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Situation of *Armillaria* spp. and *Heterobasidion* spp. in Slovenia

ANA BRGLEZ* AND NIKICA OGRIS

Slovenian Forestry Institute, Vecna pot 2, 1000 Ljubljana, Slovenia

** Corresponding author; e-mail: ana.brglez@gozdis.si; tel: + 386 1 200 78 69*

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Abstract

Species of the genus *Armillaria* and *Heterobasidion* are among the most common causes of stem and root rot in Slovenia. *Armillaria* spp. infect deciduous and coniferous trees, while *Heterobasidion* spp. mainly threaten *Picea abies*, *Pinus* spp., and *Abies alba*. Based on the data from the sanitary felling of infected trees, we estimated the current state and calculated the proportions represented in total felling, total sanitary felling, total sanitary felling due to root rot diseases, in wood stock, and in increments from 2013 to 2017. Since 2014, there has been a constant increase in the sanitary felling of deciduous and coniferous trees due to infections by *Armillaria* spp. In 2017, 32,849 m^3 of timber were harvested due to *Armillaria* spp. Given the present situation, we assume that the amount of sanitary felling will continue to increase, but it will not account for large shares in wood stock or increment. In 2017, sanitary felling of *Armillaria* infected conifers represented 27.6% of all sanitary felling due to diseases. In the case of deciduous trees, the share was lower, i.e. 7.1%. *Armillaria* spp. was the main cause of sanitary felling due to disease (51.9%) in the Postojna forest management unit (FMU), while elsewhere shares of up to 10% were recorded. Regarding *Heterobasidion* spp., the amount of felling decreased over the years. In 2017, 33,922 m^3 of wood, accounting for 15.7% of the total sanitary felling due to disease, was felled due to *Heterobasidion* spp. Out of the total sanitary fellings due to these fungi, on average 79.5%, 12.9%, and 34.3% of *Picea abies*, *Abies alba* and *Pinus sylvestris*, respectively, were felled due to *Heterobasidion* infection. We predict that the volume of timber harvested due to *Heterobasidion* spp. will gradually decrease over the years due to the lower wood stocks of Norway spruce, which has recently been hit by numerous natural disasters and infestation of bark beetles. The trend of *Heterobasidion* incidence from our study conflicts with other research that expect higher incidence of root rots due to climate change effects.

Keywords: sanitary felling, *Armillaria* spp., *Heterobasidion* spp., root rot, root disease, Slovenia

Introduction

According to the Slovenia Forest Service (SFS), Slovenia possesses 1,184,526 ha of forests that represent 58.4% of its area. In the wood stock, 45% are conifers with a predominance of Norway spruce, which represents 30% of the wood stock (ZGS 2017) and is widespread from the lowlands to the subalpine zone. In the past, it was greatly promoted and expanded beyond its natural habitat. Due to inadequate site conditions, these stands are more exposed and susceptible to fungal infections and insect attacks.

Among diseases, the most frequent and most significant coniferous disease in Slovenia is a root rot caused by *Heterobasidion annosum* (Fr.) Bref. *sensu lato* (Munda 1997). This is an aggressive pathogen that causes root and butt rot primarily on conifers and some deciduous trees in temperate forests of the Northern Hemisphere (Korhonen et al. 1998, Niemelä and Korhonen 1998, Asiegbu et al. 2005). The species complex is mainly associated with spruce, fir and pine and consists of three European species (Garbelotto and Gonthier 2013). *Heterobasidion annosum* (Fr.) Bref. *sensu stricto* is most common on pines (*Pinus* spp.) on sandy soils and infects a wide range of hosts, such as Norway spruce, common juniper, larch and also some deciduous trees: birch, alder, rowan, European aspen, etc. *Heterobasidion parviporum* Niemelä & Korhonen infects spruce and larch, very rarely also fir trees. *Heterobasidion abietinum* Niemelä & Korhonen is associated with the prevalence of fir trees, occurring as a saprophyte on fir and spruce stumps and rarely causing decay in living trees (Jurc 2001).

