Comparing methods for assessing the health of regeneration in Scots pine culture

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Abstract. This study's aim was to describe the health condition of Scots pine cultures of up to 10 years old using and comparing various field assessment methods. Since forest districts report on the health of stands annually, we assumed that for a proper health analysis it is necessary to develop a simple and yet reliable assessment method that allows for determining the share of fungal pathogen infection in the stand (both foliar and root pathogens) and their differentiation from symptoms of abiotic factors such as drought. Six different methods of health assessment were tested in selected Forest Districts across Poland. We found that the most reliable assessment of the health condition of young stands is obtained with the surface method 'MF' (phytopathological monitoring method) and the linear 'Z' method, which uses transects of 30 meters in three rows in the shape of the letter Z.

1. Introduction and rationale for the work

The current assessment of health and sanitary condition of the forest is one of the important sections of the annual report on the state of the forest (Raport 2018), sent to state, local government and scientific units, as well as to publicly available websites. The assessment is a synthesis of information collected annually in the field and sent by forest districts to Forest Protection Teams (*Zespoły Ochrony Lasu* – ZOL), Regional Directorates of State Forests (RDSF), and after verification – to the General Directorate of State Forests (DGLP) and the Forest Research Institute (IBL), produced as the 'Short-term forecasts of the occurrence of harmful forest insects and infectious diseases' (Krótkoterminowa 2019). Such an assessment contains not only data on factors predisposing or initiating certain phenomena or disturbances in the stands, but also information on the temporal and spatial changes of the extent of the occurrence of selected insects and fungi in Poland. It is also an attempt to infer and predict the consequences of current and predicted threats. For such information to be credible – as it usually is the basis for making important decisions of both an ad hoc and strategic nature – it must be

based on methodological foundations that ensure repeatability, verification and the value of the data for knowledge. These requirements were indicated by the State Forests Research Institute as early as 1935, and their importance resulted from many premises, based on the annual (since 1931) Disease Prevalence Questionnaire together with the Forest Diseases Table overview (Orłoś 1935).

The reliability of the data should result from its authors and therefore from the declared responsibility of the contractor for the reliability of the information obtained on the basis of a verified methodology. It is in this context that considerations are presented here on the process of obtaining information about the health condition of the forest, and more closely – about the health condition of crops in renewals and afforestation. The intention of the authors is to indicate the potential and actual conditions shaping the health condition of crops, which are usually not taken into account in their assessment. They occur in places that are difficult or even inaccessible to observe directly, have a non-specific nature, or encourage easy simplification and a certain formulaic approach.

An illustration of such information is the data contained in the reports on the occurrence of annosus root rot in tree stands, on

the example of three forest districts, presented by the authors in forestry journals (Sierota, Małecka 2018; Sierota 2019). The official data from various assessment periods indicate the difficulties in assessing changes in the area that is threatened – a decrease from 1,700 ha to 300 ha, an increase of 1,300 ha in the next period, and then a decrease in the reported area to zero (Sierota 2019). Where do such discrepancies come from?

The interpretation of the described situation, which after all, affects the overall picture of the threats and economic decisions made in the assessment year, requires the clarification of several facts that may have occurred individually or jointly in a given year. The assessment contractor may have lacked knowledge about the disease cycle, the stand could have entered a different age class and become subject to a different reporting protocol (up to vs. over 20 years of age), the age of the assessed trees could have indicated different phases of the current growth rate, felling or the reconstruction of species composition may have been undertaken in the infected stands – and assessed as 'no existing threat', there may have been a change in the assessment contractor who lacked knowledge about the site, a local drought may have occurred causing the foliage to start browning, and finally – the given assessment was performed during the period when the methodology of the most recent editions of the Forest Protection Instructions (*Instrukcja Ochrony Lasu* – IOL) changed four times. It follows that there are many reasons for the weaknesses in visually assessing stand health in terms of fungal pathogens, and especially of root pathogens – the perpetrators of annosus root rot and *Armillaria* root rot.

Annosus root rot is a dangerous tree disease caused by pathogenic fungi of the genus *Heterobasidion*, occurring especially in afforestation on former agricultural land (caused by *H. annosum* (Fr.) Bref.) and in spruce trees (caused by *H. parviporum* Niemelä & Korhonen) (Sierota 2001). The method of infection with the above mentioned pathogens is hidden because it is initiated by basidiospores and conidiospores germinating in tree roots, on the surface of vertical wounds (damage to the root collar of trees) or horizontal wounds (stumps after tree felling) and forming mycelium. By releasing the enzymes required for taking up nutrients, mycelium blocks the natural and induced tree defences and causes the breakdown of wood cells. The tree – depending on its species, age, genetically determined defensive abilities, as well as the aggressiveness of the pathogen – dies within a shorter (young trees, especially pine, larch, birch) or longer time (older trees, especially spruce). Dieback is visible in the first phase by the reduced turgor of shoots and leaves/needles, decreasing or disappearing current height and thickness increments, followed by a change in crown colour (decreased density, rusting, browning), premature leaf/needle fall, and finally by dying cambium and phloem and then the whole tree. The pathogen produces fruiting bodies on the root collar or inju-

red roots, which are perennial and produce basidiospores over a long period, causing further infections. At the same time, when the roots of the infected (diseased) tree touch or grow together with the roots of healthy, hitherto uninfected trees, secondary infections occur, in which the pathogen's mycelium grows over the contacting roots and extends the infection. Disease outbreaks arise, spreading from year to year (Żółciak et al. 2006).

Knowledge of the developmental cycle of the pathogen is essential for understanding the nature of the threat posed by infected roots remaining in the soil. According to numerous sources (Greig, Pratt 1976; Stenlid 1987; Piri 1996), the mycelium of *Heterobasidion* pathogens can remain in the soil, in the heartwood of the roots, for decades (even over 60 years) maintaining full biological activity. It is a real source of secondary infections for successive trees in a given stand, as well as for successive generations of the forest in that area – both for natural and artificial regeneration. In this context, the above mentioned reporting data from Forest District A on the absence of a pathogenic threat becomes quite unreliable.

