Case Study of bacteria associated with acute oak decline in an oak stand in Central Germany

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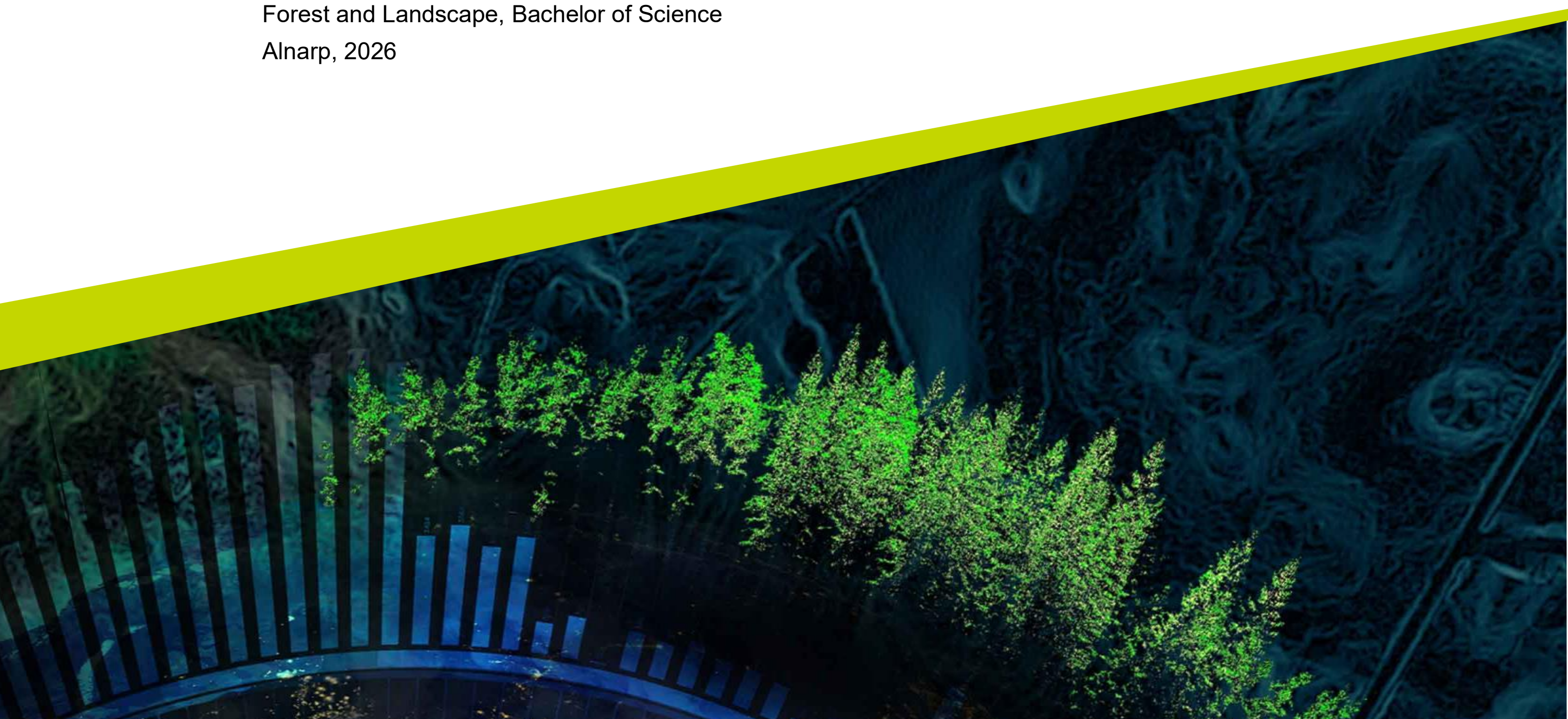

Case Study of bacteria associated with acute oak decline in an oak stand in Central Germany

Fallstudie av bakterier associerade med akut ekdöd i ett ekbestånd i centrala Tyskland

Clarissa Sophia Schimmel

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Abstract

Acute Oak Decline (AOD) is an emerging disease affecting oak stands across Europe, associated with symptoms like stem lesions, slime flux, and rapid tree death. This study investigates the occurrence and special distribution of AOD in a Sessile Oak (*Quercus petraea*) stand in Central Germany, combining a full stand inventory with field assessments and laboratory analysis.

A total of 451 trees were surveyed, recording tree characteristics, mortality, and AOD-associated symptoms. Bark samples out of lesions from 18 trees were analyzed using quantitative qPCR to detect the bacteria *Brenneria goodwinii*, *Gibbsiella quercinecans*, and *Rahnella victoriana*. The mortality in the stand increased to 14.4% of all trees in 2026, and lesions were widespread among living oaks. However, no clear special pattern of symptoms was identified. All three AOD-associated bacteria were detected, particularly in the lower slope part of the area, with *B. goodwinii* occurring most frequently. The results indicate that AOD is driven by a combination of biotic and abiotic stressors rather than a single causal factor. Drought, pest pressure, and stand conditions likely reduce tree vitality and promote disease development. The findings support the concept of a complex host-microbe interaction, in which *B. goodwinii* may persist endophytically within the host at low levels, while other bacteria are more associated with the surrounding environment. The pathogenicity of the bacteria seems to be triggered by the interaction of these bacteria in combination with host stress.

Overall, the study highlights the importance of maintaining stand vitality and continued monitoring to better understand and manage AOD in forest ecosystems.

Keywords: Acute Oak Decline, disease complex, forest health, phytopathogenic bacteria

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Finally, I would like to thank everyone else who contributed to this work through their advice, assistance, and encouragement.

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Abbreviations

Abbreviation	Description
AOD	Acute oak decline
DBH	Diameter at breast height
FM	Field maple (*Acer campestre*)
HAW	Common hawthorn (*Crataegus monogyna*)
SLI	Small-leaved lime (*Tilia cordata*)
SOK	Sessile oak (*Quercus petraea*)
SP	Scots pine (*Pinus silvestris*)
WST	Wild service tree (*Sorbus torminalis*)

1. Introduction

Climate change is placing increasing pressure on our forest ecosystems. In recent years, mean annual temperatures have risen, alongside repeated drought periods, with increased mortality (Hartmann et al., 2022). These changing conditions stress trees, weakening their defenses and making them more susceptible to pests and pathogens (Gullino et al., 2022; La Porta et al., 2008). This phenomenon is observed in wide parts of the forest ecosystem, also in broadleaved forests, especially in oak forests (Oak et al., 2016).

Oaks (*Quercus spp.*) are an important tree species across Europe with ecological, cultural, and economic importance (Altenkirch et al., 2002; Nicolescu et al., 2025; San-Miguel-Ayanz et al., 2016). The genus has long been considered as one with very low risk for damage, but the decline of oak trees is an increasing phenomenon that, especially with a changing climate, has gained more attention in forest health research (Altenkirch et al., 2002; Prien, 2016). Damaging agents of oak in Europe have been mostly leaf-eating insects, bark-breeding beetles, fungi, or Oomycetes like *Phytophthora spp*. (Hoch and Cech, 2021). Bacterial plant diseases have predominantly been of concern to agricultural systems (Dennert et al., 2024; Schumann, 1991) rather than forestry. Though there are notable exceptions, for example, *Xyllela fastidiosa,* which has been causing tree decline (Desprez-Loustau et al., 2021). However, in recent years, bacteria have also been identified as causal agents of newly emerging oak decline symptoms. A polybacterial disease called acute oak decline (AOD) is posing an emerging threat to oaks across Europe. Acute oak decline is capable of killing affected trees within just a few years and has already caused significant damage and mortality in oak stands in the UK (Denman and Webber, 2009).

Even though AOD is a relatively new disease, it has been recorded in several countries in Europe. Despite the growing impact of the disease, there is still a significant knowledge gap regarding its origin and patterns of distribution. Because AOD is considered a disease involving multiple interacting biotic and abiotic factors (Bene et al., 2025), this study focuses on a set of measurable variables that can be quantified consistently across the studied area: tree size (DBH), topographic position (slope), lesion abundance, and the presence of AOD-associated bacteria. Accordingly, the central research question is: How are topographic position (slope), DBH, mortality, and the occurrence of AOD-associated bacteria related to the distribution of acute oak decline symptoms within an oak stand in Central Germany?

To address this research question, a field-based case study was conducted, combining a full inventory of trees with detailed measurements of symptoms and laboratory analysis of the AOD-associated bacteria. The findings are intended to contribute to a broader understanding of this emerging disease.

1.1 Disease Complex on Oak

Although AOD has only recently been recognized as a threatened disease in forest research, symptoms of oak decline have been noticed over Europe at least since the past century (Altenkirch et al., 2002; Biosca et al., 2003; Butin, 2011; Hartmann et al., 1989; Vansteenkiste et al., 2004). The phenomenon of oak decline exists over the majority of the distribution area of *Quercus spp.* (Prien, 2016). Oak decline is caused by the interaction of abiotic and biotic stressors, which can have different impacts depending on the area itself (Altenkirch et al., 2002; Bene et al., 2025; Prien, 2016). This interaction makes it a disease complex because multiple factors need to be taken into account to understand its biology. Depending on the number of stressors and interactions between the abiotic and biotic factors, symptoms can be expressed differently (Butin, 2011; Prien, 2016). The stressors can occur simultaneously or sequentially as a "chain disease" (Prien, 2016). A disease complex of oak has been shown to occur especially after extreme weather changes (Prien, 2016). Drought, in conjunction with the disruption of the water supply (Hoch and Cech, 2021), is a crucial abiotic stressor of oaks. This is often followed by pests like leaf-eating as well as wood-boring insects and pathogens like *Phytophthora spp.* or *Armillaria spp.* (Hartmann and Grüner, 2025; Prien, 2016). Acute Oak Decline is also described as a multifactorial disease, making it part of the complex diseases of oak as well (Bene et al., 2025).

1.2 Acute Oak Decline

1.2.1 AOD-associated Bacteria

The most associated bacteria with AOD are *Brenneria goodwinii* (Denman et al., 2012), *Gibbsiella quercinecans* (Brady et al., 2010), and *Rahnella victoriana* (Brady et al., 2014). Like the majority of bacteria, they are heterotrophic, but also show behavior of saprophytes in infected tissue. This means they are not able to synthesise organic carbon by themselves and need to take it up from other sources (Schumann, 1991). As saprophytes, nutrients are also obtained from non-living material (Schumann, 1991).

These saprophytes and bacteria have been increasing in trees, which together display symptoms of AOD (see chapter 1.2.2). *B. goodwinii* and *G. quercinecans* appear to play the largest roles in diseased and weakened oak trees, with both having the ability to cause necrosis. Because of this, AOD is described as a polymicrobial disease, with the interaction of the bacteria at the same time proposed to have a synergic effect and, following, being pathogenic as well as being part of active tissue degradation, and with that, also the factor of lesion formation (Broberg et al., 2018; Denman et al., 2016; Denman et al., 2018). *Brenneria goodwinii* appears to be more dominant in the virolance-associated activity of AOD-symptomatic trees (Broberg et al., 2018; Tkaczyk and Sikora, 2024). *Rahnella victoriana* has similarly been commonly recovered in trees but in both healthy and infected individuals (Denman et al., 2016), but so far, its role within AOD is not well understood (Bene et al., 2025; Denman et al., 2018).

1.2.2 External Symptoms

External symptoms of bacterial diseases can be very similar to those caused by fungi. Therefore, it can be quite difficult to determine the causal agent just by the visual symptoms (Schumann, 1991).

Denman et al. (2014) define these symptoms in relation to AOD. Stem bleeding is one of the most obvious symptoms indicating AOD (Fig. 1). Lesions can occur 30-50 cm above ground up to five meters up on the trunk of the tree. Fresh lesions can be seen early in spring, up until June, as well as in autumn (October -

November). The fluid is dark in color, and there is no specific aspect to the location on the stem where the bleeding occurs. Early stages of the infection can be suspected because of cracks in the bark, which can vary in length from 3 - 22 cm (Denman et al., 2014).

Figure 1: Formation of lesions following cracks in the bark of sessile oak (Quercus petraea) with dark colored slime flux.

These symptoms can be mistaken for other agents causing infections in the tree, as described in the following. Cracks can be caused by severe frost or droughts, but are much deeper than those associated with AOD (Denman et al., 2014). The fungal pathogens of *Phytophthora spp.* and *Armillaria spp.* expresses itself as well with bleeding cankers on the stem of the tree. They usually only appear around the base of the stem, compared to lesions caused by AOD, which also appear in higher parts of the trunk (Denman et al., 2014). Stem bleeding can also be an indicator of an attack of *Agrilus spp.* (Coleoptera, Buprestidae), first described by Falck (1918) in Germany. The lesions would mark the feeding tunnels of the larvae as a defense mechanism of the tree, following the boring of the insect larvae (Vansteenkiste et al., 2004). This type of lesion cannot be differentiated from those caused by AOD (Denman et al., 2014).

1.2.3 Distribution and Spread

First detected in 2009 in England, AOD was described by Denman and Webber (2009). Since then, it has spread over the European mainland and has been detected in northern Spain (González and Ciordia, 2020), Portugal (Fernandes et al., 2022), France (Eichenlaub et al., 2024), Switzerland (Ruffner et al., 2020), Austria (Hoch and Cech, 2021), southern Italy (Carluccio et al., 2024) as well as Slovakia (Tkaczyk et al., 2024), Poland (Tkaczyk and Sikora, 2024), Latvia (Zalkalns and Celma, 2021) and Sweden (Knapp et al., 2025). The disease has mainly been found in *Quercus robur* and *Q. petraea*. However, there have been detections of the AOD-associated bacteria also in *Q. suber* (Fernandes et al., 2022), *Q. ilex* (Carluccio et al., 2024), *Q. cerris* and *Q. pubescens* (Ruffner et al., 2020).

In Germany, the first detection was in the southern part of the country in 2022 (Bayerische Landesanstalt für Landwirtschaft, 2022). In 2023, it was detected in a pure oak stand of *Q. petraea* in the state of Thuringia, located in central Germany. At this site, sampling was done at three trees, which all tested positive for one of the bacteria individually, indicating a potentially bigger outbreak of the disease (Wenzel et al., 2024).

Symptomatic trees are more commonly found in warmer regions with lower rainfall, where the availability of water is limited (Brown et al., 2018). Because of a changing climate, drought is a widely spread stress factor for the forest ecosystem, which was proven to make the trees more susceptible to the disease and support the spreading of the bacteria, especially *Brenneria goodwinii* (Zolfaghari et al., 2022). Schumann (1991) states that, unlike fungi, pathogenic bacteria do not spread over long distances through the air because they do not produce endospores. They primarily rely on dispersal via water, wind-driven rain, insects, birds, and contaminated tools or machinery (Schumann, 1991). Because of their saprophytic behavior, some can survive in the soil, at least until the tissue is removed (Schumann, 1991). Bacteria can also commonly persist in cankers of their host plant, as well as in seeds or other propagative tissues (Schumann, 1991). Bacterial diseases are a common phenomenon in warm and humid areas (Schumann, 1991).

1.2.4 Role of *Agrilus biguttatus*

Insects can act as vectors for pathogens (Macháčová et al., 2022) like in the Dutch elm disease (Santini and Faccoli, 2015) and numerous other forest pathosystems. Near the start of AOD research, it was assumed that the two-spotted oak buprestid (*Agrilus biguttatus*) could act as a possible vector of AOD-associated bacteria (Denman et al., 2014; Denman and Webber, 2009). Brown et al. (2018) demonstrated that the galleries of the beetle are associated with the exit points of the lesions, which are a typical symptom of AOD. Denman et al. (2014) also found that stem bleeding is co-occurring with galleries of the beetle in >90%.

The warm loving insect prefers trees with thick bark. The characteristic D-shaped exit holes can be found mostly on parts of the trunk facing direct sunlight. It infests the trees, especially in the lower part of the trunk up to the first larger branches. *A. biguttatus* is a secondary pest that occurs mostly after the trees have been physiologically damaged by leaf-eating pests, experienced damage to the root system, or abiotic stressors (aid infodienst Ernährung, Landwirtschaft Verbraucherschutz e.V., 2014; Ebner, 2012).