Heterobasidion infection and spread is performed with basidiospores and mycelium (Jurc 2001). Basidiospores are important for the infection of freshly felled stumps and root wounds, while mycelium serves for spreading from infected stumps to healthy trees through root contacts or grafts (secondary infections) (Korhonen and Stenlid 1998). Release and infection of basidiospores depend on weather conditions, especially humidity and temperature (Jurc 2001). In temperate regions, the basidiospores are mainly released during summer when tree stumps are most susceptible to infection (Redfern and Stenlid 1998). The fungus does not infect during periods when the substrate temperature exceeds 35 °C (Ross 1973) or is below 5 °C (Jurc 2001). Conidia are also produced but their role is unclear. Basidiospores germinate and colonize stumps and roots. The fungus grows necrotrophically within the sapwood of living trees but with time, in most species it expands in the heartwood. The rate of spread depends on stand type and history, forest composition and soil properties (Korhonen and Stenlid 1998). In the northern temperate forests, average growth rates of 20–50 cm per year have been documented (Swedjemark and Stenlid 1993, Jurc 2001). The main macroscopic sign indicating the presence of *Heterobasidion* root rot is a perennial, irregularly shaped sporocarp. Those fruiting bodies grow in hidden places, on the roots and stumps. On infected living trees, it is difficult to see them, except in the case of deep wounds on the bark or in the cavities of rotting trunks. Since *Heterobasidion* species usually do not develop typical external signs on living trees, it is difficult to distinguish them from other rots. Reliable signs of *Heterobasidion* spp. are sporocarps and the formation of conidiophores on the mycelium. The fungus is problematic because even after the felling of the infected trees, it resides in stumps and roots, and from there extends to the roots of the surrounding trees. The rot fungi destroy timber and threaten conifers that will be planted in the future. *Heterobasidion* root disease is economically important and affects mainly lowland Norway spruce stands that locate outside its natural habitat (Jurc 2001). It is estimated that *Heterobasidion* infections in European forests cause an economic loss of approximately 800 million euros per year (Woodward et al. 1998).

In addition to the *Heterobasidion* root rot, in the forests of Slovenia, also *Armillaria* spp. are widespread and cause massive dieback of trees. Conifers are more sensitive to *Armillaria* species in comparison to deciduous trees; Scots pine, Norway spruce, and European larch being particularly affected. Among the deciduous trees, oak, chestnut, and elm are the most affected. The first signs of the disease are the death of branches, browning and the cast of needles and leaves. In the infected conifers, one can observe resin flow from the roots and the root neck. The cambium dies and is replaced by a thin, white mycelium. The fungus can also spread from tree to tree, with the use of rhizomorphs. A characteristic sign of infection with *Armillaria* spp. is the appearance of sporocarp tufts, which can be easily seen on stumps or dead roots from the late summer to severe autumn frost. The genus *Armillaria* is a complex of seven species, of which *A. mellea* and *A. ostoyae* are predominant in Slovenia. *A. mellea* predominates in deciduous forests, and *A. ostoyae* occurs mainly on conifers, such as pine and Norway spruce (Munda 1990, Maček 2008).

In Slovenia, there are only a few studies dealing with *Armillaria* spp. and *Heterobasidion* spp., although those two fungal genera are among the most destructive. Last research papers date back to the year 1990 and 1997. Because of a huge economic impact, we suggest that there should be more attention paid to those species. Our paper aims to assess the situation and prospects of *Armillaria* and *Heterobasidion* species in Slovenia and it is the first attempt to evaluate distribution of these two rot fungi at the country level.

Materials and Methods

The Slovenia Forest Service (SFS) records sanitary felling due to several root and stem rot diseases in their daily routine (ZGS 2017). The SFS differ between 9 types of cuttings. Sanitary felling is one of them and refers to a chosen number of trees of the same species, which are felled because of biotic (insects, diseases and game damage) or abiotic factors (wind, snow, ice, drought and landslide) in the same forest sub-compartment. Damaged trees are felled to improve the health status of the stand. Foresters choose the type of felling for each tree species. In the event of sanitary felling they also visually define what the cause of damage is. Only primary damaging agent is recorded. It is important to know that also healthy-looking trees have rot, but they are not included in the calculations. In our study, we used data on sanitary felling from 2013 to 2017. Since frequencies of root and stem rot fungi are extremely low, only data on *Armillaria* spp. and *Heterobasidion* spp. were selected for further calculations (Table 1).