The methodology for assessing the health status of trees and stands is found in the official document 'Forest Protection Instructions' (IOL), which was previously approved by the Minister for Forests and is now annexed to Directive No. 57 of the Director-General of the State Forests of 2011. Several IOLs have been published so far, the first in 1954, the next ones in 1960, 1972, 1988, 1995 (reprint), 1999, 2004 and the most recent one, currently in force, in 2012. One of its chapters consists of instructions for controlling damage caused by pathogenic fungi and other disease-causing factors, as well as damage caused by abiotic factors. Successive editions contained different thresholds of the harmfulness of pathogens, serving as the determinant for required reporting on threats or damage. For example, in the 1999 IOL, root pathogens were reported after having exceeded 5% of the number of infected trees or area of gaps in the stand. In the 2004 and 2012 IOLs, on the other hand, healthy stands were considered to be those in which the proportion of infected trees did not exceed 10% of the total number of affected trees or gap areas and could therefore be, for example, 9.5%. Is this a healthy stand?

The Forest Protection Instructions of 2004, in the section on 'Mandatory actions' II.3 (§67–80) and – unfortunately – 'Non-mandatory actions', part III.A.2 (§177–185), contained the methodological basis for site indexing the degree of tree infestation and assessing the threat to the stands. The data obtained allowed a spatial visualization to be obtained of the severity of the disease in the Forest Numerical Map (*Leśna Mapa Numeryczna* – LMN). However, this capability was not used sufficiently, and the apparent difficulty of making such an assessment, even if only once, probably led to the simplification of the methodology. The current IOL from 2012 (Part III/B/6.1.8.1; Part IIB, p.2, §99, 101) contains simplified assess-

ment formulas, which, according to the authors, do not reflect the essence of the specificity of the development of infectious diseases, focusing primarily on assessing the threat from insects. The risk to stands from pathogens is defined as weak with 5–10% of the trees assessed as diseased and/or dead, medium at 11–30% and catastrophic at over 30%. This assessment is used to develop a recovery program and to select appropriate intervention measures (section 4 §6.1.8.1). Reporting the level of damage and danger to trees in the crop (Part II/B/2, §95- 104) in Form 4 takes place when the number of infested and dead trees exceeds 10%, at least 3 disease outbreaks have been identified or when the total gap area exceeds 10% of the stand (§101). There are no precise explanations for determining the symptoms of the disease (e.g. recognition of etiological signs) and differentiating the threat, for example with the symptoms of drought or frost, end so on. So does Form 1 (the Signal sheet) provide new or additional information about the current state of the forest?

The question arises of whether the arbitrarily set boundaries reflect the current state of health? Or maybe they only inform about the area of the specific symptoms observed visually, not the etiological signs of the causative agents? Do they allow the infectious potential and the probable direction of the stand's development to be determined in a given area? Do they support the decision-making process regarding the intensity and recurrence of intermediate cutting, salvage cutting, or finally, the type of harvesting used and the scope of implementing prophylactic and therapeutic methods?

The methodology developed by IBL (Sierota, Lech 1996), called phytopathological monitoring (*monitoring fitopatologiczny* – MF), adapted from the method originally used in the United States of America (Lech 2000; Woodall et al. 2011), should be mentioned here. It assessed trees in four circular measurement plots of specific dimensions, where the zero plot was located at a randomly selected GPS-marked point in the stand (Sierota, Lech 1996, 1997, 1998; Sierota 1997a,b; Sierota et al. 1999). In addition to assessing the tree, stump condition was also assessed, which was new for monitoring studies (Sierota 1998), and later used in subsequent methodologies for the Large-scale Inventory of the State of the Forest (*Wielkoobszarowa Inwentaryzacja Stanu Lasu* − WISL) methodology (Michalak et al. 2004, 2010; Jabłoński et al. 2014). The MF method was successfully tested by Forest Protection Teams and implemented in the State Forests in 1996−2004, becoming the basis for several forest health assessments (Sierota, Lech 1999; Lech, Żółciak 2006). The monitoring indicators developed by Sierota and Lech (10 in total) allowed many aspects of the stand assessment to be interpreted – economic (assessment of the intensity of cleaning and thinning, backlog of treatments, stand spacing), phytopathological (presence of pathogens, saprotrophs, share of infected trees and stumps), as well as ecological (exposure of stumps to infections, presence of wood decomposing fungi,

threat to the stand). However, the method has not been implemented and is performed only occasionally in health assessments (Lech, Sierota 1999; Małecka, Sierota 2000). According to the authors, it is still an excellent tool for monitoring the health status of stands at the level of the forest district – it ensures the repeatability of the assessment, is reliable and can be performed only once every 10 years, for example. This method and other monitoring assessments (Sierota et al. 2000) were described in detail by Sierota et al. (2017).

Phytopathological assessments of the health condition of crops have been performed by many authors – in the 1992 post-fire area studies (Sierota, Małecka 1997; Hawryś et al. 2004), in monitoring the threat of pine twist rust (Małecka 2008), in assessments of pine root diseases (Łakomy 1998; Mańka, Janczyk 2000; Szewczyk, Mańka 2002; Szewczyk 2014), and in analyses of the mycorrhizal status of pines in post-agricultural soil (Małecka, Hilszczańska 2015). This paper is a further methodological development of IBL's assessment of the health status of trees cultivated for several years. Knowledge about the current state of the health of the crop is an essential source of information on the future of the next development phases of the stand. It can determine specific economic activities in silviculture and forest protection, as well as check forest management plans directing the performance of future intermediate cuttings, harvesting volume or type of felling.

