3 strefa zagrożenia zanieczyszczeniem powietrza. Leśnictwo Poraza położone jest w odległości 2 km od składowiska odpadów komunalnych w Machnaczu. Leśnictwo Szpetal graniczy bezpośrednio z rzeką Wisłą. Obszar badań obejmował drzewostany sosnowe w wieku od 50 do 121 lat.

Zinwentaryzowano łącznie 780 drzew (ryc. 1). Stopień defoliacji określono na podstawie ubytku aparatu asymilacyjnego sosny [%], wykorzystując „Atlas ubytków aparatu asymilacyjnego drzew leśnych" (Borecki i Keczyński 1992) (tab. 1; ryc. 3). Sosny porażone przez jemiołę stanowiły

53,8% wszystkich drzew (ryc. 2). Oszacowano prawdopodobieństwo defoliacji w zależności od liczby osobników jemioły i wieku drzew (tab. 2; ryc. 4), od wieku drzewa, liczby osobników jemioły i lokalizacji drzewostanu (tab. 3; ryc. 5), od lokalizacji (tab. 4; ryc. 6) oraz od wieku i lokalizacji drzewostanu (tab. 5; ryc. 7). Zaobserwowano, że niezależnie od wieku drzew prawdopodobieństwo defoliacji w stopniu 3 rośnie wraz ze wzrostem liczby osobników jemioły. Z przeprowadzonych badań wynika, że prawdopodobieństwo znacznego ubytku aparatu asymilacyjnego wzrasta wraz z nasileniem występowania jemioły niezależnie od wieku drzewa. Drzewo, na którym występuje więcej niż 10 osobników jemioły, ma wysokie prawdopodobieństwo defoliacji w stopniu 3; przy tej liczbie osobników jemioły nie ma drzew o niższej defoliacji. Wyjątek stanowią drzewa 121--letnie, dla których w zasadzie liczba osobników jemioły nie wpływa na prawdopodobieństwo defoliacji w stopniu 3. Następnie przeanalizowano zależność defoliacji w zależności od wieku drzew, a także od liczby osobników jemioły na drzewie. W badanych drzewostanach dominowały defoliacje stopnia 2 (Lipiny i Poraza) oraz stopnia 3 (Szpetal). W porównaniu ze średnią krajową stopnie te charakteryzowały się niskim udziałem i wynosiły odpowiednio 15,4 i 1%. Można przypuszczać, że sąsiedztwo zakładów azotowych lub składowiska odpadów nie przyczyniło się do zwiększenia stopnia uszkodzenia sosny.

Stale pogarszający się stan drzewostanów sosnowych zaatakowanych przez jemiołę stanowi nowe wyzwanie dla gospodarki leśnej oraz leśników i naukowców, którzy stoją przed koniecznością opracowania skutecznych metod zwalczania tego półpasożyta. Promowanie lokalnej i regionalnej różnorodności biologicznej lasów na poziomie ekosystemu może mieć praktyczne implikacje dla ochrony i zarządzania lasami sosnowymi.