Table 1. Types of root and stem rot fungi recorded in sanitary felling from 2013 to 2017 in Slovenia

Root and stem rot fungus	Sanitary felling [m^3]	Shares [%]
***Armillaria* (Fr.) Staude**	**92,704**	**29.803**
Climacocystis borealis (Fr.) Kotl. & Pouzar	1,291	0.415
Fomes fomentarius (L.) Fr.	4,586	1.474
Phellinus hartigii (Allesch. & Schnabl) Pat.	226	0.073
Fomitopsis pinicola (Sw.) P. Karst.	41	0.013
Ganoderma lipsiense (Batsch) G.F. Atk.	54	0.017
***Heterobasidion* Bref.**	**211,144**	**67.880**
Phaeolus schweinitzii (Fr.) Pat.	792	0.254
Phellinus igniarius (L.) Quél.	50	0.016
Phellinus pini (Brot.) Pilát	27	0.009
Pholiota squarrosa (Vahl) P. Kumm.	14	0.005
Sparassis crispa (Wulfen) Fr.	70	0.022
Stereum rugosum Pers.	6	0.002
Stereum sanguinolentum (Alb. & Schwein.) Fr.	40	0.013
Porostereum spadiceum (Pers.) Hjortstam & Ryvarden	13	0.004
Total sum	**311,056**	**100**

In this paper, we do not distinguish between the individual species of *Armillaria* and *Heterobasidion*, since data on the occurrence of these species are recorded only at the genus level. In the absence of sporocarps reliable determination of the species in *Armillaria* is possible only with special laboratory tests, in which pure cultures are crossed with characterized strains or analysed with molecular techniques. In the case of *Heterobasidion* spp., somewhat more effort is needed to distinguish between species (Munda 1990).

We used disease agent, forest management unit (FMU) and tree species as variables. From the Forest Funds database of the Slovenia Forest Service we also obtained data on wood stock and increment (ZGS 2016). Then we calculated proportions of *Armillaria* and *Heterobasidion* felling in the relation to total felling, total sanitary felling, total sanitary felling due to root rot diseases, to wood stock, and increments from 2013 to 2017. Before the calculations, we critically reviewed the data and filtered away data about the felling of deciduous trees due to *Heterobasidion* spp.

For queries and calculations, we used Microsoft SQL Server Management Studio v. 17.8.1 and the previously mentioned database about tree felling. The graphs were prepared in Microsoft Excel v. 1708. For mapping the geographic distribution of disease incidences, ESRI ArcMap v. 10.4.1 was used.

Results

Armillaria spp.

During the period 2013–2017, 92,704 m^3 of coniferous (78%) and deciduous (22%) trees were cut down due to *Armillaria* spp. *Armillaria* (*Arm*) sanitary felling represented less than 0.6% of total felling every year, while the share of wood stock and increment was even lower. In 2013, 17,139 m^3 of timber was felled due to *Armillaria* spp., this constituting 7.9% of total sanitary fellings due to diseases. *Armillaria* sanitary felling then underwent a major shift in 2014 and 2015 (4.4 or 5.7%) due to catastrophic ice storm that occurred in February 2014. In 2014, only 6,964 m^3 of timber was felled due to *Armillaria* spp. The natural disaster affected mainly conifers, which is reflected in a drastic decline in the proportion of *Armillaria* sanitary felling in the relation to total sanitary felling (Figure 1). In the case of deciduous trees, the decline in proportion of *Armillaria* sanitary felling in the year of the ice storm is not prominent (Figure 2). Furthermore, shares represented by *Armillaria* sanitary felling in total sanitary felling due to diseases do not reach as high numbers as they do with conifers. After 2014 *Armillaria* sanitary felling increased. In 2016, the volume of *Armillaria* sanitary felling rose above the initial values (11.6% of sanitary felling due to diseases). The highest value was recorded in 2017 when 0.6% of the annual increment, 1.1% of total sanitary felling and 27.6% of sanitary felling due to diseases in conifers was felled due to *Armillaria* species. In deciduous trees in the same year *Armillaria* felling amounted to 2.2% of total sanitary felling and 7.1% of sanitary felling due to diseases. In 2017, 15.2% of overall sanitary felling due to diseases was resulted from *Armillaria* spp. The volume of felled timber represented 0.6% of the total felling.