The data used in this paper are the result of selected assessments and field measurements performed at IBL and by engineering students from the University of Warmia and Mazury in Olsztyn in several forest districts in Poland. They were conducted on pine crops, as this species dominates in the area being regenerated. A hypothesis was posed that the result of the assessment, that is the share of particular stress factors or so-called damage-producing factors shaping the health condition of the crop and assessed on the basis of a visual assessment, is not unequivocal. It depends on the assessment method and is determined by external causative (pathogens, insects) and environmental factors (age of the crop, occupied habitat, presence of stumps in the area). This paper presents selected results of the measurements taken of specific crops, as well as for easier interpretation and visualization – averaged assessment results for all crops in a given forest district. They were referenced to the entries of the current IOL in force to illustrate the degree of agreement between the data obtained using different assessment methods.

2. Materials and methods

The measurements were conducted in different years in the selected forest districts (Table 1), where *Pinus sylvestris* L. is artificially regenerated with seedlings from both open nurseries and container production, and naturally regenerated.

Table 1. Characteristics of measurement areas and used assessment variants

Forest District, Forest Subdistrict	Site type/No of cultures	Variant of assessment					Measurement, year of assessment
		MF	T100	Z	3x33+1	10 po 10	
Rudy Raciborskie Ruda Kozielska, Borowiec	BMśw/4	-	-	-	+	-	M. Małecka, 1997
Myszyniec, Warmiak, Rudne	BMśw/6	+	-	-	-	-	I. Miller, 2016
Potrzebowice Dziewanna, Osina	Bśw/3	-	+	-	+	-	M. Małecka, 1999
Spychowo	BMśw/2; Bśw/2	+	+	-	-	-	P. Bogumił, 2017
Miłomłyn-1, Bagieńsko	BMśw/2	+	-	-	+	-	R. Fil, 2015
Miłomłyn-2, Kaczory, Borsuki, Sarni Dół	LMśw/4	+	+	+	-	-	M. Krzaczek, 2017
Olsztyn Kośno	BMśw/2	-	-	+	+	+	J. Dębek, M. Damszel, 2019

Bśw – coniferous fresh site, BMśw – mixed coniferous fresh site, LMśw – mixed deciduous fresh site

Crops of similar age were selected for the assessment, planted after preparing the soil with a forest plough and identically spaced, or from self-seeding, in areas representing one or two forest habitat types (Table 1).

This paper presents the results of research on selected groups of diseases reported in accordance with the current IOL, using one, two or three methods, from among the following (Fig. 1a-f):

a) The phytopathological monitoring method 'MF' (Sierota, Lech 1996), modified, was used in 4 measurement plots and consisted of the random selection of the centre of plot 0, located at least 20 m from the outermost row of trees in the crop, delineating a circle with a 5.65 m radius and the selection of three consecutive plots of the same dimensions 20 m from the centre of plot 0 in the directions of 0°, 120° and 240°; the total measurement area of the 4 plots was 100 m².

b) The linear or strip transect method 'TL100' consisted of the random selection of one row of trees in the crop, located about 1/3 of the distance from the edge of the crop's width and marking out a strip 100 LM long and 1 m wide (Cieślak 2000); the measurement area of the transect was 100 m².

c) The '10 by 10' method, used in Sierota et al. (2000) and Hawrys et al. (2004), consisted of assessing the trees in 10 randomly selected rows, each 10 LM long; the first measurement row was 3–4 rows away from the crop's edge, and the subsequent ones were also 2–3 rows away from each other, depending on the width of the crop; the total measurement area of the strips was 100 m².

d) The '3x33+1' method consisted of delineating three transects with lengths of 33, 33 and 34 LM respectively and

a width of 1 m at a randomly selected location in the crop, 3–4 rows away from its edge. The transects were 5–6 rows of trees away from each other, covering the largest possible cultivated area (modification of method c); the total measurement area of the strips was 100 m²;

e) The '10×10' method consisted of delineating 2–3 10×10 m plots in randomly selected locations in the crop, at least 3 rows of trees from its edge; the measurement area of one plot was 100 m²;

f) The 'Z' method consisted of randomly selecting one crop row, 3–4 rows of trees distant from the edge of the crop and delineating the first strip with a length of 33 LM and width of 1 m, then delineating a second strip with a length of 34 LM and width of 1 m 'diagonally' across the rows (modification of method d) and then delineating a third strip with a length of 33 LM and width of 1 m at least 5–6 rows of trees away from the first strip; the total measurement area of the 3 strips was 100 m².

An assessment using each method was performed on each crop in two or three repetitions (depending on the size of the crop) in order to measure as large an area as possible; none of the plots in the crop using the specific methods overlapped spatially. Each measurement was converted to 1 ha and averaged.

All the trees were assessed in each of the plots. The number of trees and the number of losses were determined up to the time of the assessment, based on the spacing of the planting. Stumps occurring within the plot assessed with the given method were also recorded. Stumps located partly on the plot (on its border) were included in the assessment. The assessment involved recording the following characteristics of each of the assessed trees:
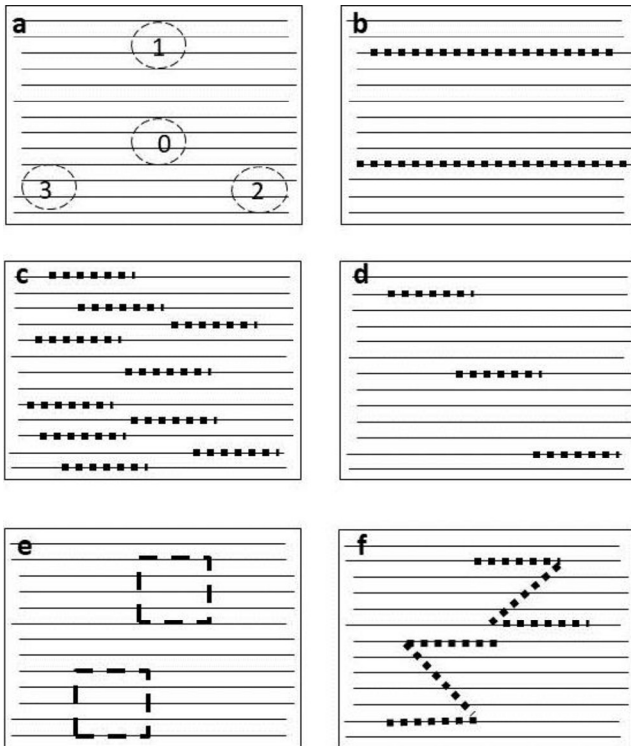
Figure 1. Diagram of the location of measurement plots in the plantation