However, the hypothesis of *A. biguttatus* being a vector of the bacteria has not been supported, and more recent research shows that oak trees can be infected with AOD without displaying signs of the beetle (Zalkalns and Celma, 2021). It is worth noting that Cambon et al. (2023) found that larval-associated chemicals elicit an increase in the bacterial growth rate of *B. goodwinii*, strengthen the pathogenic reaction of the bacterium, and, with that, initiate tissue degradation. This would also be applicable for the larvae of other bark-boring insects, which can produce these types of elicitors as well (Cambon et al., 2023). Denman et al. (2018) also found that the larvae potentially spread the bacteria within the tissue, which is followed by new breakout points of the lesions.

1.3 Aim and Hypotheses

A field-based case study was conducted in an oak stand in central Germany previously affected by AOD-associated symptoms. A full stand inventory was combined with spatial mapping of symptoms, measurements of tree and stand characteristics, and laboratory detection of AOD-associated bacteria using qPCR analysis of bark samples. These methods were used to investigate potential relationships between bacterial occurrence, symptom distribution, stand structure, and topographic position within the stand.

Since previous studies at the site detected each of the AOD-associated bacterial species in three individual trees (Wenzel et al., 2024), it is possible that the bacteria have spread further within the stand since the initial detection. Following this, it is hypothesized that (H1) the number of trees infected with AOD-associated bacteria in the stand has increased since the first sampling in 2022 and shows spatial spread along the slope.

Based on acute oak decline being associated with rapid tree decline and mortality (Denman and Webber, 2009), tree mortality in the stand is hypothesized to be higher than during the first inventory of the stand (H2).

The main symptoms of the disease are lesions induced by bacteria that block the sap flow within the tissue of the tree, resulting in cracks in the bark and an exuding sap. Since lesions occur on the bark (Denman et al., 2014) and larger trees provide a greater bark surface area available for colonization, it is hypothesized that (H3) tree size (DBH) influences lesion abundance, with larger trees exhibiting a higher number and size of lesions.

Water is considered an important factor in the dispersal and survival of many bacteria (Schumann, 1991). Since the studied area has a significant slope, water availability and soil depth are assumed to be greater downslope than upslope (Tromp-van Meerveld and McDonnell, 2006). Because water availability also influences sap flow within the tree, and following the appearance of lesions, it is hypothesised that (H4) the slope of the studied area affects the abundance of AOD symptoms and lesions, with fewer symptoms in the higher slope compared to the lower part.

2. Materials and Methods

2.1 Description of the Study Area

The study area was located in the state of Thuringia in Central Germany (Fig. 2a). It is a municipal forest of the city of Bad Collberg-Heldburg and belongs to the forest district of Heldburg (Fig. 2b).

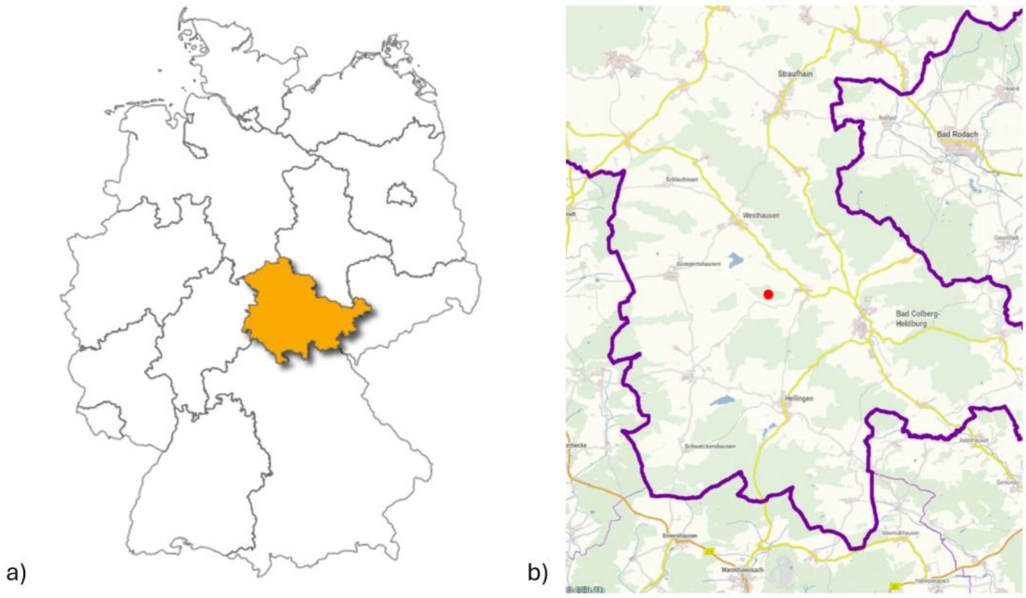

Figure 2: a) Map of Germany highlighting the state of Thuringia (GermanSights.com, 2026). b) Zoomed map, showing the forested area near the city of Bad Collberg-Heldburg, Germany (Behrens, 2018). The red dot marks the place of the forested area with the investigated stand.

Based on the last forest inventory and management plan (see Appendix, Fig. A1), the study area is part of a 7.77 ha strand dominated by sessile oak (*Quercus petraea*, SOK) with younger small-leaved lime (*Tilia cordata*, SLI), wild service tree (*Sorbus torminalis*, WST), hornbeam (*Crataegus monogyna*, HBM), and field maple (*Acer campestre*, FM). According to the management plan with a qualifying date of 01.01.2017, the oaks are 149 years old with an average height of 21 m, an average DBH of 42 cm, and a basal area of 32 m^2. The trees are standing quite dense with a closed canopy cover (Fig. 3). The soil is nutrient-rich and characterized by moderately dry clay subsoil. The loamy-sandy topsoil of this area typically forms a cambisol (Thüringer Landesanstalt für Wald und Fortwirtschaft, 1997).

Figure 3: Crown density of Quercus petraea trees within the studied area near the city of Heldburg, Germany.

The stand is located on the south-facing side of a ridge, ranging from 315 – 350 meters above sea level with a slope gradient of 31% (Fig. 4). On the southern edge of the stand, it is bordered by an agricultural field, and on the northern edge, the stand is separated from another stand by a logging road.

Figure 4: Monocultural Sessile Oak (Quercus petraea) stand near the city of Heldburg, Germany. All trees within the study area have been numbered individually with spray paint.

The stand is part of the Natura2000 area 5730-303 "Wälder im Grabfeld" with a habitat type of bedstraw-oak-hornbeam forest (Bundesamt für Naturschutz, 2019), but is used as a production forest. Nevertheless, there have not been any commercial logging operations in the stand for at least 10 years. Because of that, no strip rows are visible in the stand.

The studied area has a size of 8,665 m^2 and is based on a previous study from 2018, which investigated the presence of *Lymantria dispar* in the stand (Behrens, 2018). The location of the studied area was chosen to represent the stand as well as the hillslope (see Appendix, Fig. A2). In 2018, every tree in the selected area with a DBH higher than seven centimeters was numbered in lines parallel to the slope, starting from the lower part to the top. Digitally, the area was divided into three main parts based on the slope: down-, mid-, and upslope (Fig. 5), with every tree belonging to one part of the slope (Behrens, 2018).

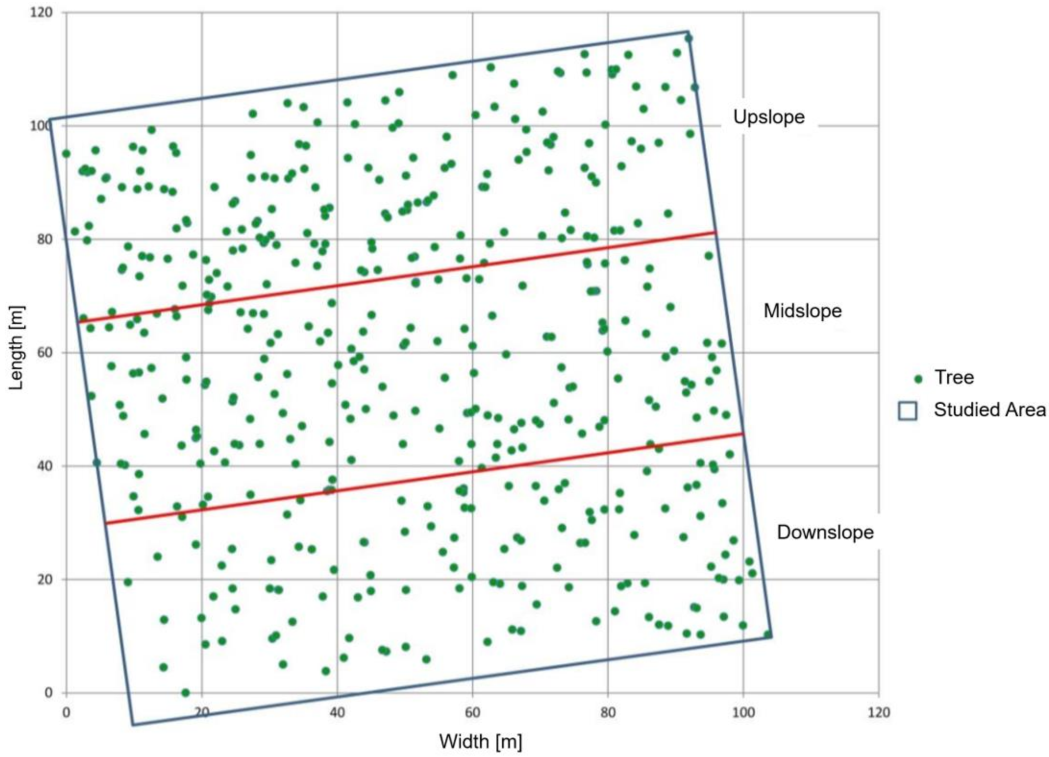

Figure 5: Tree map of the studied area with division of the slope parts (Behrens, 2018).

2.2 Survey of the Trees within the Study Area

In order to gather data for the testing of hypotheses H2, H3, and H4, the following measurements were done. From every tree in the studied area, the tree species was identified and then measured for diameter at breast height (DBH) with a circumference measuring tape. Visually, Kraft's class was recorded to assess the social standing of the tree within the stand, depending on the height and the formation of the crown (Kraft, 1884). It is divided into five classes: 1) predominant, 2) dominant, 3) codominant, 4) intermediate, and 5) overtopped or dead. Up to a height of two meters on the stem, visible egg masses of spongy moth (*Lymantria dispar*) or nests of oak processionary moth (*Thaumetopoea processionea*), lesions, and cracks in the bark were counted. The height of two meters was chosen in order to reduce the error of lesions being overlooked without the support of further tools. Because of the high number of trees that were surveyed, additional measurements, like the usage of a ladder in order to reach higher heights, were seen as not manageable and critical for work safety. Furthermore, notes were taken if there were symptoms or signs of pests causing damage to the trunk, e.g., woodpecker holes or exit holes from insects such as jewel beetles (*Agrilus spp.*). Other abnormalities that could have a relation to AOD were noted as well; for example, crown abnormalities like damage based on dead branches, secondary crown formation, indicators of other insects, damage to the trunk, or if the lesions were fresh. The data collection was conducted during week 11 in 2026. The full table can be found in the Appendix (see Appendix, Table B1).

2.3 Sample Trees and Labwork

In order to test hypotheses H1 and H4, six trees on each slope section were selected randomly for a detailed analysis of the lesions, as well as testing in the laboratory for all three bacterial species related to AOD (*B. goodwinii, G. quercinecans, R. victoriana*). The number of sample trees (N=18; 6/slope) was chosen based on the capacity of the laboratory. To maximise the likelihood of detecting AOD-associated bacteria within the available sample size, only living oak trees displaying at least one visible lesion were included in the selection.

The criteria for the selection were that a tree should be alive, and at least one lesion had to be present on the trunk. To obtain an impression of the special distribution of the bacteria within the stand, six trees were sampled from each slope section. In Excel, the RANDBETWEEN – function (=INDEX(XX: XXX; RANDBETWEEN(1; ROWS(XX: XXX)))) was used to randomly select those trees.

For a detailed analysis of the lesions on the 18 selected trees, every lesion that was counted before was measured crosswise in width and length with a meter stick. The height of the lesion on the trunk was noted as well. The location for the height on the trunk is based on the estimated exit of the slime flux out of the stem. The orientation was noted as well. The table can be found in the Appendix (see Appendix, Table B2). All data, which was collected in the stand, was noted by hand and later on transferred to Excel for analysis.

A statistical analysis was done using the Kruskal–Wallis test followed by Dunn's post hoc in order to test for H2. A Spearman rank correlation test was done in order to test for H3. These non-parametric methods were used because preliminary assessments showed that the data were not normally distributed. The tests were done in R. The script can be found in the Appendix (see Appendix, Fig. C1)

To test for AOD-associated bacteria, bark samples with slime flux on them were taken from the trunk because the amount of bacteria was assumed to be the highest in the lesions. If possible, the samples were collected by hand, wearing one-time usable gloves that were changed after each tree to prevent cross-contamination. The material was collected in separate sterilized containers (Fig. 6a), which were marked with the individual tree number after closing the lid. If necessary, a scalpel was used to remove pieces of the bark (Fig. 6b). The used tool was sterilized on site after every use with Meliseptol® rapid (Fig 6c).

Figure 6: Method and materials for the bark sampling. a) The bark samples were collected directly from the lesions in a small container using one-time gloves for each tree. b) If necessary, a scalpel was used to cut out bark pieces. c) Sterilized and individually sealed containers were used. A permanent marker was used to mark the samples with the individual tree number. If the scalpel was used, it was disinfected after every usage with Meliseptol® rapid.

Nine samples were taken on 16/03/2026, and the other nine on 27/03/2026 (Fig. 7). Until further analysis, the samples were stored in a fridge at 4°C for three days and then shipped to the lab for immediate analysis. To test for AOD-associated bacteria in the laboratory, a quantitative PCR (qPCR) method was used (Crampton et al., 2020). The testing was done in the Northwest German Forestry Research Institute in Göttingen. To extract the DNA, the E.Z.N.A. SP Plant DNA Kit (by Omega Bio-tek) was used. Deviating from the manufacturer's protocol, a retching step with 20-30 mg of drill dust and three millimeter metal balls was applied. Every sample was tested for all three bacteria associated with AOD.

Figure 7: Isolated bark samples of the 18 sampled trees (Quercus petraea) from the studied area (images taken by Steffen Bien).

3. Results

3.1 Stand Description

Within the studied area, the 451 trees of (Behrens, 2018) were identified again. The stand is dominated by sessile oak (*Quercus petraea,* SOK), at 70%, followed by 16.6% small-leaved lime (*Tilia cordata*, SLI) and 13.2% wild service tree (*Sorbus torminalis*, WST). Single trees of Scots pine (*Pinus silvestris,* SP), field maple (*Acer campestre*, FM), and common hawthorn (*Crataegus monogyna,* HAW) (Fig. 8).

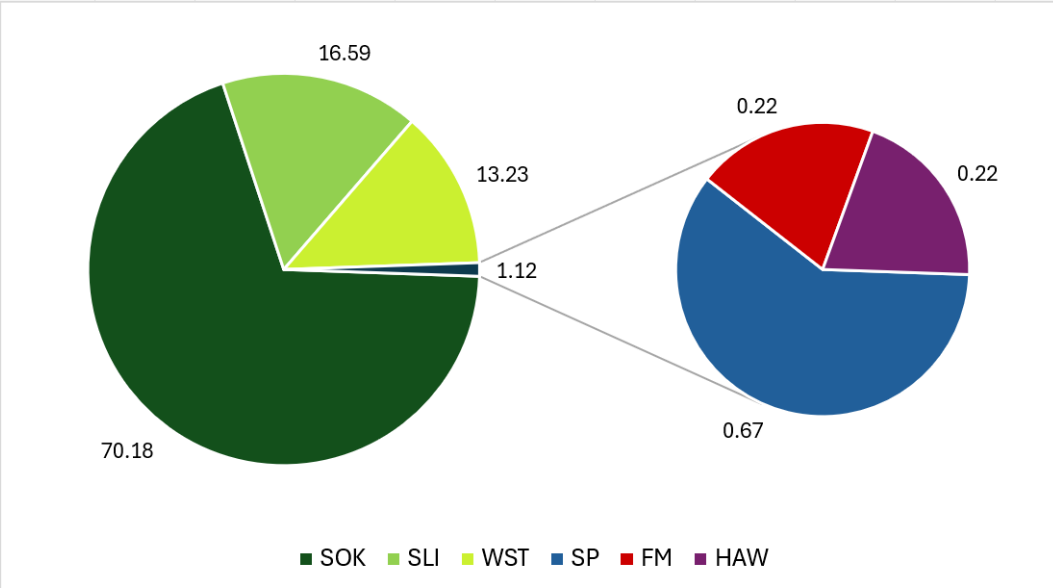

Figure 8: Distribution of tree species in the studied area near the city of Heldburg, Germany. Distribution in percentage [%] based on the total number of trees. SOK = Quercus petraea; SLI = Tilia cordata; WST = Sorbus torminalis; SP = Pinus silvestris; FM = Acer campestre; HAW = Crataegus monogyna

The measured DBH also shows a clear dominance of *Q. petraea* in the stand, with a mean DBH of 39 cm (Fig. 9). Trees of SLI and WST are building the understory, with single trees of lime also reaching the upper canopy. The mean DBH of lime is 16 cm, and 14 cm for WST (Fig. 9). Based on the number of trees, the understory is not present over the whole site.