The following figures (Figure 1 and Figure 2) show the growing trend in the proportion of sanitary felling due to the *Armillaria* root rot with a typical minimum in 2014. Using a linear regression, we calculated a trend indicating a gradual increase in felling due to *Armillaria* spp., also in the coming years (b = 4975 m^3 year^{-1}; r^2 = 0.55).

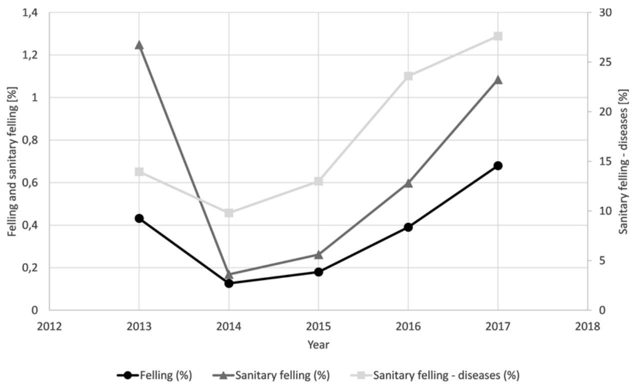

Figure 1. Proportion of conifers felled due to *Armillaria* spp. within the period between 2013 and 2017 with regard to total felling, total sanitary felling and sanitary felling due to diseases

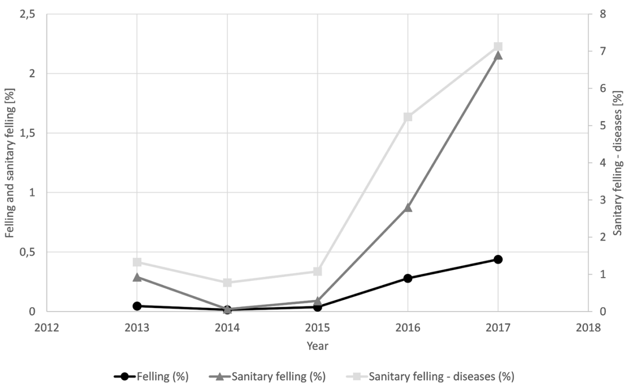

Figure 2. Proportion of deciduous trees felled due to *Armillaria* spp. within the period between 2013 and 2017 with regard to total felling, sanitary felling and sanitary felling due to diseases

Geographically, most of the *Armillaria* sanitary fellings were concentrated in the southern half country, around Novo Mesto, Logatec, Snežnik, Krakovo, and in the northeast part, at the Mura River region (Figure 3). The portion of *Armillaria* felling due to the diseases is more fragmented, and difficult to precisely attribute to certain geographic areas. The greatest amounts of damaged forests due to *Armillaria* root rot were in FMU Postojna and the lowest ones in FMUs Kočevje and Nazarje (Figure 4).