Figure 2. An example of a tree rated on the needle discoloration scale 3 and with symptoms of *Armillaria* root rot – the picture does not show the rhizomorphs in the root neck (photo M. Krzaczek)

– the degree of needle discoloration (and/or crown thinning) on a scale of

  0 – no change;
  1 – discoloration/thinning to 30%;
  2 – discoloration/thinning to 60%;
  3 – discoloration/thinning over 60%;
  4 – dead, no needles (Fig. 2);

– etiological signs of pathogens:

  1 – assimilation apparatus and/or shoots;
  2 – root systems after uprooting the tree and eventualroot deformation; the assessment used a key to identify the infectious diseases of forest trees (Sierota, Szczepkowski 2014);

– signs of feeding and/or damage caused by insects, if any;

– signs of foraging by wildlife, unless the area was thoroughly fenced;

– etiological signs of fungi (mycelia, fruiting bodies, rhizomorphs) and symptoms of root wood decomposition on stumps.

The results obtained for each repetition of the measurement plot were added together, averages were calculated and then converted into 1 ha. For assessing the averages for the methods, habitats or plots (crops, forest districts), the chi-square and NIR$_{ANOVA}$ tests were used after first normalizing the distribution with log$_{10}$.

For selected crops, an inoculum density index (GI) was calculated, which is the quotient of the number of trees in the plot to the number of stumps; this index indirectly determines the degree of threat to the root systems of trees located in the vicinity of the roots of one stump (GI=N$_{drzew}$/n$_{pniaków}$).

For the purpose of this paper, the results were omitted on assessed tree damage caused by insects and animals, which was also recorded during the measurements in accordance with the proposed methods.

3. Results

3.1. Comparison of the condition of same-age crops assessed with one method

3.1.1. Assessment of the occurrence of assimilation apparatus and shoot diseases in Rudy Raciborskie Forest District

The areas were located in four 4- and 5-year-old Scots pine crops in an area that had experienced a fire in 1992. The assessments performed using the '3x33+1' method allowed not only the success of the regenerations to be determined in the conditions of a strongly changed soil environment, but also the pathological changes within the crown to be captured.

The performed assessments indicated that the examined crops were in poor health (share of diseased trees – 54.5–68.0%). The share of trees that had died up to the assessment period was small and was 10.1–17.0% by age (Table 2), but trees lacking any pathological symptoms only amounted to

Table 2. Share [%] of trees with etiological signs or other disease symptoms

Age [years]	Share of trees on the transects studied [%]					
	without symptoms	lack or died trees	needle cast	pine twist rust	several diseases	diseases average
4	25.0	17.0	41.0	10.0	7.0	**68.0**
5	37.0	10.1	38.0	6.4	8.5	**54.5**

25.0–37.0% respectively. The main causes of needle discoloration and drop were the pathogens causing pine needle cast (38.0–41.0%, respectively) and to a small extent, pine twist rust (6.4–10.0%). The occurrence of root pathogens at this age was not expected, not only due to the significant destruction of the inoculum (infected roots of burnt trees), but also due to the lack of secondary infections in the case of contact between the roots of the cultivated trees and the deeper roots of the previous generation.

In the light of the IOL (2012), these crops should be qualified as very heavily infected.

3.1.2. Assessment of the occurrence of pine needle cast in the Myszyniec Forest District

The visual assessment of the condition of the crop focused on the threat from pine needle cast, assessed on the basis of the appearance of the tree crowns – changes in survival (fallen trees, dead trees), the presence of etiological signs of causative agents, the degree of discoloration (foliage turning pale, rusting) and needle loss. Crown discoloration was associated with the occurrence of needle cast diseases (etiological signs) and their differentiation (no etiological signs) from the changes caused by drought (lack of precipitation and insolation). Such a preliminary assessment is done on the majority of crops in Poland, is often described as a total and frequently presented in IOL form no. 4 – as pine needle cast or abiotic diseases.

The assessment was performed in an area of six 4 to 5-year-old pine trees, which occupy a fresh mixed coniferous forest habitat in Myszyniec Forest District (divisions 95g, 96g, 83k in the Rudne Forest Unit and divisions 17b, 16d, 23f in the Warmiak Forest Unit). Three plots had artificially regenerated crops and three were naturally regenerated. In order to differentiate the causes of problems resulting from environment factors, the crops were located both in the vicinity of stands of younger or older age classes, as well as in the close vicinity of a national road or urbanized area. The measurements were made in three repetitions on each crop, on 4 plots of phytopathological monitoring 'MF', each with a radius of 5.65 m.

Healthy trees (75–90%) exhibiting no symptoms of needle cast (no etiological signs typical of the causative agent), or changes resulting from drought (uniform crown thinning or rusting) prevailed in the studied crops. 18–20% of the cultivated trees assessed at level 1 (changes encompass up to 30% of the needles in the crown) were characterized by some variability resulting from the location of crop in the stand, as well as the type of regeneration (natural – artificial). The proportion of this variability was reversed in the group of trees at level discoloration (representing only 3–11% of the total number of trees) –it was much higher in the artificially regenerated crops and lower in the naturally regenerated ones in the Warmiak Forest Unit(Fig. 3, left).

The results of the non-parametric Chi-square test confirmed that the naturally regenerated trees were in a worse health condition in terms of the average number of trees at individual levels of discoloration than those from the artificial regeneration. However, the differences between the averages for all crops were not large, which was confirmed by the coefficient of variation V [%], which did not exceed 7% for levels 0 and 1 (Fig. 3, on the right).