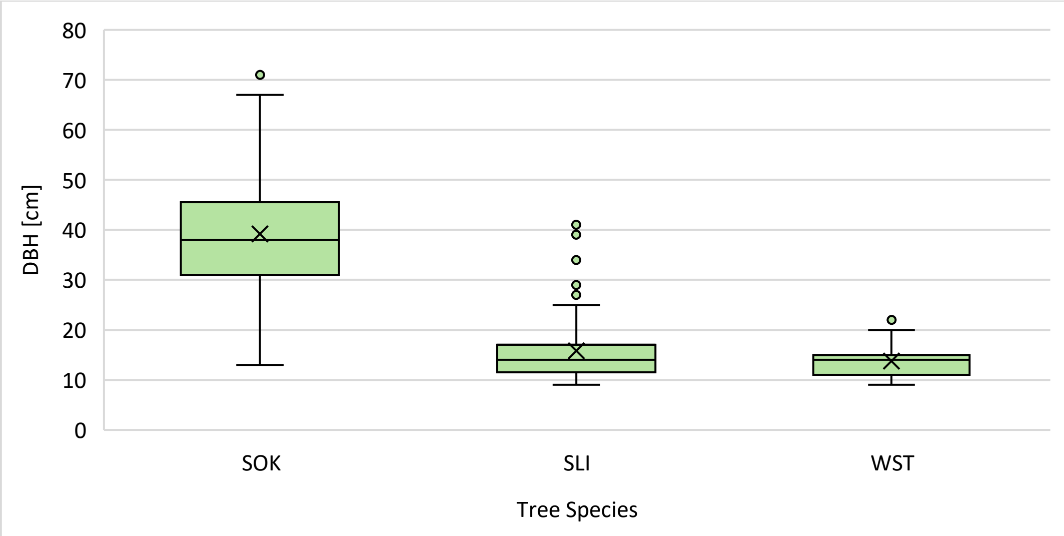

Figure 9: Variation of the measured diameter (DBH, cm) for the most present tree species in the studied area. SOK = Quercus petraea; SLI = Tilia cordata; WST = Sorbus torminalis

Compared to the inventory in 2018, based on Behrens (2018), the mean DHB of oak is two centimeters higher, the same goes for lime, and the mean DBH for WST is three centimeters higher.

The dominance of oak and the social standing of the single tree species within the area are also shown by the distribution over Kraft's classes (Fig. 10).

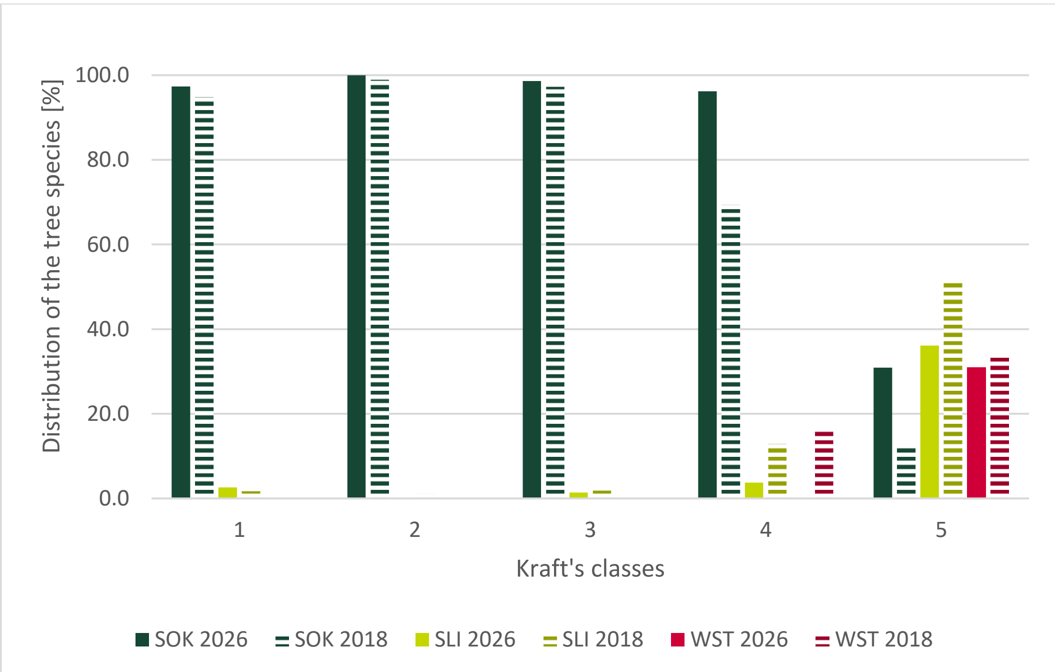

Figure 10: Comparison of the proportion of the most abundant tree species [in %] in the studied area based on Kraft's class [1) predominant, 2) dominant, 3) codominant, 4) intermediate, and 5) overtopped or dead] between the inventory in 2026 and 2018 from all trees within the studied area. SOK = Quercus petraea; SLI = Tilia cordata; WST = Sorbus torminalis

There is a clear dominance of oak in classes 1-4, which has not changed much since the inventory in 2018. SLI has single trees in classes one, three, and four. Most differences based on time can be seen in the lower classes four and five. In 2026, class four had a very high proportion of SOK, while in 2018, more SLI as well as WST were present. In class five, the proportion of SOK increased by 18.2%, and SLI decreased.

When looking at the diameter classes of oak (Fig. 11), there is a clear dominance of trees within the third diameter class. Most of the trees are in the third and fourth strength classes. There are only a few trees with a DBH over 60 cm.

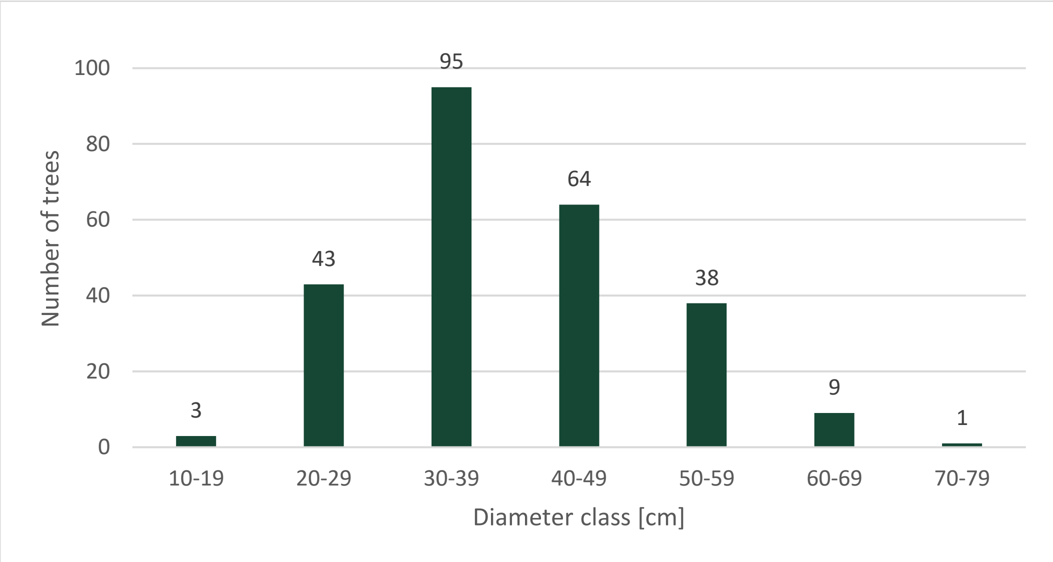

Figure 11: Distribution of all standing oak trees (Quercus petraea) in the studied area over the strength classes. Strength classes are a typical classification of trees by diameter (DBH, cm). Strength classes: 1) DBH 10-19 cm; 2) DBH 20-29 cm; 3) DBH 30-39 cm; 4) DBH 40-49 cm; 5) DBH 50-59 cm; 6) DBH 60-69 cm; 7) DBH 70-79 cm.

Compared to 2018, the mortality in the stand has increased by 13.75% (Table 1). In 2018, three oak trees were already dead, with one lying and two standing (Behrens, 2018). In 2026, a total of 65 out of 451 trees were dead, with 39 trees still standing and 26 lying.

Table 1: Comparison of mortality in the studied area based on inventories done in 2018 and 2026 (Behrens, 2018).

Year	Percentage of all dead trees in the study area [%]	Total dead	Lying	Standing
2018	0.66	3	2	1
2026	14.41	65	26	39

Besides three pine, all the dead trees are oaks. Based on the hillslope, 17 trees in the downslope are dead, and there are 24 dead trees per mid- and upslope.

3.2 Symptom of Lesions

There were 254 living oak trees within the studied area. 222 had at least one lesion recorded. Some living oaks lacked visible lesions but exhibited severe crown damage, indicated by numerous dead branches in the crown. 20 oak trees in the whole studied area do not show any symptoms of vitality loss in the crown, lesions, or cracks on the trunk. 16 of those are standing upslope, two in the middle part, and two downslope. Among trees with visible lesions, the number of lesions per tree ranged from 1 to 53. Most symptomatic oak trees had between 1 and 20 lesions, while relatively few trees had 30 or more lesions (Fig. 12).

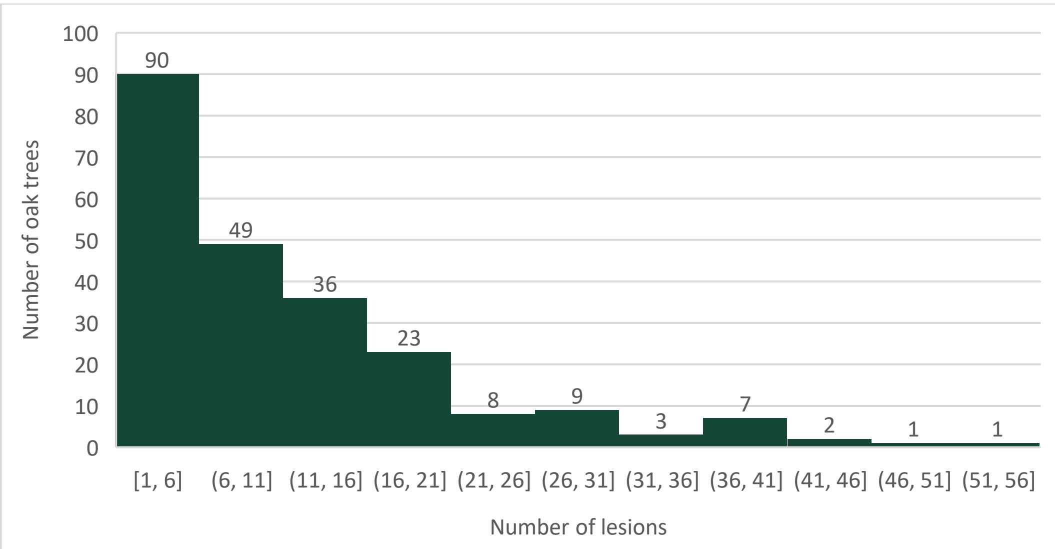

Figure 12: Number of oak trees (Quercus petraea) based on the number of lesions, which are grouped.

Based on the growing spot of the tree, in the lower part of the slope, five trees did not show any lesions. Midslope, eight trees did not show any lesions, and in the upper part, 19 trees did not show any lesions or symptoms of AOD. The average number of lesions on a single tree is the highest midslope, intermediate downslope, and upslope has the lowest average lesion abundance (Fig. 13). Generally, there is a substantial overlap between the different groups, and all show several outliers.

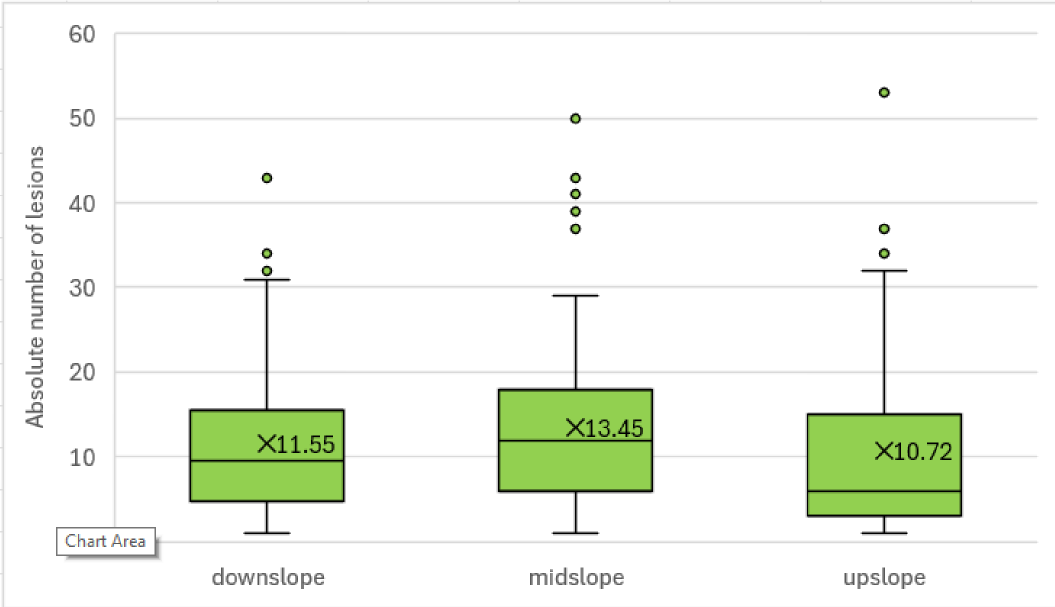

Figure 13: Distribution of the number of lesions on a single oak (Quercus petraea) based on its growing spot in the studied area.

With a p-value of 0.04527, resulting from the Kruskal-Wallis test, there is a significant difference in the abundance of the lesions between at least one slope group. Dunn's post hoc test showed that midslope trees had significantly higher lesion abundance than upslope trees (adjusted $p = 0.0395$), while downslope trees did not differ significantly from either midslope or upslope trees (Table 2).

Table 2: Adjusted p-value for the comparison between the different slope parts based on Dunn's post-hoc test.

Comparison	**Adjusted p-value**
Downslope - Midslope	0.633
Downslope - Upslope	0.762
Midslope - Upslope	0.0395

When looking at the DBH of the tree and the number of lesions, there is a positive trend for all three slope parts (Fig. 14). The trend is the strongest midslope, followed by downslope, and lastly upslope.

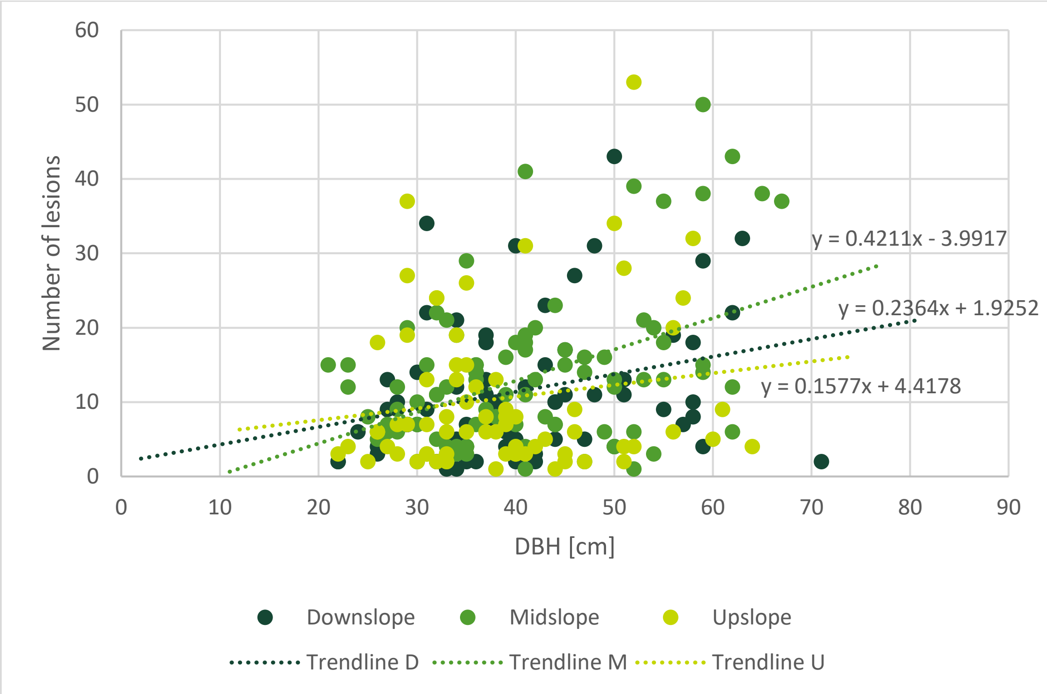

Figure 14: Relation of the number of lesions and the DBH of a single tree based on the different slope parts in the studied area.