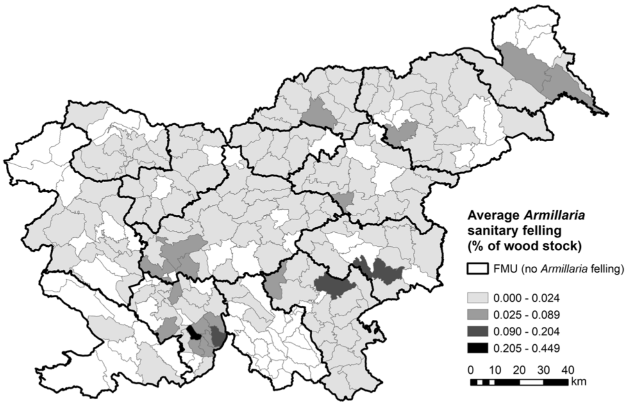

Figure 3. Average sanitary felling due to *Armillaria* spp. in Slovenia within the period between 2013 and 2017, expressed as % of wood stock in forest management units (considering all tree species) (Source: ZGS 2016, 2017)

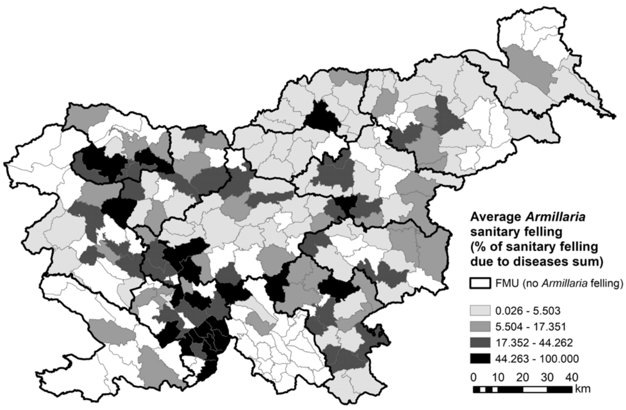

Figure 4. Average sanitary felling due to *Armillaria* spp. in Slovenia within the period between 2013 and 2017, expressed as % of sanitary felling due to diseases in forest management units (considering all tree species) (Source: ZGS 2016, 2017)

***Heterobasidion* spp.**

From 2013 to 2017, 211,144 m^3 of conifers were felled due to *Heterobasidion* spp. From 2014 onwards, around 40,000 m^3 of timber has been felled every year due to *Heterobasidion* root rot. The values exceed the felling due to *Armillaria* root rot. In 2017, the lowest quantity of wood (33,000 m^3) was felled due to *Heterobasidion* root rot, which represented 0.6% of the total felling at the country level or 1.3% of total sanitary felling or 15.7% of total sanitary felling due to diseases. In Norway spruce (Figure 5), the highest *Heterobasidion* proportion of sanitary felling was recorded in 2013: sanitary felling of Norway spruce represented 2.1 % of the annual increment and 5.9% of total sanitary felling. In 2014, spruce felling due to *Heterobasidion* root rot accounted for 84.3% of total sanitary felling due to disease. In the following years, the proportion slowly declined. In 2017, it was 70.3%. This is not necessarily a sign of reduced *Heterobasidion* infections, but the impact of massive overall sanitary felling due to an infestation of bark beetles. From 2014 to 2017, *Heterobasidion* sanitary felling of Norway spruce represented more or less fixed shares in total felling, total sanitary felling and increment.

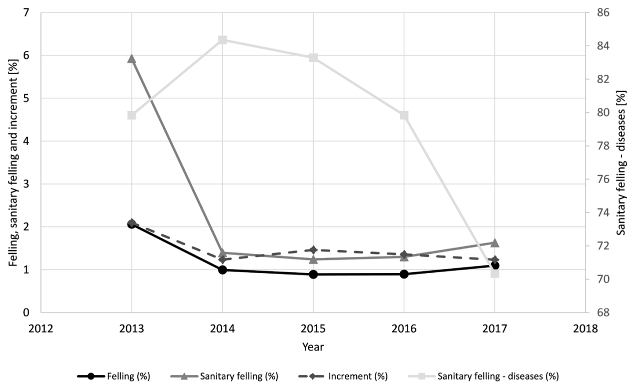

Figure 5. Portions of sanitary felling of Norway spruce in Slovenia due to *Heterobasidion* spp. within the period between 2013 and 2017 in comparison to total felling, total sanitary felling, sanitary felling due to diseases and increment

Even in the silver fir trees, we can talk about a gradual decrease in the proportion of sanitary felling due to *Heterobasidion* root rot depending on other indicators (Figure 6). The highest values were recorded in 2015. At that time, the *Heterobasidion* sanitary felling of firs accounted for 1% of total felling, 2% of total sanitary felling and 24.5% of total sanitary felling due to diseases.