Reporting on the health status of the crop in relationship to pine needle cast or abiotic factors based on one averaged assessment (here as 'crop'), albeit in this case based on an in-depth tree survey of 72 circular plots, each with an area of 100 m^2, is information of a more statistical nature than factual. It does not describe the degree of the intensity of the threat (inoculum size resulting from the number of infected trees) or the degree of susceptibility of trees to other infections, resulting from the number of trees at discoloration levels 3 and 4 (e.g. root pathogens).

If a routine review of the crops and their assessment according to the proposed 'MF' method were conducted, information would be obtained that, on average, about 27% of the 4–5 year-old trees in the crops occupying the described habitat show symptoms of needle cast. According to §96 of the IOL, the area of this crop would be attached to the report on the occurrence of diseases (>10%), but assessed as threatened to an intermediate degree (§6.1.8.1p.3).

Are the 'MF' or '3x33' transect methods credible and the only ones to propose? This question can be answered by comparing the results of the assessment variants, which is described below.
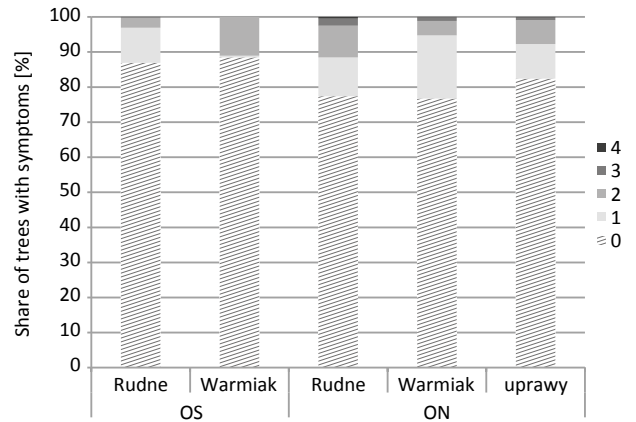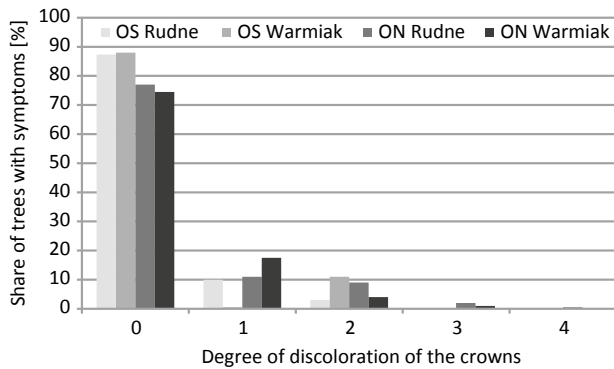
Figure 3. Share [%] of trees in artificial regeneration (OS) and natural regeneration (ON) cultures in. Rudne and Warmiak Forest Units – according to the degree of crown discoloration (left) and the cumulative share and value of the coefficient of variation V [%] for all crops (right)

3.2. Comparison of the condition of crops assessed with two methods

3.2.1. Assessment of the occurrence of pine twist rust in the Potrzebowice Forest District

The assessment was performed on three 5 year-old crops located in fresh coniferous habitat that was affected by a fire in 1992. The analysis used the linear transect method 'T100' and three shorter transects '3x33+1' in the same areas. Due to the widespread occurrence in 1996–1997 of pine twist rust caused by the heteroecious rust fungus *Melampsora populnea f. sp. pinitorqua* Boerema & Verh., the extent of the occurrence of this shoot disease was assessed. In addition, attention was paid to the share of trees with proleptic shoots, deforming the crown shape. Due to very similar results obtained by both linear methods, with a coefficient of variation for individual traits not exceeding 5%, the results were averaged, assuming that in the case of this particular disease, each of the performed methods provides an analogous result.

It was shown that, on average, the condition of crops in the post-fire area in the Potrzebowice Forest District was unsatisfactory. Only 41.4% of trees had what would be considered normal crown features, with no deviations (Fig. 4). The presence of the needle castfungi complex together with shoot deformations was recorded on 76.9% of the assessed trees and pine twist rust was found on 30.5% of the trees. The linear methods, with the random location of measurement transects, are easy to perform, usually work well in describing diseases whose infectious material disperses, and to a lesser extent, take into account the specificity of root diseases, whose inoculum spreads through outbreaks (clusters).

According to IOL (2012), the assessment of the described disease qualifies the examined crops as very strongly threatened by pine twist rust.
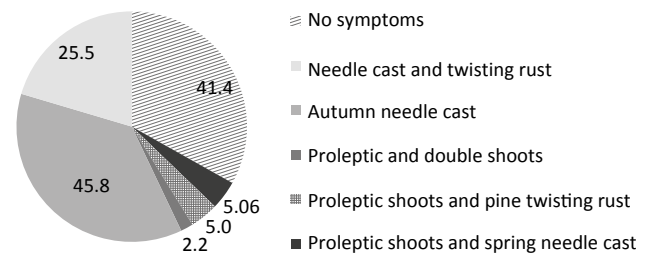

Figure 4. Average share [%] of trees without symptoms and with shoot deforestation and needle diseases in the area of regeneration after a forest fire in Potrzebowice Forest District

3.2.2. Assessment of the occurrence of root pathogens in Spychowo Forest District

The measurement plots were located in 4 crops of artificial regeneration after the removal ofa pine stand with an admixture of oak, occupying fresh mixed coniferous (105m, 117d) and fresh coniferous habitats (163h, 93Ag), each 5 years of age (Table 3). Due to the cluster character of the development of root diseases, also related to the presence of stumps in the stand, the areal 'MF' method was used in the assessment, while the linear transect method 'T100' was used for comparison, in two repetitions for each crop.