The Spearman correlation analysis showed that the relationship is significant for downslope and midslope but not upslope (Table 3). Midslope shows the strongest correlation among the tree slope parts and provides good evidence that larger trees tend to have more lesions. In contrast, the relationship is not significant for upslope ($p = 0.88$), suggesting that tree size does not influence lesion abundance. Based on the results of Spearman's rho, the strength of the relationship also differs between the single slope parts. With $\rho = 0.299$, the correlation downslope is weak to moderate and moderate in the middle part of the slope. Upslope shows a very weak relationship, where the correlation essentially equals zero.

Table 3: Results of the Spearman rank correlation test between the number of lesions and the DBH of the tree based on the different slope parts.

Slope part	**ρ**	**p-value**
Downslope	0.299	0.0148
Midslope	0.323	0.00199
Upslope	0.0188	0.880

Regarding the appearance of pests, within the whole study area, there are 13 trees that are still alive and showing signs of *A. biguttatus* (Fig. 15). All of them have a heavily damaged canopy. Eight of these trees have lesions, ranging from an amount of one to 43.

Figure 15: Oak trees (Quercus petraea) displaying signs of Agrilus biguttatus based on the D-shaped exit holes of the adult beetle. a) tree number 67 b) tree number 314 c) tree number 78.

On 27 of the living trees within the whole study area, old egg masses of *L. dispar* were found. Two of those trees were without lesions. Generally, there is a positive trend in the relation between the number of old egg masses of *Lymantria dispar* and the number of lesions on a tree. Old nests of oak processionary moth were found on eight living oak trees within the whole stand.

3.3 Detection of AOD-associated Bacteria

The DNA analysis of bark pieces taken from the lesions of some oak trees shows that *B. goodwinii*, *G. quercinecans*, and *R. victoriana* are present on site (Table 4). Those trees that tested most frequently positive for AOD-associated bacteria were those in the lowest part of the slope. Here, five of the six trees have tested positive for at least one of the bacteria. One tree displayed weak signals for *B. goodwinii* and *G. quercinecans*. In the lower slope, there was also a single tree that tested positive for all three bacteria.

Table 4: The table shows the inventory data for all sample trees and the test results from the DNA extraction of bark pieces, which were taken out of some parts of the visual lesions on the trunk of the trees in the studied area. Legend: Green = trees downslope; Pink = trees midslope; Blue = trees upslope; ■ = positive; □ = negative; / = weak positive.

Sample Tree No.	DBH	Number of lesions	*B. goodwinii*	*G. quercinecans*	*R. victoriana*
04	29	7	/	/	□
21	41	12	■	■	□
32	31	34	■	■	□
56	62	22	■	/	□
85	59	29	■	■	/
109	28	10	■	■	■
78	36	24	□	□	□
121	59	16	□	□	□
147	47	14	/	/	/
174	45	18	/	□	□
213	30	11	□	□	□
244	43	8	/	□	□
314	57	24	■	■	/
342	35	10	■	□	□
356	61	9	/	□	□
389	29	27	□	□	□
418	52	4	/	□	/
420	29	37	□	□	□

None of the tested trees on the middle slope has a positive result, except for three trees, which have weak positive test results for at least one of the bacteria. On the upper slope, two trees were positive, and two had weak positive results. The bacterium *B. goodwinii* was found to be the most common, with positive and weak positive results in 13 out of the 18 sampled trees, followed by *G. quercinecans* and lastly *R. victoriana*. Five of the seven trees had positive results for at least two bacteria.

For this study, the number of cracks does not seem to influence bacterial presence. Three trees had more than ten cracks and tested negative for all three bacteria. There is no specific pattern for a relation between the number of visible lesions and positive test results. The tree with the highest number of counted lesions (37 lesions) tested negative for all bacteria, and the tree with the least amount of lesions has weak results for *B. goodwinii* and *R. victoriana*. Generally, all trees that have tested positive for at least one bacterium have ten or more lesions. Trees with an amount of lesions under ten have weak positive test results for at least one bacterium. Trees with only negative test results have eleven or more lesions.

Also, DBH does not seem to have a relation to the presence of AOD-associated bacteria. The tree that has tested positive for all three bacteria also has the lowest DBH of 29 cm of all the tested trees. Smaller trees within diameter classes two or three have tested positive as well as negative. The same pattern goes for bigger trees within diameter classes five and six.

Two of the tested trees displayed signs of jewel beetle (tree numbers 78 and 314), which were visible as D-shaped exit holes of the adult beetles from previous years (see Appendix, Table D1). Tree 314 tested positive for *B. goodwinii* and *G. quercinecans,* and a weak result for *R. victoriana.* On the other hand, tree 78 tested negative for all three bacteria. All other tested trees did not show any signs of jewel beetle.

None of the selected trees for sampling had noticeable drought damage in the form of dead branches in the crown during the inventory in August 2018 (Behrens, 2018). Some trees had signs of defoliators at different intensities, since there had been a major outbreak of *L. dispar* in the stand (Behrens, 2018). In 2026, none of these trees showed symptoms of vitality loss in the crown (see Appendix, Table D1). Other trees that had been vital in 2018 were showing major crown damage based on dead branches in 2026. Especially tree number 109, which had been completely vital in 2018, is now displaying a heavily damaged crown with a build-up of secondary crown based on epicormic shoots. Other trees, like numbers 121 (see Appendix, Fig. D1) and 389, also had lesions on the trunk and a heavily damaged crown, but have tested negative for AOD-bacteria.

Based on the detailed analysis of the lesions on the 18 sampled trees (see Appendix, Table D2), lesions can be punctual and very small or quite long (following a heavy slime flux), with the longest measuring 37 cm in length. The mean height of the expected exit point of the lesions over all sampled trees is 123 cm. Trees with at least one positive test for AOD-bacteria have a mean height of the exit point of the lesion of at least 121 cm. Trees that have been tested negative for all bacteria also show lesions at a mean height of 144 cm. Tree No. 213 has the highest mean length of the lesions, indicating a heavier slime flux per lesion. Still, it has tested negative for AOD. Regarding the aspect of the lesions, it is quite distributed over the south, east, and west, while the least amount of lesions are facing north.

4. Discussion

4.1 Stand Development

The increased mortality and low diameter growth suggest a decline in stand vitality over the past nine years. The combination of high mortality, limited growth, and crown damage indicates that the oaks within this stand are stressed by different factors. These findings are consistent with H2 (tree mortality in the stand is hypothesized to be higher than during the first inventory of the stand). The death of the trees cannot be linked directly to AOD, but since the associated bacteria were found on site, there is a strong possibility that it is contributing to the death of some trees, since the disease leads to the death of the trees within just a few years (Denman and Webber, 2009).

Based on the inventory of this study, there are several stressors of the trees that are leading to the rapid death, which can be from the following: drought, because of heavily damaged crowns with many dead branches, combined with biotic stressors that were found, like the presence of spongy moth [with a heavy outbreak in the past (Behrens, 2018)], oak processionary moth, jewel beetle, and newly detected AOD-bacteria.

By looking at the forest inventory data, another stress factor might also be due to silvicultural delays. This stand was established for high-quality wood production. Based on visual observation, no treatment has been done for at least 30 years. In older oak stands, management should be conducted in the form of low-intensity thinnings at least once a decade to reduce competition and support optimal crown development, leading to diameter growth (Nicolescu et al., 2025). For this stand, the trees are standing very densely, with the crowns intermixing. Nicolescu et al. (2025) states that by increasing the spacing of the trees, individual trees will be able to grow larger crowns, increasing their health and lowering their susceptibility to secondary pests or pathogens. Thinning also reduces competition for water and nutrients, which is important, especially during drought periods (Nicolescu et al., 2025).

4.2 AOD-associated Symptoms

The widespread occurrence of lesions throughout the stand suggests that the factors driving symptom development are not confined to a localized infection. This contrasts with the findings of Brown et al. (2016), who reported that symptomatic trees tended to occur in clusters. The tendency for AOD symptoms to occur mostly on the warmer southerly aspect is also shown by Brown et al. (2016). The present study found lesions with no clear dominance of a single direction. However, there is a limitation to the detection of lesions on the north side of the trunk because of the appearance of mosses on most trunks, which led to a possible underestimation in this direction.

Tree size (DBH) appears to influence lesion abundance only to a limited extent. Relatively low results for Spearman's rho (ρ), especially in the upper part of the slope, indicate that the size of the tree explains the number of lesions only for some of the trees along the slope. Although some positive relationship between DBH and lesion abundance was observed, the considerable variation among similarly sized trees suggests that additional factors are more important drivers. Thus, support for H3 is limited (tree size (DBH) influences lesion abundance, with larger trees exhibiting a higher number and size of lesions).

The hypothesis (H4) that lesion abundance decreases from the lower to the upper part of the slope was only partially supported. The observed pattern suggests that the slope may influence symptom expression but is unlikely to determine symptom development alone. If water availability alone controlled lesion development, a more consistent gradient across all slope parts could be expected. Instead, the results indicate that local stand conditions, like competition and crown development, may also have an influence on tree vitality and symptom formation. Midslope trees may experience greater competition due to higher stand density than trees growing upslope, which can grow a bigger crown.

4.3 AOD-associated Bacteria

The detection of all three bacterial species confirms that the microbial community associated with AOD is present within the stand and confirms H1, that the number of trees infected with AOD-associated bacteria has increased since the first sampling in 2022. However, the occurrence of symptomatic trees without detectable bacteria suggests that lesion formation may result from multiple factors, such as other bacteria, pathogens, or pests associated with the damage/lesions observed.

In relation to the local spread of the bacteria, there may be a positive relationship between the assumed local water availability and bacterial occurrence. Pettifor et al. (2020) concluded that *G. quercinecans* can survive in rainwater for at least 84 days and 28 days in forest soil. In the present study, *G. quercinecans* was mostly tested positive in the lower part of the slope, which might be due to the spread of (rain-)water on the ground, which flows downslope, where it is available for the trees to take up (Tromp-van Meerveld and McDonnell, 2006).

Maddock et al. (2023) identified *B. goodwinii* from acorns of healthy as well as symptomatic trees and concluded an endophytic lifestyle of the bacterium within oak trees. This goes hand in hand with results from Pettifor et al. (2020), which have detected *B. goodwinii* only in low proportions in rainwater or forest soil, indicating that it can hardly survive outside the host tree. Broberg et al. (2018) also analysed host-microbe interactions and showed that *B. goodwinii* can be present in healthy tissue without being in a pathogenic state, but to a much lower proportion than in affected trees. The predominance of *B. goodwinii* in the samples analysed in this study supports its role as the bacterial species most closely associated with AOD and may indicate an endophytic behavior. This type of host-microbe interaction, where organisms live inside the host and become pathogenic under certain conditions, has been generally described already by Stengel et al. (2022).

Broberg et al. (2018) showed that the bacteria can act as pathobionts with a shift in the activity triggered by their simultaneous presence or when the tree is stressed by other factors. Also, Gathercole et al. (2021) reported that low-level amounts of the bacteria can be found in leaf and leaf-bud tissues, concluding that their ubiquity is triggered by other factors. Denman et al. (2016) suggest that AOD might have a polymicrobial cause, because *G. quercinecans* and *R. victoriana* were detected especially in advanced stages of the lesions, possibly aiding the virulent activities of *B. goodwinii*. The findings of this study are somewhat consistent with this concept, and the interactions among multiple bacterial species may play a role in disease development. However, while the co-occurrence of AOD-associated bacteria supports the possibility of microbial interactions, no conclusions can be drawn regarding an actual synergistic effect or increased virulence.

Broberg et al. (2018) showed that *B. goodwinii* is highly active when lesions mature. Studies comparing healthy and diseased tissue of oak trees show a higher abundance and activity of the AOD-associated bacteria on symptomatic trees (Denman et al., 2016; Gathercole et al., 2021). This indicates that even though the bacteria might be present already in the trees, it is only at a very low concentration, which makes it hard to detect them. Generally, it appears to be that *G. quercinecans* and *R. victoriana* are capable of surviving in a wide range of environmental niches (Maddock et al., 2023). Since this study was done using bark pieces out of visible lesions, the presence of *G. quercinecans* or *R. victoriana* was always in combination with *B. goodwinii*. In order to give an answer about the local distribution of *G. quercinecans* or *R. victoriana,* soil samples should be analysed as well.

4.4 Relation to Pests

Studies support that trees can be infected with AOD, but not display any symptoms of insect presence (Tkaczyk et al., 2024; Tkaczyk and Sikora, 2024; Zalkalns and Celma, 2021). This was also shown in the present study. As a result, the bacteria may not need an insect vector in order to be spread.

However, the presence of insect damage may facilitate bacterial colonization by creating entry points into the tissue (Denman et al., 2018). Pests pose a stress factor to the trees, which can make them more susceptible to secondary diseases like AOD (Bene et al., 2025). In the present study, the presence of multiple insect species suggests that the affected trees are exposed to additional biotic stressors, which may increase susceptibility.

4.5 Management of AOD

As of now, no concrete recommendations for the management of AOD-infected stands have been proposed. Since AOD is likely caused by the interaction of multiple factors, management might be more complicated (Maddock et al., 2023).

As shown by this study, abiotic damage plays an important role as a first initiator of stress for the trees. Abiotic damage cannot be prevented by forestry (Altenkirch et al., 2002), but risk management in order to create resilient stands is a method to support healthier forests. This can be done by silvicultural measures, when establishing new stands, choose tree species that are adapted to the site and the creation of structural diversity, as well as species diversity based on the site (Altenkirch et al., 2002).

Since AOD is occurring very locally at the moment, strategies of management on the individual stand level in order to keep tree vigour play an important role (Brown et al., 2018). Monitoring also proposes another tool to control forest health and notice the first symptoms in early stages (Bene et al., 2025). Testing for AOD should be expanded to more sites that might be prone to it.

4.6 Limitations

The applicability of the results in this study is limited to an area in Central Germany with specific site characteristics. Also, the relatively small number of sampled trees, with the limitation of only analysing symptomatic trees, poses a limitation to statistical analysis of factors influencing the abundance of AOD-associated bacteria. The sample collection was done only in March. Zalkalns and Celma (2021) suggest that the presence of the bacteria changes depending on the climatic conditions over the year, with positive tested trees becoming tested negative in autumn. Data collection was done manually, and most of the data is based on visual observations that depend on factors like lighting conditions. This proposes a chance for manual errors. Most trees were covered with moss on the hill-facing side of the trunk. Because of this coverage, lesions were not / hardly visible.

5. Conclusion

Overall, this study contributed to increasing the knowledge about AOD and its local spread, and it can be concluded that the occurrence of AOD is driven by the interaction of multiple abiotic and biotic factors rather than a single causal agent. The results show that AOD should be considered part of a complex disease system of oak. The interaction among different stress factors seems to play a crucial role in symptom expression, but trees that have not been previously stressed by biotic factors can also be infected. Climate change appears to be a key driver of the disease, as increasing temperatures and recurring drought periods weaken the vitality of the trees (Bratu et al., 2025). Thus, making them more susceptible to infections, since the studied area has been subject to droughts, especially over the last few years. These extreme weather events, in combination with the local water distribution and availability, may contribute significantly to the progression of AOD (Dennert et al., 2024).