In the case of the Scots pine (Figure 7), we notice a slight increase in the proportion of sanitary felling due to *Heterobasidion* spp. in the years of 2016 and 2017. Volumes of felled timber ranged between those calculated for Norway spruce and silver fir. In 2017, the *Heterobasidion* sanitary felling of Scots pine accounted for 0.7% of total felling, 1.8% of total sanitary felling, and 17.6% of sanitary felling due to diseases.

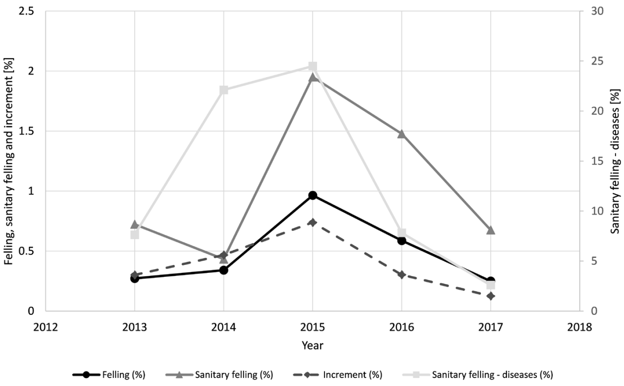

Figure 6. Portions of sanitary felling of silver fir in Slovenia due to *Heterobasidion* spp. within the period between 2013 and 2017 in comparison to total felling, total sanitary felling, sanitary felling due to diseases and increment

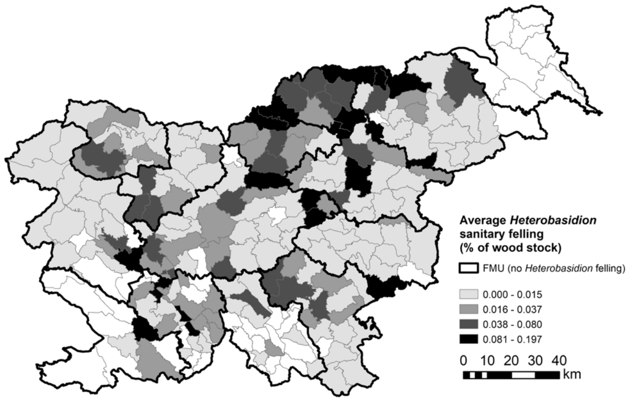

Figure 8. Average sanitary felling due to *Heterobasidion* spp. in Slovenia within the period between 2013 and 2017, expressed as % of wood stock in forest management units (considering only conifers) (Source: ZGS 2016, 2017)

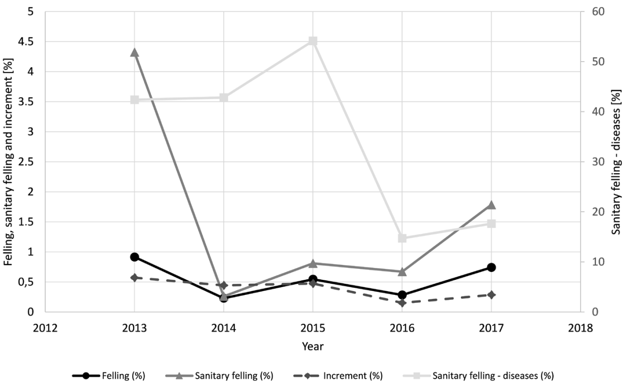

Figure 7. Portions of sanitary felling of Scots pine in Slovenia due to *Heterobasidion* spp. within the period between 2013 and 2017 in comparison to total felling, total sanitary felling, sanitary felling due to diseases and increment