The number of trees per 1 ha indicates the presence of infected trees and the scale of possible corrections and additions, whereas the percentage of pathogens and the GI indicator indicate the degree of infection of a given crop, allowing for a prognosis to be made for the given stand. Comparing the share of pathogens in the same crops (Table 3) using two different methods gave different results, which is understandable given the way the assessment is performed and the different potential threat to the trees. This is due

Table 3. The number of trees and stumps within the assessed areas, the value of the GI index and the total share [%] of pathogens

Variant	Number per hectare		GI index	Pathogens per hectare		Pathogens average [%]
	trees	stumps		*Armillaria*	*Heterobasidion*	
Phytopathological monitoring MF						
MF 1	7021	1630	4.3	251	251	5.8
MF 2	6394	1253	5.1	502	125	8.2
105m Average	**6708**	**1442**	**4.6**	**376**	**188**	**6.9**
MF 1	11158	627	17.8	502	125	5.3
MF 2	13666	501	27.3	251	125	2.7
117d Average	**12412**	**564**	**22.0**	**376**	**125**	**3.9**
Average per site	**9560**	**1003**	**9.5**	**376**	**157**	**5.0**
MF 1	11158	376	29.7	376	125	3.9
MF 2	10281	250	41.1	376	501	8.3
163h Average	**10720**	**313**	**34.2**	**376**	**313**	**6.2**
MF 1	10281	501	20.5	502	125	5.8
MF 2	10406	626	16.6	627	376	9.1
93Ag Average	**10344**	**564**	**18.3**	**564**	**251**	**7.5**
Average per site	**10532**	**439**	**24.0**	**470**	**282**	**6.9**
MF average	**10046**	**721**	**13.9**	**423**	**220**	**6.0**
Linear transect T100						
T 1	9600	1000	9.6	200	0	1.9
T 2	9000	1200	7.5	400	300	6.8
105m Average	**9300**	**1100**	**8.5**	**300**	**150**	**4.3**
T 1	14300	800	17.9	600	300	6.0
T 2	12500	1200	10.4	900	100	7.3
117d Average	**13400**	**1000**	**13.4**	**750**	**200**	**6.6**
T 1	13400	1000	13.4	900	500	9.7
T 2	10300	1000	10.3	400	300	6.2
T100 Average per site	**11350**	**1050**	**10.8**	**525**	**225**	**5.5**
Average	**11850**	**1000**	**11.9**	**650**	**400**	**8.2**
T 1	13400	1000	13.4	900	500	9.7

| Variant | Number per hectare | | GI index | Pathogens per hectare | | Pathogens average [%] |
	trees	stumps		*Armillaria*	*Heterobasidion*	
T 2	10300	1000	13.4	400	300	6.2
93Ag Average	**11850**	**1000**	**11.9**	**650**	**400**	**8.2**
Average per site	**11850**	**1000**	**11.9**	**650**	**400**	**8.2**
T100 average	**11600**	**1025**	**11.3**	**588**	**313**	**6.9**
Four cultures average	**10823**	**873**	12.6	506	267	6.5

to the different inoculum density (GI index) in the stump roots in the different habitats – and thus possible secondary root infections. The value of this index varied in different sites of the examined crops – from GI=4.3 for MF1 in 105m to 41.1 for MF2 in 163h, and even in the same crop – in 117d, from GI=10.4 for T2 to 17.9 for T1. The presence of root pathogens in the crop was confirmed by assessments of weakened and dead trees showing etiological signs of the causative agents and the fungi *Armillaria ostoyae* (Romagn.) Herink and *H. annosum* (Table 3). On average, based on the assessments made in 2 repetitions on the 4 studied crops, both confirmed pathogens were recorded in 6.5% of the trees, but their share in the crops using both methods (MF and T100) was higher in the fresh coniferous habitat (6.9 and 8.2% respectively) than in the fresh mixed coniferous habitat (5.0 and 5.5%). The share of pathogens in the assessment of crops based on the individual methods also differed (Fig. 5).

The results indicate a large spread in the assessment of the threat to the crops occupying different habitats, up to 4% (MF2 and T100 1) depending on the assessment method adopted. In averaging the result characterizing the condition of the assessed crops at the same age in Spychowo Forest Inspectorate, which simulates the reporting using the IOL (2012), it should be stated that despite the share of infected trees in one of the crops at a level of 9.6%, the average does not exceed the determined boundary of 10%. However, it does provide information about the high potential threat to future stands, especially from *Armillaria* root rot.

3.2.3. Assessment of the threat of disease for crops of various ages in Miłomłyn Forest District

A 100 m long linear transect, even if randomly selected, gives a picture of a small fraction of the crop and does not fully inform about the actual threat of disease, so in addition to the 'MF' plot method, the assessment of trees in three shorter rows of 33 m each, 5–6 m apart, was used. A health analysis of trees in the category of 'up to 20 years' (IOL
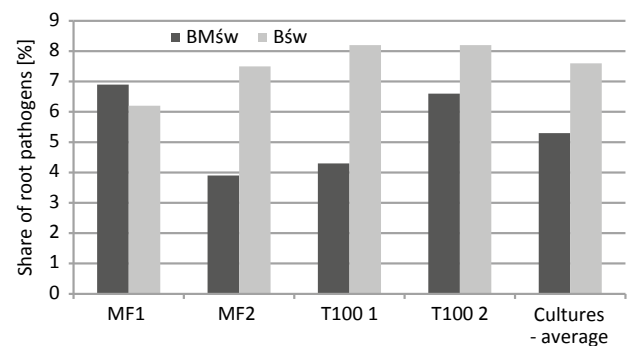

Figure 5. Share [%] of root pathogens together depending on the type of habitat (BMśw, Bśw) and assessment methods (MF and T100, in duplicate) and averaged rating for four crops in Spychowo Forest District

2012) was performed in the Bagieńsko Forest Unit of the Miłomłyn Forest District, to assess the health status of crops mainly aged 4 and 11 years, naturally regenerated in a fresh mixed coniferous forest habitat.