At the same time, the study supports the presence of AOD-associated bacteria even in the absence of symptoms caused by other biotic stressors. This demonstrates that the bacteria may exist at low levels within the host and the environment (Broberg et al., 2018; Pettifor et al., 2020). The pathogenicity might then be triggered by the interaction of them (Broberg et al., 2018) and the influencing environmental and climatic conditions. The study also demonstrates that AOD occurs in already weakened stands. The high mortality rate, reduced growth, and visible crown damage suggest that the studied area is under considerable stress. With this finding, AOD should not be interpreted as an isolated cause of decline, but rather as part of a broader interaction of multiple factors within complex diseases of oak (Brown et al., 2018).

From a forest management perspective, this study highlights the importance of maintaining stand vitality. Since direct control measures are currently lacking, preventive strategies such as reducing competition and enhancing structural and species diversity should be implemented in order to increase the resilience of the trees against stress factors (Nicolescu et al., 2025).

In order to further understand the development of the disease, continued monitoring and repeated testing following the initial detection of AOD should be done. Especially, the investigation of healthy trees may provide insights into host-microbe interactions and help to better understand the process of latent presence to active pathogens. Expanding research is needed to better understand the dynamics and importance of bacterial diseases within forestry, including AOD, as well as developing effective long-term management strategies.

In conclusion, AOD represents a complex and emerging threat to our oak ecosystems, shaped by the interaction of bacteria, environmental conditions, and host stress. Addressing this challenge requires an integrated approach combining monitoring and adaptive forest management.

Further research into the ecological and physiological mechanisms of the disease is needed. Future studies should focus on analysing more factors that might influence the distribution of the disease, especially in conjunction with the availability of water in the ground and samples of the soil. Tissue sampling might also give valuable insights into the interaction of the different bacterial species based on the comparison of symptomatic vs. asymptomatic trees.

6. References

aid infodienst Ernährung, Landwirtschaft Verbraucherschutz e.V. (ed) (2014) *Wichtige Forstschädlinge: Erkennen, überwachen und bekämpfen*, 7th edn, Bonn, aid infodienst Ernährung Landwirtschaft Verbraucherschutz e. V.

Altenkirch, W., Majunke, C. and Ohnesorge, B. (2002) *Waldschutz auf ökologischer Grundlage*, Stuttgart (Hohenheim), Ulmer.

Bayerische Landesanstalt für Landwirtschaft (2022) *Jahresbericht 2022 – Bakteriologie* [Online]. Available at https://www.lfl.bayern.de/ips/ueberuns/324838/index.php (Accessed 28 April 2026).

Behrens, C. (2018) *Untersuchungen zum Schwammspinner-Befall 2018 in einem Eichenbestand des Thüringer Forstamtes Heldburg: Erhebung von Präferenzen des Schwammspinners bei der Eiablage in Bezug auf die Höhe am Stamm, die Exposition und die Verteilung in der Fläche*, Erfurt.

Bene, A., Vergine, M., Carluccio, G., Portaccio, L., Delle Donne, A. G., Bellis, L. de and Luvisi, A. (2025) 'Acute Oak Decline-Associated Bacteria: An Emerging Worldwide Threat to Forests', *Microorganisms*, vol. 13, no. 5.

Biosca, E. G., González, R., López-López, M. J., Soria, S., Montón, C., Pérez-Laorga, E. and López, M. M. (2003) 'Isolation and Characterization of Brenneria quercina, Causal Agent for Bark Canker and Drippy Nut of Quercus spp. in Spain', *Phytopathology*, vol. 93, no. 4, pp. 485–492.

Brady, C., Denman, S., Kirk, S., Venter, S., Rodríguez-Palenzuela, P. and Coutinho, T. (2010) 'Description of Gibbsiella quercinecans gen. nov., sp. nov., associated with Acute Oak Decline', *Systematic and applied microbiology*, vol. 33, no. 8, pp. 444–450.

Brady, C., Hunter, G., Kirk, S., Arnold, D. and Denman, S. (2014) 'Rahnella victoriana sp. nov., Rahnella bruchi sp. nov., Rahnella woolbedingensis sp. nov., classification of Rahnella genomospecies 2 and 3 as Rahnella variigena sp. nov. and Rahnella inusitata sp. nov., respectively and emended description of the genus Rahnella', *Systematic and applied microbiology*, vol. 37, no. 8, pp. 545–552.

Bratu, I., Dinca, L., Constandache, C. and Murariu, G. (2025) 'Resilience and Decline: The Impact of Climatic Variability on Temperate Oak Forests', *Climate*, vol. 13, no. 6, p. 119.

Broberg, M., Doonan, J., Mundt, F., Denman, S. and McDonald, J. E. (2018) 'Integrated multi-omic analysis of host-microbiota interactions in acute oak decline', *Microbiome*, vol. 6, no. 1, p. 21.

Brown, N., Jeger, M., Kirk, S., Xu, X. and Denman, S. (2016) 'Spatial and temporal patterns in symptom expression within eight woodlands affected by Acute Oak Decline', *Forest Ecology and Management*, vol. 360, pp. 97–109.

Brown, N., Vanguelova, E., Parnell, S., Broadmeadow, S. and Denman, S. (2018) 'Predisposition of forests to biotic disturbance: Predicting the distribution of Acute Oak Decline using environmental factors', *Forest Ecology and Management*, vol. 407, pp. 145–154.

Bundesamt für Naturschutz (2019) *Natura 2000 Gebiete in Deutschland: Wälder im Grabfeld* [Online], Bonn. Available at https://www.bfn.de/natura-2000-gebiet/waelder-im-grabfeld (Accessed 19 May 2026).

Butin, H. (2011) *Krankheiten der Wald- und Parkbäume: Diagnose, Biologie, Bekämpfung* [Online], Stuttgart, Verlag Eugen Ulmer. Available at http://nbn-resolving.org/urn:nbn:de:bsz:24-epflicht-1397780.

Cambon, M. C., Thomas, G., Caulfield, J., Crampton, M., Reed, K., Doonan, J. M., Hussain, U., Denman, S., Vuts, J. and McDonald, J. E. (2023) *Chemical cues from beetle larvae trigger proliferation and putative virulence gene expression of a plant pathogen*.

Carluccio, G., Sabella, E., Greco, D., Vergine, M., Delle Donne, A. G., Nutricati, E., Aprile, A., Bellis, L. de and Luvisi, A. (2024) 'Acute and Chronic Oak Decline in urban and forest ecosystems in Southern Italy', *Forestry*, vol. 97, no. 5, pp. 739–749.

Crampton, B. G., Plummer, S. J., Kaczmarek, M., McDonald, J. E. and Denman, S. (2020) 'A multiplex real-time PCR assay enables simultaneous rapid detection and quantification of bacteria associated with acute oak decline', *Plant Pathology*, vol. 69, no. 7, pp. 1301–1310.

Denman, S., Brady, C., Kirk, S., Cleenwerck, I., Venter, S., Coutinho, T. and Vos, P. de (2012) 'Brenneria goodwinii sp. nov., associated with acute oak decline in the UK', *International journal of systematic and evolutionary microbiology*, vol. 62, Pt 10, pp. 2451–2456.

Denman, S., Brown, N., Kirk, S., Jeger, M. and Webber, J. (2014) 'A description of the symptoms of Acute Oak Decline in Britain and a comparative review on causes of similar disorders on oak in Europe', *Forestry*, vol. 87, no. 4, pp. 535–551.

Denman, S., Doonan, J., Ransom-Jones, E., Broberg, M., Plummer, S., Kirk, S., Scarlett, K., Griffiths, A. R., Kaczmarek, M., Forster, J., Peace, A., Golyshin, P. N., Hassard, F., Brown, N., Kenny, J. G. and McDonald, J. E. (2018) 'Microbiome and infectivity studies reveal complex polyspecies tree disease in Acute Oak Decline', *The ISME journal*, vol. 12, no. 2, pp. 386–399.

Denman, S., Plummer, S., Kirk, S., Peace, A. and McDonald, J. E. (2016) 'Isolation studies reveal a shift in the cultivable microbiome of oak affected with Acute Oak Decline', *Systematic and applied microbiology*, vol. 39, no. 7, pp. 484–490.

Denman, S. and Webber, J. (2009) 'Oak Declines: New definitions and new episodes in Britain', *QUARTERLY JOURNAL OF FORESTRY*, no. 103, pp. 285–290.

Dennert, F., Augustinus, B. A., Ruffner, B. and Queloz, V. (2024) 'Bacterial Diseases: An Emerging Threat for Central European Forest and Urban Trees?', *Forest Pathology*, vol. 54, no. 6.

Desprez-Loustau, M.-L., Balci, Y., Cornara, D., Gonthier, P., Robin, C. and Jacques, M.-A. (2021) 'Is Xylella fastidiosa a serious threat to European forests?', *Forestry*, vol. 94, no. 1, pp. 1–17.

Ebner, S. (2012) *Die wichtigsten Forstschädlinge: Insekten, Pilze, Kleinsäuger*, 4th edn, Graz Stuttgart, Stocker.

Eichenlaub, L., Denman, S., Brady, C., Maddock, D., Robledo-Garcia, F., Aubert, A., Husson, C. and Robin, C. (2024) 'First report of Brenneria goodwinii, Gibbsiella quercinecans and Rahnella victoriana in declining oaks in France', *New Disease Reports*, vol. 49, no. 2.

Falck, R. (1918) 'Eichenerkrankung in der Oberförsterei Lödderitz und in Westfalen', *Zeitschrift für Forst- und Jagdwesen*, no. 50, pp. 123–132.

Fernandes, C., Duarte, L., Naves, P., Sousa, E. and Cruz, L. (2022) 'First report of Brenneria goodwinii causing acute oak decline on Quercus suber in Portugal', *Journal of Plant Pathology*, vol. 104, no. 2, pp. 837–838.

Gathercole, L., Nocchi, G., Brown, N., Coker, T., Plumb, W., Stocks, J., Nichols, R., Denman, S. and Buggs, R. (2021) *Evidence for the Widespread Occurrence of Bacteria Implicated in Acute Oak Decline from Incidental Genetic Sampling*.

GermanSights.com (2026) *Travel to Thuringia* [Online]. Available at https://www.germansights.com/thuringia/travel.php.

González, A. J. and Ciordia, M. (2020) 'Brenneria goodwinii and Gibbsiella quercinecans isolated from weeping cankers on Quercus robur L. in Spain', *European Journal of Plant Pathology*, vol. 156, no. 3, pp. 965–969.

Gullino, M. L., Albajes, R., Al-Jboory, I., Angelotti, F., Chakraborty, S., Garrett, K. A., Hurley, B. P., Juroszek, P., Lopian, R., Makkouk, K., Pan, X., Pugliese, M. and Stephenson, T. (2022) 'Climate Change and Pathways Used by Pests as Challenges to Plant Health in Agriculture and Forestry', *Sustainability*, vol. 14, no. 19, p. 12421.

Hartmann, G., Blank, R. and Lewark, S. (1989) 'Oak Decline in Northern Germany: distribution, symptoms possible causes.', *Forst Holz*, no. 44, pp. 475–487.

Hartmann, G. and Grüner, J. (2025) *Waldschäden: Diagnose von Baumkrankheiten*, Stuttgart, Ulmer.

Hartmann, H., Bastos, A., Das, A. J., Esquivel-Muelbert, A., Hammond, W. M., Martínez-Vilalta, J., McDowell, N. G., Powers, J. S., Pugh, T. A. M., Ruthrof, K. X. and Allen, C. D. (2022) 'Climate Change Risks to Global Forest Health: Emergence of Unexpected Events of Elevated Tree Mortality Worldwide', *Annual review of plant biology*, vol. 73, pp. 673–702.

Hoch, G. and Cech, T. (2021) 'Altbekannte und neue Schadinsekten und Pathogene an Eichen', *BFW-Praxisinformation*, no. 53, pp. 22–24.

Knapp, D. G., Sunde, J., BakhshiGanje, M. and Witzell, J. (2025) 'Bacterial Communities Associated With Acute Oak Decline of Sessile Oak (Quercus petraea) in Southern Sweden', *Environmental microbiology reports*, vol. 17, no. 6, e70244.

Kraft, G. (1884) *Beiträge zur Lehre von den Durchforstungen, Schlagstellungen und Lichtungshieben*, Klindworth, Pennsylvania State University.

La Porta, N., Capretti, P., Thomsen, I. M., Kasanen, R., Hietala, A. M. and Weissenberg, K. von (2008) 'Forest pathogens with higher damage potential due to climate change in Europe', *Canadian Journal of Plant Pathology*, vol. 30, no. 2, pp. 177–195.

Macháčová, M., Nakládal, O., Samek, M., Baťa, D., Zumr, V. and Pešková, V. (2022) 'Oak Decline Caused by Biotic and Abiotic Factors in Central Europe: A Case Study from the Czech Republic', *Forests*, vol. 13, no. 8, p. 1223.

Maddock, D., Brady, C., Denman, S. and Arnold, D. (2023) 'Bacteria Associated with Acute Oak Decline: Where Did They Come From? We Know Where They Go', *Microorganisms*, vol. 11, no. 11.

Nicolescu, V.-N., Vor, T., Brus, R., Đodan, M., Perić, S., Podrázský, V., Andrašev, S., Tsavkov, E., Ayan, S., Yücedağ, C., Trajkov, P., Kolevska, D. D., Buzatu-Goanţă, C., Pástor, M., Mačejovský, V., Modranský, J., Klisz, M., Gil, W., Lavnyy, V., Madsen, P., La Porta, N. and Bartlett, D. (2025) 'Management of sessile oak (Quercus petraea (Matt.) Liebl.), a major forest species in Europe', *Journal of Forestry Research*, vol. 36, no. 1.

Oak, S. W., Spetich, M. A. and Morin, R. S. (2016) 'Oak Decline in Central Hardwood Forests: Frequency, Spatial Extent, and Scale', in Greenberg, C. H. and Collins, B. S. (eds) *Natural Disturbances and Historic Range of Variation,* Cham, Springer International Publishing, pp. 49–71.

Pettifor, B. J., Doonan, J., Denman, S. and McDonald, J. E. (2020) 'Survival of Brenneria goodwinii and Gibbsiella quercinecans, associated with acute oak decline, in rainwater and forest soil', *Systematic and applied microbiology*, vol. 43, no. 2, p. 126052.

Prien, S. (2016) *Ökologischer Waldschutz: Für eine biozidfreie Waldwirtschaft*, Stuttgart, Verlag Eugen Ulmer.

Ruffner, B., Schneider, S., Meyer, J., Queloz, V. and Rigling, D. (2020) 'First report of acute oak decline disease of native and non-native oaks in Switzerland', *New Disease Reports*, vol. 41, no. 1, p. 18.

San-Miguel-Ayanz, J., Rigo, D. de, Caudullo, G., Houston Durrant, T. and Mauri, A. (Eds.) (2016) *European Atlas of Forest Tree Speices*, Luxembourg, Publication Office of the European Union.

Santini, A. and Faccoli, M. (2015) 'Dutch elm disease and elm bark beetles: a century of association', *iForest - Biogeosciences and Forestry*, vol. 8, no. 2, pp. 126–134.

Schumann, G. L. (1991) *Plant diseases: Their biology and social impact*, St. Paul, Minnesota, USA, APS Press.

Stengel, A., Drijber, R. A., Carr, E., Egreja, T., Hillman, E., Krause, T., Reese, S. and Herr, J. R. (2022) 'Rethinking the Roles of Pathogens and Mutualists: Exploring the Continuum of Symbiosis in the Context of Microbial Ecology and Evolution', *Phytobiomes Journal*, vol. 6, no. 2, pp. 108–117.

Thüringer Landesanstalt für Wald und Fortwirtschaft (1997) 'Die forstlichen Wuchsbezirke Thüringens: Kurzbeschreibung', *Mitteilungen der Landesanstalt für Wald und Forstwirtschaft*, no. 13.

Tkaczyk, M. and Sikora, K. (2024) 'The Role of Bacteria in Acute Oak Decline in South-West Poland', *Microorganisms*, vol. 12, no. 5.

Tkaczyk, M., Sikora, K. and Galko, J. (2024) 'First report of bacteria causing Acute Oak Decline on Quercus robur in Slovakia', *European Journal of Plant Pathology*, vol. 169, no. 1, pp. 113–120.

Tromp-van Meerveld, H. J. and McDonnell, J. J. (2006) 'On the interrelations between topography, soil depth, soil moisture, transpiration rates and species distribution at the hillslope scale', *Advances in Water Resources*, vol. 29, no. 2, pp. 293–310.