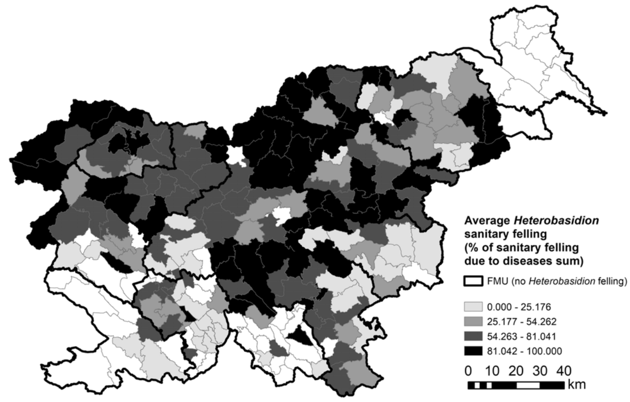

Figure 9. Average sanitary felling due to *Heterobasidion* spp. in Slovenia within the period between 2013 and 2017, expressed as % of sanitary felling due to diseases in forest management units (considering only conifers) (Source: ZGS 2016, 2017)

Most of the sanitary felling due to infections with *Heterobasidion* spp. are located in the northern part of Slovenia (Figure 8), where the highest share of conifers in wood stock is present. The areas of Koroška and Savinjska are the most affected. Here, a high proportion of conifers in the wood stock resulted in higher sanitary felling due to *Heterobasidion* root rot. FMU Slovenj Gradec has 84% of conifers in its wood stock, while the share of FMU Nazarje is somewhat lower, i.e. 74% (ZGS 2012b, 2012a). Figure 9 shows that *Heterobasidion* sanitary felling represents an extremely high proportion of total sanitary fellings due to diseases in conifers. In more than one third of forest management areas, the share of felling due to *Heterobasidion* root rot in the total sanitary felling of coniferous trees due to disease exceeds 50%. The lowest average values were recorded in Brežice and Sežana, where the share of conifers in the wood stock is also low.

Discussion and Conclusions

The sanitary felling of coniferous and deciduous trees has been rising since 2014. In the event of felling due to *Heterobasidion* spp. in Norway spruce and silver fir, there is a slight decrease, while in Scots pine the share of felled timber has been increasing in recent years. The total amount of felled timber due to the *Heterobasidion* root disease has been decreasing. For the future, we also expect a downward trend (b = – 4725 m^3 $year^{-1}$; $r^2 = 0.60$). One of the possible explanations for this is the reduction of Norway spruce wood stock, the tree species most susceptible to the root rots. The wood stock of Norway spruce is decreasing in Slovenian forests, mainly due to natural disasters and infestations of bark beetles in recent years. To meet these challenges in

Slovenia we are trying to increase the proportion of deciduous trees in former monoculture stands of conifers. Losses caused by *Heterobasidion* spp. in mixed stands are reported to be lower than in pure spruce stands (Piri et al. 1990, Linden and Vollbrecht 2002). Mixed stands are also more stable and can withstand other biotic and abiotic disturbances. Another probable explanation for the downward trend of the total amount of felled timber due to the *Heterobasidion* root rot is the rise-up trend of other damaging factors and the limitation of the Timber database managed by SFS that accounts only the primary damaging agents and not the secondary ones.

Felling rates due to *Armillaria* spp. and *Heterobasidion* spp. are relatively low in total wood stock and increment. For example, the highest value for *Heterobasidion* root rot is 0.7% of the annual increment and 0.02% of wood stock for one year. In the event of felling due to *Armillaria* spp., these shares are even lower. Sanitary felling due to *Armillaria* spp. represents comparable shares in total felling, total sanitary felling, and sanitary felling due to diseases, such as sanitary felling due to *Heterobasidion* spp. Interestingly, in 2016, the volume of *Armillaria* sanitary felling rose above the initial values. We assume that happened because of massive ice storm in 2014 that weaken many forest stands. Studies of Tsykun et al. (2012) and Marcais and Breda (2006) indicate that *Armillaria* spp. rapidly colonize the roots and the root collars as soon as the trees are weakened by other factors. Holuša et al. (2018) also report attacks by *Armillaria* root disease after Norway spruce trees have been weakened. Decline is often an interaction between abiotic and biotic factors that limit tree growth, reduce foliage, and weaken root systems.