The assessments performed confirm the assumption that the trees are threatened at different levels depending on the type of method used, regardless of the age of the crops being assessed. Method 'MF' precisely informs about occurring diseases, both of a focal character (root pathogens) and of a surface character (needle cast fungi). On the other hand, the method of shorter transects located in three nearby rows allows a certain section of the crop to be described, but also importantly – the trees adjacent to the row, enabling the direction of secondary infections and the occurrence of needle and shoot diseases to be tracked, especially at a younger age. In the case in question (Table 4), the 'MF' method assessment showed an average of 9.3% of infected trees and 11% (10.1% on average) using the '3x33+1' method in younger crops. On the other hand, in older crops, the share of infected trees was 6.6% and 7.0% (average 6.8%), respectively.

By averaging the similar results of both methods for IOL reporting (IOL 2012), a theoretical stand threat score of 8.5% – and therefore 'no threat' – is obtained for stands up to 20 years of age. Is this consistent with the actual condition and a good prognosis for these stands?

3.3. Comparison of the condition of crops assessed with three methods

3.3.1. Crops of various ages in Miłomłyn Forest District (2)

The measurement areas were located in 4 crops in the Miłomłyn Forest District (2), occupying a fresh mixed broadleaved habitat, aged 4 and 8 years respectively. Due to the fertile habitat and species composition of the previous stand, in which the share of deciduous species was significant, etiological signs of the fungus *A. ostoyae*, the cause of *Armillaria* root rot, were expected.

The health assessment of the trees was performed using three methods: 'MF', 'T100' and 'Z'. As expected, this pathogen dominated among the weakened and dead trees, reaching the number of 250 trees/ha using the 'MF' and 'Z' assessment methods, which indicates a significant scale of planned corrections and additions. In the same plots, annosus root rot was also recorded, which occurred with greater intensity using method 'MF' than 'Z'. (Fig. 6).

The scale of the threat to the 4 studied crops indicates a varied, despite being averaged, picture of their health condition (Fig. 7). In these age-differentiated crops, a) younger (4 years old) and b) older (8 years old), the averaged share of root pathogens did not exceed 5%, but this was differentiated locally – the highest in the older crop in division 75d, where it was 6.8% (data not presented).

All the areas were dominated by *Armillaria* root rot. Symptoms of this disease were found on 2–4.5% of the number of trees with etiological signs, while annosus root rot was recorded on 0.9–2.3% of trees. According to the IOL methodology (2012), these crops would qualify as 'healthy'.

3.3.2. Crops of the same age, general assessment of the trees in Olsztyn Forest District

Observations of the health condition of the artificial regeneration in 4-year-old pine tree crops in Olsztyn Forest District were performed in divisions 436d and 437h, occupying a fresh mixed coniferous habitat. The trees in each of the assessed areas were analysed twice in three repetitions for each of the three adopted methods (3x33+1, 10×10, Z). The condition of needles, etiological signs on trees, the condition of the root system of damaged trees, as well as other assimilation apparatus damage resulting from biotic factors (e.g. insect feeding) affecting the general condition of trees were taken into account.

Table 4. Share [%] of infected trees in crops from natural regeneration assessed using the 'MF' method and the '3x33+1' method in individual repetition of the assessment

Age [years]		MF method		Linear method (3x33+1)	
		plot No.	pathogens [%]	transect No.	pathogens [%]
4 years	repetition 1	0	7.0		
		1	12.0	1	12.1
		2	5.7	2	14.7
		3	12.9	3	6.1
		average	9.7	average	**11.0**
	repetition 2	0	5.1		
		1	13.4		
		2	12.0		
		3	7.6		
		average	8.8		
	Average cultures		**9.3**		
11 years	repetition 3	0	3.7		
		1	3.5	4	6.1
		2	0	5	8.8
		3	9.3	6	6.1
		average	4.2	average	**7.0**
	repetition 4	0	12.1		
		1	6.9		
		2	10.2		
		3	6.8		
		average	9.0		
	Average cultures		**6.6**		

Depending on the location of the plot and the assessment method adopted, different results of needle and root disease severity were obtained (Table 5). The lowest deviation of assessment error was obtained (coefficient of variation V=8.6%) in the analysis of the degree of infection by needle cast fungi, which indicates a fairly stable level of threat, relating more

to the size of the fungus's inoculum and the susceptibility of the trees than to the adopted assessment method. Significant differentiation in the assessment depending on the adopted method was obtained in the analysis of the occurrence of root pathogens *H. annosum* and *A. ostoyae*. The scope of the assessments on root pathogen infections differed between the plots by 5.3% to even 22.6%. Taking into account the life cycle of root rot fungi and the forms of their occurrence in the environment, such a large spread in the assessment data may result not only in the lack of a proper diagnosis and identification of potential long-term disturbances, but also in the inappropriate planning of silviculture work.

All three tested methods of assessing the health of *Pinus sylvestris* were useful in estimating the degree of crop infection, however, the smallest differences in measurement deviation between the crops were recorded using method Z (V=8.5%), which has transects placed diagonally across the study plot. Each of the methods indicated different, dominant threats to the particular crops, which indicates that every assessment subject should be treated individually and simplifications should be avoided (Table 5).