Vansteenkiste, D., Tirry, L., van Acker, J. and Stevens, M. (2004) 'Predispositions and symptoms of Agrilus borer attack in declining oak trees', *Annals of Forest Science*, vol. 61, no. 8, pp. 815–823.

Wenzel, A., Thiel, J. and Stürtz, M. (2024) 'Waldschutzsituation 2023 in Thüringen', *AFZ - derWald*, 9/2024, pp. 30–33.

Zalkalns, O. and Celma, L. (2021) 'The distribution of bacteria Gibbsiella quercinecans and Brenneria goodwinii in oak (Quercus robur L.) stands in Latvia', *IOP Conference Series: Earth and Environmental Science*, vol. 875, no. 1, p. 12033.

Zolfaghari, R., Dalvand, F., Fayyaz, P. and Solla, A. (2022) 'Maternal drought stress on Persian oak (Quercus brantii Lindl.) affects susceptibility to single and combined drought and biotic stress in offspring', *Environmental and Experimental Botany*, vol. 194, p. 104716.

Appendix A – Stand Information

6.1 Revierbuch kurz

Forstamt : 29 - Heldburg
Revier : 02 - Heldburg
Waldbesitzer: 069002 - Stadt Bad Colberg-Heldburg — **Stichtag : 01.01.2017**

Die Auswertung wurde über Auswerteparameter eingeschränkt. Die Auswerteparameter befinden sich am Berichtsende

Revier : 02

Wbes	Abt	Uabt	TF	B	S-INH	BHE-Fl. ha	Sl-Nr	OB ha	UN ha	B°	GF	BA	Alt	OHö m	RBon	BHD	Vor/ ha	Vor ges	Zw/ ha*J	ISF	ZL	HiebA	NFlä ha	PD	EGH	NFlä (tatsächl.) (ha)	Efm/ha	Efm ges	V-Baum	V-Art	V-Flä
069002	0062	a	01	1	§	7,77	1	7,77		1,41	32,0	TEI	149	21,0	4,0	42	335	2602	2,8	2	1	DF	7,77	X	2	15,54	40	311			
Summe Abt.:			**7,77**					**7,77**	**0,00**								**335**	**2.602**	**2,8**				**7,77**			**15,54**	**40**	**311**			
Summe Rev.:			**7,77**					**7,77**	**0,00**								**335**	**2.602**	**2,8**				**7,77**			**15,54**	**40**	**311**			

In den Gesamtvorräten der Abteilung und des Reviers wurden Rest- und Unterstandsvorräte nicht berücksichtigt.

Die Standardauswertung wurde mit folgenden Auswerteparametern erstellt:
Objektadresse: 16|29|02|069002|0062|a|01

dsw, 9.1.16.1-1612 — 24.09.2018 14:18:59 — Seite 1 von 1
Standardauswertung, V1.0

Figure A1: Inventory- and management plan of the stand, including the study area in Heldburg, Germany.

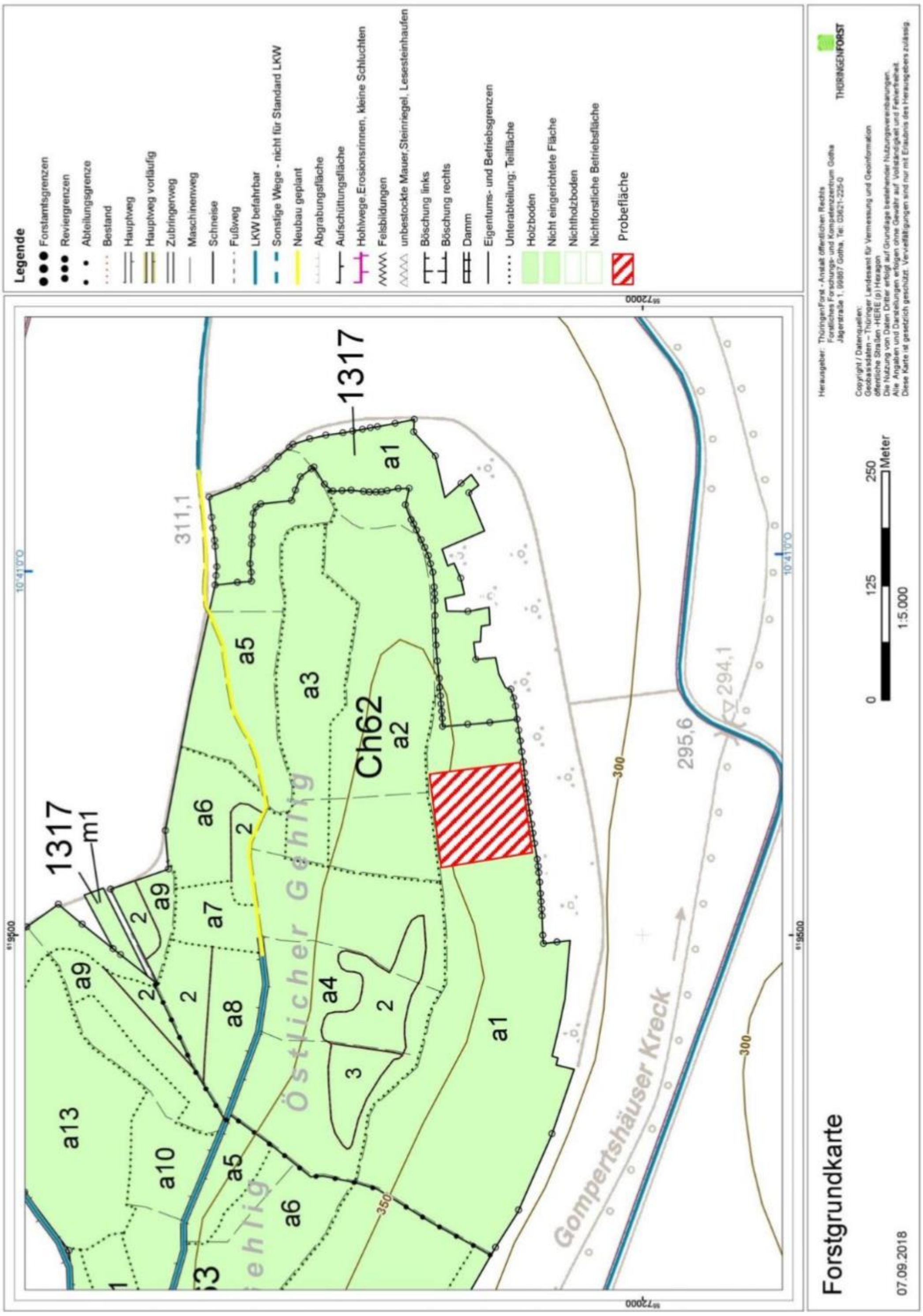

Figure A2: Forest base map of the forested area near Heldburg (Germany), including the study area, indicated with a red/white square (Behrens, 2018).

Appendix B – Collected Data

Table B1: Full inventory data of all trees within the study area, collected in week 11 in 2026.

Tree No.	Tree species	Slope	DBH [cm]	Kraft's class	Vitality	Amount egg masses spongy moth	Slime flux	Amount slime flux	Bark cracks	Pests/ pathogens	Notes
1	SOK	D	34	3	alive		yes	1	5		
2	SLI	D	11	5	alive		no				
3	SOK	D	37	2	alive		yes	19	10		
4	SOK	D	29	4	alive		yes	7	4		
5	SOK	D	33	2	alive		yes	1	2		
6	SOK	D	37	2	alive		yes	7	6		
7	SOK	D	24	5	dead		no			woodpecker, jewel beetle	standing
8	WST	D	18	5	alive		no				
9	WST	D	15	5	alive		no				
10	WST	D	15	5	alive		no				
11	WST	D	14	5	alive		no				
12	SOK	D	45	5	dead		no			jewel beetle	standing
13	SOK	D	26	4	alive		yes	4	4		
14	SOK	D	27	3	alive		yes	9	3		
15	SOK	D	34	4	alive		yes	21	5		fresh slime flux
16	WST	D	16	5	alive		no				
17	SOK	D	57	2	alive		yes	7	3		
18	SOK	D	26	4	alive		yes	3	6		
19	SOK	D	55	1	alive		yes	9	4		
20	SOK	D	22	4	alive		yes	2	4		
21	SOK	D	41	2	alive		yes	12	3		
22	SOK	D	51	3	alive		yes	11	2		
23	WST	D	13	5	alive		no				
24	SOK	D	63	1	alive	11	yes	32	8	OPM	fresh slime flux
25	SOK	D	37	2	alive		yes	13	8		
26	WST	D	11	5	alive		no				
27	SOK	D	48	1	alive		yes	11			
28	SOK	D	26	5	dead		no			jewel beetle	standing
29	SOK	D	39	2	alive		yes	4	1		
30	SOK	D	44	2	alive		yes	10	4		
31	SLI	D	15	5	alive		no				
32	SOK	D	31	3	dead		yes	34	4		old trunk damage
33	SOK	D	32	4	alive		yes	2	6		
34	WST	D	11	5	alive		no				
35	WST	D	18	5	alive		no				
36	SOK	D	31	3	alive		yes	22	11		
37	SOK	D	22	5	dead		no			jewel beetle	standing
38	WST	D	10	5	alive		no				
39	SOK	D	51	2	alive	1	yes	13	8		old trunk damage
40	SOK	D	37	3	alive		yes	18	7		
41	SOK	D	36	2	alive	1	yes	14	8		
42	SOK	D	42	3	alive		yes	2			
43	SOK	D	30	4	alive	1	yes	14	9		
44	SOK	D	22	4	alive		yes	2	2		
45	SOK	D	37	4	alive		yes	11	5		

46	SOK	D	46	3	alive		yes	27	9		
47	SOK	D	30	3	alive		no				
48	SOK	D	32	5	dead		no			woodpecker, jewel beetle	standing
49	SOK	D	42	2	alive		yes	3	2		
50	SOK	D	40	5	dead		no			woodpecker, jewel beetle	standing
51	SOK	D	35	4	alive		yes	2	1		
52	SLI	D	41	1	alive	7	no				
53	SOK	D	48	4	alive		yes	31	18		
54	SOK	D	16	5	alive		no		1		
55	WST	D	12	5	alive		no				
56	SOK	D	62	1	alive	1	yes	22	3		
57	SOK	D	43	2	alive		yes	15	12	OPM	fresh slime flux
58	SOK	D	31	3	alive		yes	9			
59	WST	D	13	5	alive		no				
60	SOK	D	38	5	dead		yes	1		woodpecker, jewel beetle	standing
61	SOK	D	44	2	alive		yes	5			
62	SOK	D	50	1	alive		yes	4			
63	SLI	D	12	5	alive		no				old trunk damage
64	SLI	D	14	5	alive		no				old trunk damage
65	SOK	D	50	2	alive		yes	43	16	jewel beetle	fresh slime flux
66	SLI	D	29	5	alive		no				
67	SOK	D	71	2	alive	6	yes	2	2	jewel beetle	heavily damaged
68	WST	D	12	5	alive		no				
69	SOK	D	44	1	alive		yes	10	6		
70	SOK	D	37	5	dead		no			woodpecker, jewel beetle	standing
71	SOK	D	59	1	alive		yes	4	1		
72	SOK	D	43	3	alive		yes	23	10		
73	SLI	M	34	4	alive		no				
74	SOK	D	34	4	alive		yes	12	3		
75	WST	D	14	5	alive		no				
76	WST	M	15	5	alive		no				
77	SOK	M	35	4	alive		yes	4		OPM	
78	SOK	M	36	3	alive		yes	24		jewel beetle	
79	SOK	M	26	4	alive		yes	6			old wire
80	SOK	D	38	5	dead		yes	1		jewel beetle	standing
81	SOK	D			dead		no				lying
82	SOK	D			dead		no				lying
83	WST	D	16	5	alive		no				
84	WST	D	14	5	alive		no				
85	SOK	D	59	1	alive		yes	29	7	OPM	2022 positive tested for Rahnella
86	WST	D	11	5	alive		no				
87	SOK	D			dead		no				lying
88	SOK	D			dead		no				lying
89	SOK	D	47	3	alive		yes	5	3		
90	SOK	D	46	1	alive		no				glue ring
91	SOK	D	29	4	alive		yes	7	2		glue ring
92	SOK	D	38	2	alive		yes	10	3		

93	SOK	D	36	3	alive		yes	2			glue ring, old wire
94	SOK	D	40	2	alive	2	yes	2	1		glue ring
95	SOK	D	58	2	alive		yes	10	3		
96	SOK	D	58	1	alive		yes	18	5		
97	SOK	D	40	2	alive		yes	31	4		
98	SLI	D	13	5	alive		no				
99	WST	D	10	5	alive		no				
100	WST	D	11	5	alive		no				
101	SOK	D	56	3	alive	8	yes	19	7		2022 postive tested for Brenneria, heavily damaged
102	SOK	D	45	2	alive		yes	11	6		
103	WST	D	12	5	alive		no				
104	SOK	D			dead		no				lying
105	WST	D	12	5	alive		no				
106	SOK	D	39	3	alive		yes	6	5		
107	SOK	D	46	5	dead		no			woodpecker, jewel beetle	standing
108	SOK	D	58	2	alive		yes	8	2		
109	SOK	D	28	5	alive		yes	10	1		damaged, secondary crown
110	SOK	M	53	2	alive	1	yes	13	4		old wire
111	SOK	D			dead		no				lying
112	SOK	D			dead		no				lying
113	SOK	D	27	4	alive		yes	13	5		fresh slime flux
114	SOK	D	40	1	alive		yes	5	4		glue ring
115	SOK	D	29	4	alive	1	yes	7	2		glue ring
116	SOK	D	30	4	alive		yes	7	3		
117	SOK	D	30	3	alive		no		2		glue ring
118	SOK	D	34	3	alive		yes	5	1		
119	SOK	M	62	5	dead	11	yes	6		woodpecker, jewel beetle	standing
120	SOK	M	33	3	alive		no		2		
121	SOK	M	59	2	alive		yes	16	4	OPM, woodpecker	heavily damaged
122	WST	M	14	5	alive		no				
123	SOK	M	50	5	dead		yes	13		woodpecker, jewel beetle	standing
124	SOK	M	28	5	dead		no			jewel beetle	standing
125	SOK	M	52	2	alive		yes	1			
126	WST	M	17	5	alive		no				
127	SOK	M	32	3	alive		yes	22	5		
128	SOK	M	34	2	alive		yes	3	1		
129	SOK	M	62	5	dead		no			jewel beetle	standing
130	SOK	M	23	5	alive		yes	12	11	Woodpecker	heavily damaged
131	SOK	M	41	2	alive		yes	41	21		old wire, fresh slime flux
132	SOK	M	29	4	alive		yes	20	7		fresh slime flux
133	SOK	M	23	5	alive		yes	15	9		
134	WST	M	13	5	alive		no				
135	SOK	M	32	2	alive		yes	11	10		old wire
136	SOK	M	21	5	dead		no			jewel beetle	standing

137	WST	M	10	5	alive		no				
138	SOK	M	33	2	alive	1	yes	21	10		heavily damaged
139	SOK	M	32	5	alive		yes	5		Woodpecker	heavily damaged, crown breakage, secondary crown
140	WST	M	16	5	alive		no				
141	SOK	M			dead		no				lying
142	SOK	D	45	1	alive		yes	17			
143	SOK	D	24	5	alive		yes	6	5		fresh slime flux
144	SOK	D	35	4	alive	6	yes	7	9		heavily damaged
145	FM	D	16	5	alive		no				
146	WST	D	11	5	alive		no				
147	SOK	M	47	2	alive		yes	14			
148	WST	M	14	5	alive		no				
149	WST	M	11	5	alive		no				
150	SOK	M	32	3	alive		yes	11	7		
151	SOK	M	37	3	alive	1	yes	9			
152	SOK	M	36	4	alive		yes	13	4		
153	SOK	M	40	3	alive		yes	4	2		cocoon of Braconidae
154	SOK	M	45	3	alive		yes	17	5		
155	SOK	M	40	1	alive		yes	7	5		
156	SOK	M	36	3	alive		yes	7	6		
157	SOK	M	47	3	alive		yes	2			
158	SOK	M	31	3	alive		yes	15	10		
159	SOK	M	50	1	alive		yes	12			fresh slime flux
160	SOK	M	33	4	alive		yes	12	3		cocoon of Braconidae
161	WST	M	12	5	alive		no				
162	SOK	M	35	3	alive		yes	29	10	woodpecker, Armillaria (rhizomorphs)	damage at the trunk base, heavily damaged, secondary crown
163	SOK	M	21	5	alive		yes	15	5	Woodpecker	heavily damaged, crown breakage, secondary crown
164	SOK	M	38	3	alive		yes	8	2		
165	SOK	M	16	5	dead		no			woodpecker, jewel beetle	standing
166	SOK	M	35	3	alive		yes	4	3		
167	SOK	M	26	4	alive		yes	5	6		
168	SOK	M	30	3	alive		yes	7	3		
169	WST	M	15	5	alive		no				
170	SOK	M	37	5	dead		no			woodpecker, jewel beetle	standing
171	WST	M	11	5	alive		no				
172	WST	M	10	5	alive		no				
173	SOK	M	62	1	alive		yes	12	2		
174	SOK	M	45	3	alive		yes	18	7		
175	SOK	M	55	2	alive		yes	18	2		
176	SOK	M	55	2	alive	1	yes	13	2		heavily damaged
177	SOK	M	62	1	alive		yes	43	12		fresh slime flux