In Europe, we consider *Armillaria* spp. and *Heterobasidion* spp. to be relatively dangerous rot fungi that can damage a wide range of tree species. Major problems arise in intensively managed and altered forests. This is especially true for *Heterobasidion* root and stem rot, which is the most dangerous disease on spruce. Measures against *Heterobasidion* rot must be based on changes in the silviculture and management methods used in forests. Our knowledge about the biology of different *Heterobasidion* species must play an essential role in guiding the development in the direction of reducing the occurrence of the *Heterobasidion* spp. Among direct measures to control this rot fungus, we know stump treatments with chemical or biological control agents. Sodium tetraborate decahydrate (borax), disodium octoborate tetrahydrate (DOT), urea, and the biological control fungus *Phlebiopsis gigantea* (Fr.) have all proved to be effective. However, these preparations do not have permit for use in Slovenian forests; therefore, silvicultural measures are essential for control of rot fungi (Jurc 2001). Direct control of the disease is also not possible in the case of *Armillaria* spp., so there we also need to focus on indirect silvicultural measures. The loss of timber due to *Armillaria* root rot can be reduced by ensuring adequate site conditions of stands and avoiding water stress (Maček 2008). In the case of *Heterobasidion* and *Armillaria* rot, we must keep in mind that a tree species growing in optimal conditions is also healthy, stable and fulfils many of the functions of the forest. Therefore, it is worth considering the ecological requirements of individual tree species in all silvicultural measures (Munda 1997, Jurc 2001). In Scandinavia and other countries worldwide, foresters also use stump removal as a measure for control of root rot diseases caused by *Heterobasidion* spp. and *Armillaria* spp. In clear-felled forest areas the stump removal results in reduction of root rot in the next generation, improved seedling establishment, and increased tree growth and stand productivity (Vasaitis et al. 2008, Arhipova et al. 2011). This method seems to be one of the best technique to decrease infections, but it is not practised in Slovenian forests.

Since these diseases represent a major threat to European forests, we summarize some foreign studies. For example, in Poland, the root rot diseases represent about 60% of the incidence of all diseases in the forest. In 2010, 262,000 ha were checked for the appearance of root rot; the occurrence of *Armillaria* spp. on 100,000 ha (38% of the area) and *Heterobasidion annosum* on 150,000 ha (57% of the area) were reported (Mykhayliv and Małecka 2011). In Germany, the National Forest Inventory shows that species of the genus *Heterobasidion* could potentially affect more than 6 million hectares (57.6%) of their forests (Metzler et al. 2011). Research in Serbia found that *Heterobasidion* spp. can infect 15–40 % of trees in spruce stands (Keča and Keča 2011). In Italy, the average infection on research plots was 24%, with wood losses ranging between 2 and 37% (La Porta and Pedron 2007). From the Baltic forests, the presence of rot on 23% of examined stumps is reported. The incidence increased with the age of the stand (Gaitnieks et al. 2007). In the Scandinavian countries, foresters also face severe economic losses due to *Heterobasidion* spp. on spruce (Arhipova et al. 2011). In Finland, a strong relationship was found between climate change and the activity of *Heterobasidion* spp. With the regression model, it was found that an annual average air temperature rises of 5 °C would increase the activity of *H. parviporum* in spruce by 40–91% (Müller et al. 2014). Apparently, populations of rot fungi are a serious problem throughout Europe, where rising temperature and climate changes are not attenuating circumstances. Root and stem rots will most likely be able to adapt well to the changes, and therefore we expect an upward trend in their occurrence. We used data from very short period (5 years), which can be a reason for contrary results in the case of *Heterobasidion* spp. from our study. For better and more reliable prognosis we should take data from longer time series which could be accomplished in the future when the data will be available.

There is a need for further research and investigation to get more accurate data on distribution of *Heterobasidion* spp. and *Armillaria* spp. and losses due to their proliferation in Slovenian forests.

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