4. Summary

In terms of the share of symptoms of crown discoloration on younger crops, a high degree of conformity of threat assessments is noted, regardless of the method used. On older crops, on the other hand, some quantitative differences among such trees were noted, depending on the assessment method – the lowest occurred when assessing with method Z and the highest with method MF. Crown discoloration, however, cannot be a reliable symptom of health condition without indicating the most probable cause. Crown rusting
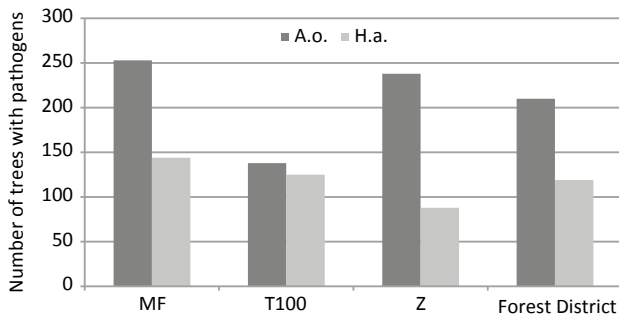
Figure 6. Average number (pcs/ha) of trees with etiologic signs of the *Armillaria ostoyae* (*A.o.*) and *Heterobasidion annosum* (*H.a.*) in the studied cultures based on evaluation by three methods (MF, T100, Z), and averaged for Miłomłyn Forest District
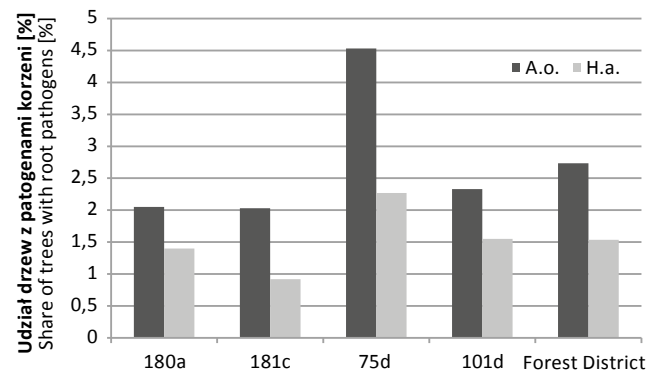
Figure 7. The average share [%] of trees with etiological signs of *A. ostoyae* (*A.o.*) and root rot (*H.a.*) on 4 examined areas and the average for cultures in Miłomłyn Forest District

Table 5. Assessment of damages (% of trees with symptoms) in the studied Scots pine cultures

Plots	436di			437h			Average [%]	Coefficient of variation V [%]
	assessment method							
Symptoms	3x33+1	10×10	Z	3x33+1	10×10	Z		
No symptoms	45.8	59.1	63.4	67.0	68.2	57.8	60.2	9.9
Non-specific needle discoloration	18.8	23.7	118	12.2	11.1	15.8	15.6	24.8
Needle cast	12.8	10.5	11.9	15.5	12.0	12.6	12.6	8.6
Root diseases	**22.6**	**15.7**	**12.9**	5.3	8.2	**13.8**	**13.1**	**32.7**
Other	0.0	0.0	0.0	0.0	0.5	0.0	0.0	-
Location of symptom dominance	roots	crown	roots	needles	needles	crown		

Bold – dominance > 10%

is a symptom that can be seen after wildlife browsing, pericambial insect feeding, grubs foraging on roots, as a result of infectious diseases – needle cast or root diseases, and drought (Sierota 1988b). The assessment methodology should therefore take into account the specificity of the formation and development of a given phenomenon and enable the symptoms to be more accurately differentiated. The consequences of the presence of root pathogens in the soil (also in the stumps remaining in the crop) are different, as are those of other diseases such as needle cast, or drought.

In the case of root pathogen assessments, assuming that all etiological signs of the causative agents can be identified without genetic analysis, it can certainly be argued that the future (sustainability) of the stand is at stake. The time remaining for the application of appropriate felling or the need for premature felling depends on the level of the threat when the crop is already several years old. Therefore, a proper assessment of its condition, preceded by a good knowledge and understanding of phytopathology and the development of forest diseases, is essential.

This paper presents examples of the results of different assessment methods used at different ages of crops, varying in their threat from different pathogens. Such are the realities of the assessments performed in the field. For assessments to be reliable and repeatable, devoid of estimates and randomness, they should be based on an appropriate methodology – fairly universal and simple to perform on the one hand, reliable, adapted to the current and properly identified health condition on the other.

The presented results indicate the need to flexibly adapt the assessment to the current local threat. Using one method, it is possible to obtain different results when assessing the occurrence of diseases of the aboveground parts of trees, and other results for root diseases. According to the IOL methodology (2012), many of the crops assessed here would be reported as 'disease-free'. The obtained results confirm the need to individually analyse the assessed areas, both in terms of the occupied habitat and the threat of infection.

In general, based on the results obtained in terms of recommending a uniform assessment of the health status of crops, ensuring the highest possible reliability and indicating the necessary conditions for its implementation (different age, habitats, method of establishment, etc.), the following conclusions can be made:
• The health status of crops (based on the example of the studied forest districts) is differentiated mainly by the share of root pathogens, which is facilitated by the traditional method of soil preparation, the presence of stumps, and planting using the slit method with a planting bar;
• Crown discoloration and thinning is an additional indicator of changes in the root systems – they should be differen-tiated depending on the presence of the etiological signs of needle (needle cast) and shoot diseases (*Sphaeropsis sapinea* [Fr.] Dyko & B. Sutton, *Gremmeniella abietina* [Lagerberg] Morelet, *Melampsora pinitorqua*) and drought-induced changes (in the absence of the etiological signs of pathogens);
• The main threat to the studied pine crops in forest districts of the Regional Directorate of State Forests in Olsztyn is *Armillaria* root rot, whose share in more fertile habitats exceeds 5% of the number of trees, and locally, together with annosus root rot, even 20%;
• The presence of *Armillaria ostoyae* in the studied plots is explained by the relatively large number of stumps remaining from the previous stand (probably not protected using the biological method), ploughing (which stimulates the development of the pathogen's rhizomorphs in the soil) and the introduction of a high proportion of pine trees in this fertile habitat;
• The assessment of the crops using the phytopathological monitoring method 'MF' and method 'Z' indicates the presence of pathological changes in trees to a greater degree than the other assessment methods, especially the T100 transect method.

Similar studies should be conducted under different physiographic and geographical conditions, with different crop species composition and different threats of infection in order to confirm the obtained results recommending the 'MF' and 'Z' methods as the most reliable and repeatable methods of assessing and monitoring forest health conditions at the forest district level.

Conflicts of interest

The authors declare the lack of any potential conflicts of interest.

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Authors' contribution