178	SOK	M	41	5	alive		yes	1		woodpecker, jewel beetle	heavily damaged, crown breakage, secondary crown
179	SOK	M	28	4	alive		yes	6	5		
180	SLI	M	10	5	alive		no				
181	SOK	M	44	2	alive		yes	7	3		
182	SOK	M	41	2	alive		yes	4	1		
183	SLI	M	10	5	alive		no				
184	SOK	M	33	4	alive		yes	4	2		
185	WST	M	11	5	alive		no				
186	SOK	M	53	2	alive		yes	21	4		very heavily damaged
187	WST	M	18	5	alive		no				
188	SOK	M	39	2	alive		yes	11	7		
189	SOK	M	28	3	alive		yes	9	1		trunk damage
190	WST	M	11	5	alive		no				
191	WST	M	10	5	alive		no				
192	SOK	M	29	5	dead		no			jewel beetle	standing
193	WST	M	16	5	alive		no				
194	SOK	M			dead		no				lying
195	SOK	M	59	1	alive		yes	50	20		fresh slime flux
196	SOK	M	67	1	alive	6	yes	37	5		
197	SLI	M	14	5	alive		no				
198	SOK	M	56	5	dead	9	no			woodpecker, jewel beetle	standing
199	SOK	M	41	3	alive		yes	19	6		cocoon of Braconidae
200	WST	M	18	5	alive		no				
201	SOK	M	41	2	alive		yes	11	5		
202	SOK	M	42	2	alive		yes	20	2		
203	SOK	M	30	4	alive		yes	2	2	OPM	
204	WST	M	17	5	alive		no				
205	WST	M	14	5	alive		no				
206	SOK	M	52	2	alive		yes	39	5		
207	SOK	M			dead		no				lying
208	SOK	M	59	2	alive		yes	38	9		fresh slime flux
209	WST	M	12	5	alive		no				
210	WST	M	15	5	alive		no				
211	SOK	M	47	2	alive		yes	14	5		
212	WST	M	14	5	alive		no				
213	SOK	M	30	3	alive		yes	11	13		fresh slime flux, secondary crown
214	SOK	M	35	3	alive		yes	4	4		
215	SOK	M	41	1	alive	1	yes	17	5		
216	SOK	M	34	4	alive		yes	19	1		very heavily damaged
217	SOK	M	39	5	dead		no			woodpecker, jewel beetle	standing
218	SOK	M	27	3	alive		yes	7	8		fresh slime flux
219	SOK	M	35	3	alive		yes	3	5		
220	SOK	M	34	3	alive		yes	4	4		

221	SOK	M	25	5	alive		no			woodpecker, jewel beetle	heavily damaged, crown breakage, secondary crown
222	SOK	M	25	5	alive		yes	8	2	Woodpecker	very heavily damaged
223	SOK	M	36	2	alive		yes	15	18		fresh slime flux
224	SOK	M	36	3	alive		yes	14	5		
225	SOK	M	38	2	alive		yes	8	7		
226	SOK	M	39	2	alive		yes	16			
227	SOK	M	28	3	alive		yes	12	2		
228	SOK	M	22	5	dead		no				standing
229	SOK	M	54	2	alive		yes	3	2		
230	WST	M	22	5	alive		no				
231	SOK	M	49	3	alive		yes	16	1		
232	SOK	M	50	2	alive		yes	4			fresh slime flux
233	SOK	M	35	3	alive		yes	4	4		growth anomaly at 40 cm
234	SOK	M	54	5	alive		yes	20	2	woodpecker, jewel beetle	heavily damaged, crown breakage, secondary crown
235	SLI	M	14	5	alive		no				
236	SLI	M	18	5	alive		no				
237	SLI	M	17	5	alive		no				
238	SLI	M	16	5	alive		no				
239	SOK	M			dead		no				lying
240	SOK	M	42	3	alive		yes	13	10		cocoon of Braconidae
241	SOK	M	41	2	alive	1	no				
242	SOK	M	49	1	alive	1	yes	6	3		
243	SOK	M	27	4	alive		yes	6	3		
244	SOK	M	43	2	alive		yes	8	1		trunk base
245	SOK	M	44	5	alive		yes	7		jewel beetle	crown breakage,
246	WST	M	18	5	alive		no				
247	SOK	M	52	1	alive	1	yes	6	1		
248	SOK	M	36	5	dead		no			woodpecker, jewel beetle	
249	SOK	M	44	3	alive		yes	23	7		fresh slime flux
250	SOK	M	40	3	alive		yes	18	10		fresh slime flux
251	SOK	M	33	4	alive		yes	2	1		
252	SOK	M			dead		no				lying
253	SLI	M	17	5	alive		no				
254	SOK	M			dead		no				lying (previously dead, but standing)
255	SOK	M			dead		no				lying (previously dead, but lying)
256	SOK	M			dead		no				lying (previously dead, but lying)
257	SLI	U	15	5	alive		no				
258	SOK	M	30	4	alive		yes	7			
259	SOK	M	59	1	alive	7	yes	14	1	OPM	
260	SLI	M	9	5	alive		no				
261	SLI	M	16	5	alive		no				
262	SLI	M	18	5	alive		no				

263	SOK	M	33	3	alive		yes	3			
264	SOK	M			dead		no				lying
265	SOK	M	23	5	alive		no				heavily damaged, crown breakage, secondary crown
266	SLI	M	20	5	alive		no				
267	SLI	M	13	5	alive		no				
268	SLI	M	12	5	alive		no				
269	SOK	M	65	1	alive		yes	38	5		
270	SLI	M	12	5	alive		no				
271	SOK	M	30	5	dead		no			woodpecker, jewel beetle	standing
272	SOK	M	50	1	alive		yes	4			cocoon of Braconidae
273	SOK	M	23	5	dead		no			woodpecker, jewel beetle	standing
274	SOK	M	27	5	alive		no				
275	SOK	M	38	4	alive		no				heavily damaged, grown over trunk damage
276	SOK	U	52	2	alive		yes	53	8		cocoon of Braconidae, very heavily damaged,
277	SOK	U	42	3	alive		yes	4	3		
278	SOK	U	30	4	alive		yes	2	1		cocoon of Braconidae
279	SOK	U			dead		no				lying
280	SOK	U	31	4	alive		yes	13			fresh slime flux
281	SOK	U	39	5	dead		no			woodpecker, jewel beetle	standing
282	SOK	U	39	5	alive		yes	8		woodpecker, jewel beetle	heavily damaged, crown breakage, secondary crown
283	SLI	U	27	5	alive		no				
284	SOK	M	44	5	dead		no			woodpecker, jewel beetle	standing
285	SOK	U	64	1	alive		yes	4			
286	SOK	U			dead		no				lying
287	SLI	U	21	5	alive		no				
288	SOK	U	56	1	alive	7	yes	20	3		
289	SLI	U	15	5	alive		no				
290	SOK	U	41	5	dead		no			woodpecker, jewel beetle	standing
291	SLI	U	11	5	alive		no				
292	SLI	U	14	5	alive		no			Woodpecker (round)	
293	SLI	U	14	5	alive		no				
294	SLI	U	12	5	alive		no			Woodpecker (round)	
295	SOK	U	46	3	alive		yes	9			
296	SOK	U	45	2	alive		no				
297	WST	U	15	5	alive		no				
298	SOK	U	46	2	alive		yes	6	4		
299	SOK	U	16	5	alive		no				
300	SOK	U	39	2	alive		yes	3			

301	SOK	U	38	3	alive		yes	6	4		
302	SOK	U	40	2	alive		yes	3	1	OPM	
303	SOK	U	32	3	alive		yes	2	1		
304	SOK	U	40	4	alive		no				
305	SLI	U	11	5	alive		no				
306	SLI	U	18	5	alive		no				
307	SOK	U	51	2	alive		yes	28	14		
308	SLI	M	15	5	alive		no				
309	SOK	M	21	5	alive		no				heavily damged
310	SOK	U	31	4	alive		yes	7	3		
311	SOK	U	33	3	alive		yes	2	1		
312	SLI	U	11	5	alive		no				
313	SLI	U	16	5	alive		no				
314	SOK	U	57	1	alive		yes	24	2	woodpecker, jewel beetle	very heavily damaged
315	SLI	U	16	5	alive		no				
316	SOK	U	39	3	alive		yes	9	3		
317	WST	U	11	5	alive		no				
318	SLI	U	11	5	alive		no				
319	WST	U	20	5	alive		no				
320	SLI	U	9	5	alive		no				
321	SLI	U	13	5	alive		no				
322	SOK	U	58	1	alive		yes	32	11		
323	SOK	U	29	4	alive		no				
324	WST	U	15	5	alive		no				
325	SOK	U			dead		no				lying
326	SOK	U	43	5	dead		no			woodpecker, jewel beetle	standing
327	SOK	U	30	2	alive		no			woodpecker, jewel beetle	very heavily damaged
328	SOK	U	40	3	alive		yes	3	2		
329	SLI	U	19	5	alive		no				
330	SLI	U	19	5	alive		no				
331	SOK	U	27	5	alive		yes	4			heavily damaged, crown breakage, secondary crown
332	SOK	U	31	4	alive		yes	3			
333	SOK	U	37	2	alive		yes	6	7		
334	SOK	U	36	4	alive		yes	12	3		
335	SOK	U	34	3	alive	1	yes	13	10		
336	SOK	U	34	3	alive		no				
337	SOK	U			dead		no				lying
338	SOK	U	25	5	dead		yes	2		woodpecker, jewel beetle	standing
339	WST	U	15	5	alive		no				
340	SOK	U	50	2	alive		yes	34	6		
341	WST	U	9	5	alive		no				
342	SOK	U	35	3	alive		yes	10	2		
343	WST	U	14	5	alive		no				
344	SOK	U	48	5	dead		no			jewel beetle	standing

345	SOK	U	29	5	alive		yes	19	6	woodpecker, jewel beetle	heavily damaged, crown breakage, secondary crown, cocoon of Braconidae
346	SOK	U	36	3	alive		no				
347	SOK	U	41	2	alive		yes	31	7		
348	SOK	U	26	4	alive	2	yes	6	9		damage at the trunk base, cocoon of Braconidae
349	SOK	U	35	2	alive		no				
350	SLI	U	12	5	alive		no				
351	SLI	U	13	5	alive		no				
352	SOK	U	33	4	alive		yes	8	3		
353	SLI	U	15	5	alive		no				
354	SOK	U	35	4	alive		yes	15	10		
355	SOK	U	26	5	dead		no			woodpecker, jewel beetle	
356	SOK	U	61	1	alive		yes	9			fresh slime flux
357	SOK	U	28	4	alive		yes	3	1		
358	SLI	U	16	5	alive		yes	1	3	Woodpecker (round)	
359	SOK	U			dead		no				lying
360	SLI	U	10	5	alive		no				
361	SLI	U	12	5	alive		no				
362	SOK	U			dead		no				lying
363	SOK	U	39	1	alive		yes	7	2		fresh slime flux
364	SOK	U	38	2	alive		yes	1			
365	WST	U	15	5	alive		no				
366	SOK	U			dead		no				lying
367	SLI	U	10	5	alive		no				
368	SOK	U	38	3	alive		yes	13	3		
369	SOK	U			dead		no				lying
370	SLI	U	35	4	alive		no				
371	SOK	U	33	3	alive		yes	6	3		
372	SLI	U	9	5	alive		no				
373	SOK	U	41	2	alive		yes	3	1		
374	SOK	U	22	5	dead		no			woodpecker, jewel beetle	standing
375	SLI	U	11	5	alive		no				
376	SOK	U	21	5	dead		no			woodpecker, jewel beetle	standing
377	SOK	U	21	5	dead		no			woodpecker, jewel beetle	standing
378	SLI	U	15	5	alive		no				
379	SLI	U	12	5	alive		no				
380	SLI	U	27	5	alive		yes				
381	SOK	U	49	2	alive		no				
382	SOK	U	23	5	alive		yes	4			
383	SOK	U	25	4	alive		no				cocoon of Braconidae
384	SOK	U	26	5	alive		yes	18	4		damage at the trunk base

385	SLI	U	10	5	alive		no			Woodpecker (round)	
386	SLI	U	11	5	alive		no				
387	SLI	U	12	5	alive		no				
388	SLI	U	21	5	alive		no			Woodpecker (round)	
389	SOK	U	29	4	alive		yes	27	16		very heavily damaged
390	SOK	U	38	3	alive		no				
391	SOK	U	44	2	alive		yes	1			
392	SLI	U	15	5	alive		no			Woodpecker (round)	
393	SOK	U	31	3	alive		yes	3	1		
394	SLI	U	9	5	alive		no				
395	SOK	U	33	4	alive		yes	3			
396	SOK	U	22	5	alive	1	yes	3	2		
397	WST	U	11	5	alive		no				
398	WST	U	15	5	alive		no				damage at the trunk base
399	WST	U	11	5	alive		no				
400	SLI	U	39	3	alive		no			Woodpecker (round)	
401	SLI	U	10	5	alive		no				
402	SLI	U	13	5	alive		no				
403	SLI	U	15	5	alive		no				
404	SOK	U	47	2	alive		yes	2	1		
405	SLI	U	12	5	alive		no				
406	SOK	U	45	3	alive		yes	2	4		
407	SLI	U	12	5	alive		no				
408	SLI	U	14	5	alive		no				
409	SOK	U	40	2	alive		yes	8			
410	SOK	U	41	1	alive		no				
411	WST	U	18	5	alive		no				
412	SOK	U	45	1	alive		no				
413	SOK	U	49	4	alive		no				
414	SOK	U	29	1	alive	1	yes	7	3		
415	SLI	U	15	5	alive		no				
416	SOK	U	35	3	alive	1	yes	6	2		
417	SOK	U	32	3	alive		no				
418	SOK	U	52	2	alive		yes	4	1		
419	SOK	U	51	1	alive		yes	2			
420	SOK	U	29	4	alive		yes	37	11		
421	SOK	U	40	5	dead		no				standing
422	SLI	U	25	5	alive		no				
423	SOK	U	39	2	alive		no				
424	SOK	U	43	3	alive		yes	5	3		
425	SLI	U	27	5	alive		no				
426	SOK	U	44	2	alive		no		6		
427	SOK	U	51	1	alive		yes	4	1		
428	SOK	U	28	5	dead		no			jewel beetle	standing
429	SOK	U	60	1	alive		yes	5	2		
430	SOK	U	40	2	alive		yes	4	2		

431	SOK	U	13	5	alive		no				
432	SOK	U	34	3	alive		yes	19	9		
433	SOK	U	37	2	alive		yes	8	3		
434	SOK	U	26	4	alive		yes	6	4		fresh slime flux
435	SLI	U	15	5	alive		no			Woodpecker (round)	
436	SLI	U	13	5	alive		no				
437	SOK	U	56	5	dead		yes	6		woodpecker, jewel beetle	
438	SOK	U	32	3	alive		yes	24	11		
439	SOK	U	35	3	alive		yes	26	14		
440	HAW	U	11	5	alive		no				
441	SOK	U	32	4	alive		yes	24	4		
442	SOK	U	34	3	alive		yes	15	9		
443	SOK	U	28	4	alive		yes	7	4		
444	SOK	U	45	1	alive		yes	3			
445	SOK	M	41	4	alive		yes	18	3		secundary crown
446	SOK	M	55	2	alive		yes	37	7		
447	SOK	U			dead		no				lying
448	SLI	U	11	5	alive		no				
449	SP	U			dead		no			Armillaria mellea, beetle	lying
450	SP	U	43	5	dead		no			Armillaria mellea, beetle	standing
451	SP	U	42	5	dead		no			Armillaria mellea, beetle	standing

Explenations:

Tree species:
- SOK sessile oak (*Quercus petraea*)
- SLI small-leaved lime (*Tilia cordata*)
- WST wild service tree (*Sorbus tominalis*)
- SP Scots pine (*Pinus silvestris*)
- FM field maple (*Acer campestre*)
- WDO common hawthorn (*Crataegus monogyna*)

Slope:
- D downslope
- M midslope
- U upslope

Kraft's class:
- 1 predominant
- 2 dominant
- 3 codominant
- 4 intermediate
- 5 overtopped or dead

Table B2: Detailed measurements of the lesions on the sampled trees.

Tree No.	Tree species	Height on the trunk [cm]	Exposition	Length of the lesion [mm]	Width of the lesion [mm]	Notes
4	EI	185	S	6	1.5	
4	EI	160	W	3	1	in crack
4	EI	156	W	8	1.5	in crack
4	EI	163	W	8	2	
4	EI	150	NW	4.5	1.5	
4	EI	87	N	3	1	
4	EI	79	N	2.5	1	
21	EI	148	S	5	1.5	
21	EI	158	SW	2	1	
21	EI	182	SW	11	1.5	
21	EI	153	W	5	1	
21	EI	172	W	6.5	1	
21	EI	131	W	3	1	
21	EI	135	W	3.5	1	
21	EI	135	W	3	1	
21	EI	191	W	8	1	
21	EI	192	W	6	1	
21	EI	162	NW	5	2	
21	EI	73	NW	4.5	1	
32	EI	166	S	2.5	1	
32	EI	174	S	2	1	
32	EI	97	S	2	1	
32	EI	122	SW	21	3	in damage
32	EI	122	SW	20	2.5	in damage
32	EI	159	SW	4	1	
32	EI	121	W	2	1	
32	EI	123	W	1	1	crack
32	EI	120	W	5	1	crack
32	EI	102	W	2.5	1	
32	EI	93	NW	4	1.5	crack
32	EI	106	NW	2	1	crack
32	EI	178	W	1.5	1	
32	EI	196	W	2.5	1	
32	EI	113	N	3.5	1.5	
32	EI	138	N	20	1	
32	EI	132	N	2	1	
32	EI	137	N	2.5	1	
32	EI	148	N	1.5	1	
32	EI	155	N	1	1	
32	EI	178	N	7.5	1	
32	EI	132	N	5	1	
32	EI	121	N	4	1	
32	EI	105	N	5.5	1	
32	EI	147	NE	2.5	1.5	

32	EI	154	E	2	1	
32	EI	149	E	7	1	crack
32	EI	161	E	4.5	1	
32	EI	176	E	1	1	
32	EI	24	E	11	2	
32	EI	76	E	12	1	
32	EI	90	E	7	1.5	
32	EI	99	SE	3	1	
32	EI	166	S	3.5	1	
56	EI	56	S	1.5	1.5	
56	EI	93	S	18	1	
56	EI	101	S	3	1	
56	EI	155	S	3	1	
56	EI	154	S	4	1	
56	EI	152	S	4	1	
56	EI	134	SW	15	1	
56	EI	144	SW	10.5	1	
56	EI	93	SW	9	2	
56	EI	130	SW	2.5	1.5	
56	EI	175	SW	7	1	
56	EI	151	W	7.5	1	
56	EI	164	W	16	1	
56	EI	143	W	8	1	
56	EI	117	W	5	1	
56	EI	154	NW	5	1	
56	EI	179	N	7	1	
56	EI	146	N	2	1	
56	EI	167	E	4	1	
56	EI	141	SE	5	1	
56	EI	97	S	5	1	
56	EI	92	S	5	1	
78	EI	50	S	1.5	1	
78	EI	65	S	1.5	1	
78	EI	63	S	1.5	1	
78	EI	114	S	18	1	
78	EI	98	S	4	1.5	
78	EI	124	S	7	1	
78	EI	128	SE	12.5	1.5	
78	EI	132	SE	1.5	1	
78	EI	141	SE	4	1	
78	EI	144	SE	1	1	
78	EI	142	SE	3	1.5	
78	EI	104	SE	9	1	
78	EI	70	SE	10	1	
78	EI	75	SE	5	1	
78	EI	131	E	18	1	
78	EI	157	SE	3	1	fresh
78	EI	163	S	2.5	1	
78	EI	125	S	3.5	2	
78	EI	142	SW	2.5	1	

78	EI	162	SW	2	1	
78	EI	173	SW	4.5	1	
78	EI	179	SW	2.5	1	
78	EI	173	W	5.5	1	
78	EI	187	E	5	1	
85	EI	58	S	11	1.5	
85	EI	56	S	4	1	
85	EI	88	S	30	2.5	crack
85	EI	122	S	10	1.5	crack
85	EI	104	S	2	1	crack
85	EI	129	S	1	1	
85	EI	170	S	7	1	crack
85	EI	180	S	6	1	crack
85	EI	188	S	5	1	
85	EI	78	SW	4	2	
85	EI	128	W	9	1	
85	EI	200	W	7	2	
85	EI	108	W	4	1	
85	EI	89	W	4	1.5	crack
85	EI	122	NW	3	1	
85	EI	154	NE	9	1.5	
85	EI	79	E	19	1	
85	EI	92	E	23	1	crack
85	EI	103	E	9	1	crack
85	EI	116	E	10	1.5	
85	EI	167	E	21	1	
85	EI	195	E	18	1	
85	EI	137	E	15	1	
85	EI	123	SE	37	1.5	
85	EI	164	SE	6.5	1	
85	EI	200	SE	9.5	2	
85	EI	122	S	7	1	
85	EI	93	S	7	1.5	
85	EI	60	S	5	1	
109	EI	167	SE	2	2	
109	EI	170	S	3	1	crack
109	EI	139	S	1.5	1	
109	EI	140	S	1	1	
109	EI	159	SW	4	1.5	
109	EI	147	SW	1.5	1	
109	EI	117	SW	3	1.5	
109	EI	91	W	2	1	
109	EI	78	W	3	1	
109	EI	184	NW	25	1	crack
121	EI	94	S	2	1	
121	EI	126	S	6	1.5	
121	EI	171	S	2	1	
121	EI	168	S	10	2	
121	EI	183	S	4	1	
121	EI	145	W	2.5	1.5	

121	EI	152	W	2	1	
121	EI	116	NW	3	1	
121	EI	102	E	3	1.5	
121	EI	190	E	5	1	
121	EI	173	E	3	1	
121	EI	143	E	18	1	crack
121	EI	127	E	10	2	
121	EI	104	E	1	1	
121	EI	152	E	9	1	
121	EI	157	SE	3	1	
147	EI	88	S	2	1	
147	EI	141	S	1	3	
147	EI	195	S	10	1	
147	EI	164	S	2	2	
147	EI	92	SW	3	1	
147	EI	92	W	4	1	
147	EI	107	W	2	1	
147	EI	122	W	1	1	
147	EI	172	SE	3	1.5	
147	EI	183	SW	2	1.5	
147	EI	153	W	2	1	
147	EI	157	W	2	1	
147	EI	107	S	1.5	1	
147	EI	71	W	10	1	
174	EI	64	S	1	1	
174	EI	57	S	3	1	
174	EI	91	S	1.5	1	
174	EI	131	S	14	1	crack
174	EI	150	S	9	1	crack
174	EI	151	S	1.5	1	
174	EI	184	S	2	1	
174	EI	179	S	4	1.5	crack
174	EI	96	SW	8	1	
174	EI	55	W	8	1	
174	EI	59	NW	6	1	
174	EI	127	NW	11	1	crack
174	EI	126	N	10	2	crack
174	EI	103	N	4	1	
174	EI	107	E	1.5	1	crack
174	EI	104	E	14	1	crack
174	EI	115	E	1	1	
174	EI	34	SE	5	1.5	
213	EI	103	S	12	0.5	
213	EI	51	SW	10	1.5	crack
213	EI	40	SW	7.5	1	crack
213	EI	69	W	5	1	crack
213	EI	99	W	1.5	1	
213	EI	49	W	22	2	crack
213	EI	139	W	3	1	crack
213	EI	107	W	0.5	0.5	

213	EI	45	E	17	1	fresh
213	EI	174	SE	25	2	crack
213	EI	69	S	19	2.5	
244	EI	98	SW	2.5	0.5	in damage
244	EI	102	SW	3	1	in damage
244	EI	38	E	2	1	
244	EI	36	E	4	1	
244	EI	50	E	1	1	
244	EI	40	E	3	1	
244	EI	108	E	3	2	crack
244	EI	162	S	5	1.5	
314	EI	73	S	6.5	1	
314	EI	84	S	1	1	
314	EI	124	S	1.5	0.5	
314	EI	105	S	9	1	crack
314	EI	138	S	2.5	0.5	
314	EI	169	S	4	1	
314	EI	161	S	26	0.5	
314	EI	163	S	11	0.5	crack
314	EI	75	SW	9	2	
314	EI	159	SW	2	1	
314	EI	139	SW	0.5	0.5	
314	EI	125	W	6	1	
314	EI	168	N	7	1.5	
314	EI	156	N	5	1	
314	EI	175	NE	12	0.5	
314	EI	181	NE	3	1	
314	EI	114	NE	15	1	
314	EI	134	E	35	1.5	
314	EI	200	E	12	1	
314	EI	158	E	19	1	
314	EI	164	E	15	0.5	
314	EI	192	SE	23	1	
314	EI	155	SE	6	1	
314	EI	101	W	6	1	
342	EI	69	S	5	2	
342	EI	131	S	4	2	
342	EI	146	S	2	0.5	
342	EI	139	S	1	0.5	
342	EI	58	SW	2	1	
342	EI	63	SW	1	1	
342	EI	110	W	1.5	0.5	
342	EI	132	W	1	0.5	
342	EI	179	NW	5	1	crack
342	EI	186	NW	3	1	crack
356	EI	84.5	S	4	1.5	
356	EI	98	S	1	0.5	
356	EI	68	S	4	1	
356	EI	87	SW	3	1	
356	EI	87	W	0.5	0.5	

356	EI	80	W	0.5	0.5	
356	EI	149	E	4	1.5	
356	EI	121	S	0.5	0.5	
356	EI	88	W	1	0.5	
389	EI	108	S	1	0.5	
389	EI	73	SW	3	1	
389	EI	72	W	4	1	
389	EI	86	W	9	1	crack
389	EI	99	W	9	1	crack
389	EI	105	W	2	1.5	
389	EI	112	W	5	2	
389	EI	126	W	11	1	crack
389	EI	128	W	12	1	crack
389	EI	125	W	5	1	
389	EI	140	NW	2	1	
389	EI	167	N	15	1	
389	EI	169	N	4	1	
389	EI	150	E	4	3	
389	EI	186	E	16	1.5	
389	EI	165	E	9	1.5	
389	EI	152	E	19	2	
389	EI	104	E	16	2.5	
389	EI	93	E	15	2	
389	EI	85	E	2.5	1	
389	EI	69	E	8	1	
389	EI	63	E	6	2	
389	EI	37	SE	3	1	
389	EI	49	S	4	0.5	
389	EI	24	S	6	2.5	
389	EI	17	S	7	1.5	
389	EI	11	S	3	2	
418	EI	128	W	9	1	
418	EI	127	W	0.5	0.5	
418	EI	165	W	5	1	
418	EI	116	E	11	0.5	crack
420	EI	121	S	2	0.5	
420	EI	183	S	5	1.5	
420	EI	157	S	0.5	0.5	
420	EI	140	S	0.5	0.5	
420	EI	119	SW	17	1	crack
420	EI	118	SW	0.5	0.5	
420	EI	177	W	13	1	crack
420	EI	66	W	7	0.5	crack
420	EI	49	W	5	1	
420	EI	74	W	1	0.5	
420	EI	81	W	4	1	
420	EI	90	W	5	1	crack
420	EI	101	W	12	1	crack
420	EI	119	W	4	1	
420	EI	121	W	14	1.5	crack

420	EI	152	W	10	1	crack
420	EI	147	W	13	1.5	crack
420	EI	89	N	3	0.5	
420	EI	173	N	8	1	crack
420	EI	163	E	2	1	
420	EI	170	E	10	1	
420	EI	181	E	15	0.5	crack
420	EI	163	E	3	0.5	
420	EI	147	E	2	1	
420	EI	141	E	8	1	
420	EI	158	E	1	0.5	
420	EI	156	SE	1	0.5	
420	EI	156	SE	5	0.5	
420	EI	66	E	4	0.5	
420	EI	90	E	1	1	
420	EI	111	S	2.5	1.5	
420	EI	119	S	4	1.5	
420	EI	139	S	1	1	
420	EI	156	S	2	0.5	
420	EI	173	S	6	1.5	
420	EI	181	S	3	1	
420	EI	41	S	3	1	

Appendix C – Statistical Analysis

```
str(data)

data$Slope_position <- as.factor(data$Slope_position)
data$DBH <- as.numeric(data$DBH)
data$Lesions <- as.numeric(data$Lesions)


results <- data %>%
  group_by(Slope_position) %>%
  summarise(
    n = sum(!is.na(DBH) & !is.na(Lesions)),
    spearman_rho = cor.test(DBH, Lesions, method = "spearman")$estimate,
    p_value = cor.test(DBH, Lesions, method = "spearman")$p.value
  )


print(results)

install.packages("FSA")
install.packages("dplyr")


library(FSA)
library(dplyr)


kruskal.test(Lesions ~ Slope_position, data = data)


dunnTest(Lesions ~ Slope_position,
         data = data,
         method = "bonferroni")
```

Figure C1: R script for statistical analysis.

Appendix D – Detailed Results

Table D1: Detailed results of the sampled trees based on multiple variables.

Sample Tree No.	**DBH**	**Number of lesions**	**Number of cracks**	**Signs of *A. biguttatus***	**Remarks on visual crown vitality 03/2026**	**Remarks on visual crown vitality 08/2018**	***B. goodwinii***	***G. quercinecans***	***R. victoriana***
04	29	7	4	no			/	/	□
21	41	12	3	no		small feeding damage of defoliators	■	■	□
32	31	34	4	no			■	■	□
56	62	22	3	no		noticeable feeding damage of defoliators	■	/	□
85	59	29	7	no		noticeable feeding damage of defoliators	■	■	/
109	28	10	1	no	heavily damaged, secondary crown		■	■	■
78	36	24	0	yes			□	□	□
121	59	16	4	no	heavily damaged, woodpecker marks, old nest of oak processionary moth		□	□	□
147	47	14	0	no			/	/	/
174	45	18	7	no		feeding damage of defoliators	/	□	□
213	30	11	13	no	secondary crown		□	□	□
244	43	8	1	no		noticeable feeding damage of defoliators	/	□	□
314	57	24	2	yes	heavily damaged, woodpecker marks, exit holes of jewel beetle		■	■	/
342	35	10	2	no			■	□	□
356	61	9	0	no		noticeable feeding damage of defoliators	/	□	□
389	29	27	16	no	heavily damaged		□	□	□
418	52	4	1	no		noticeable feeding damage of defoliators	/	□	/
420	29	37	11	no		noticeable feeding damage of defoliators	□	□	□

Table D2: Detailed measurements of the lesions on the sampled trees. Bold tree No. = tree has tested positive for at least one of the bacteria; Red tree No. = tree has been tested negative for all AOD-associated bacteria.

Sample Tree No.	Number of lesions	Mean Height of the exit point of the Lesions [cm]	Mean length of lesions [cm]	Min. Length of Lesions [cm]	Max Length of Lesions [cm]	Aspect of most lesions
4	7	140	5	2,5	8	W
21	12	153	5	2	11	W
32	34	132	5	1	21	N
56	22	134	7	1,5	18	S
85	29	125	10	1	37	S
109	10	139	5	1	25	S
78	24	127	5	1	18	SE
121	16	144	5	1	18	E
147	14	132	3	1	10	W
174	18	107	6	1	14	S
213	11	86	11	0,5	25	W
244	8	79	3	1	5	E
314	24	142	10	0,5	35	S
342	10	121	3	1	5	S
356	9	96	2	0,5	4	S
389	27	101	7	1	19	E
418	4	134	6	0,5	11	W
420	37	129	5	0,5	17	S

Figure D1: Tree number 121 displaying a heavily damaged crown with dead branches.

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