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RESEARCH

Practice and legislation of felling residue management to prevent forest pests in European forests

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Abstract
In the last few decades, bark beetle outbreaks have increased in European forests, triggered by extreme weather events, such as drought and windstorms. A core element of integrated pest management to control outbreaks are salvage logging and sanitation felling, i.e., the timely removal or treatment of potential brood material and already infested trees after disturbance events. Associated with these management operations as well as with regular, planned thinning and cutting, felling residues, such as treetops, branches and stumps that remain in the forest provide potentially suitable breeding material for bark beetles and may trigger further outbreak events. Although felling residue management is part of regular forest management in most of Europe, no overview exists on its use throughout the continent. To fill this gap, we gathered forest health experts from 20 European countries and used a questionnaire to provide information on felling residue management in the context of forest protection in managed forests. Relevant legislation in these countries was reviewed for regulations concerning this topic. We found that most countries have felling residue management in their legislation and/or perform it in practice. In 12 of the 20 countries, felling residue management is being applied to manage bark beetles, particularly in areas that have experienced large-scale outbreaks in the last few decades. Felling residues are mainly managed in forests dominated by Norway spruce (*Picea abies* L. Karst) and pines (*Pinus* spp.) (in 19 and 17 of the countries, respectively). The most frequently used management methods on a European level were piling or mulching of felling residues. These methods were used in 14 and 16 of the countries, respectively. Besides bark beetle management, use of residues for bioenergy (4 countries) and biodiversity conservation (6 countries) was reported. The diversity of felling residue management practices across Europe may reflect differences in forest policies and climatic gradients that are affecting bark beetle outbreak risks. This overview presents the variety of felling residue management applied across 20 European countries, highlighting the reasons for and implications of its use, as well as further research needs.

Keywords Bark beetles · Europe · Forest health · *Pityogenes chalcographus* · *Ips typographus* · Logging residues

Introduction

Forests provide many important ecosystem services (FAO 2020), and in Europe, countries have developed different types of forest management which are related to their socio-economic, political and ecological systems (Elands and Wiersum 2001; Maracchi et al. 2005; Nagel et al. 2025; Paillet et al. 2024). Felling residues, which consist of branches, treetops and other tree parts remaining after the timber is extracted, have historically been retained in the forest, but are sometimes removed for different reasons in different parts of Europe (Udali et al. 2025). In Fennoscandia for

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example, residues are commonly harvested because their use in bioenergy production provides additional revenue and reduces reliance on fossil fuels (Röser et al. 2008). In many parts of Europe, residues are removed or treated otherwise for forest protection purposes, i.e., to limit the spread of pest insects or pathogens that might affect the living trees or to mitigate the risk of forest fires. Because felling residues also host a great abundance and diversity of saproxylic species (fungi and insects) and contain valuable nutrients, there are often restrictions and recommendations on the quantity and quality of residues that can be extracted without jeopardizing the saproxylic biodiversity and the long-term productivity of the land (Lundborg 1998; Rothacher et al. 2023; Thorn et al. 2018). Hence, there are large differences in residue management between countries which are caused by different rationales.

Climate change has notably intensified forest disturbances in recent decades, and in particular large-scale outbreaks of bark beetles (Hlásny et al. 2025; Patacca et al. 2023; Seidl et al. 2017). The eight-toothed spruce bark beetle, *Ips typographus* (L.) is the most severe forest pest across Europe, killing several hundred million Norway spruce (*Picea abies* Karst.) trees in the last few decades (Hlásny et al. 2025; Patacca et al. 2023; Senf and Seidl 2021). To improve bark beetle management in general, a better understanding of the differences in forest management practices used across Europe to control bark beetles is required. In addition, it is also necessary to understand the factors that drive management practices in different regions to optimize bark beetle management. Several bark beetle species can become pests of Norway spruce, with the most important being *I. typographus*, followed by *Ips duplicatus* (Sahlb.), and *Pityogenes chalcographus* (L.) (Fettig and Hilszczański 2015; Vega and Hofstetter 2015). The two *Ips* species utilize the phloem of the main stem in particular, but also that of thicker branches more than 10 cm in diameter. While large-scale *I. typographus* outbreaks have been occurring for several decades (Senf and Seidl 2021), *I. duplicatus* started to spread from the north of Europe in the 1990s and is now widespread across Central and Northern Europe. It causes damage in Central Europe and the Balkan Peninsula (Knížek et al. 2006, Olenici et al. 2010) but is much less impactful than its congener *I. typographus* (Hlásny et al. 2025; Wermelinger et al. 2020). *Ips typographus* and *I. duplicatus* mainly attack weakened trees after windthrow events or other abiotic disturbances, but when beetle populations are high they can also overwhelm healthy trees (Wermelinger 2004; Holusa et al. 2010). Climate change has increased the number of beetle generations developing per year, and this accelerates population build-up following disturbances. For *I. typographus* the number of generations can range from one at higher altitudes and latitudes to three in the South and in Central European lowlands (Hallas et al. 2024; Jakoby et al. 2019; Jönsson et al. 2009; Singh et al. 2024). Attacks on mature Norway spruce trees usually occur in treetops and branches, which weaken the trees and can predispose them to attack by *I. typographus*. Whilst *Pityogenes chalcographus* attacks branches, tree tops and small trees mainly of Norway spruce, but can also breed in other conifer species such as pines (*Pinus* spp.) (Berthelot et al. 2021; Vega and Hofstetter 2015). In addition, *P. chalcographus* colonizes fresh felling residues left in the forest after felling operations (Kacprzyk and Bednarz 2015) and is by far the most common beetle species in such substrate in Scandinavia (Jonsell et al. 2007; Maňák and Jonsell 2017).

The persistent threat posed by bark beetles has led countries to adopt multiple control measures. Most of these measures aim to lower the amount or suitability of breeding substrate to reduce bark beetle reproduction and population buildup (Hlásny et al. 2021). Reactive management applied during the build-up of outbreaks mainly relies on sanitation felling and timely removal or treatment of bark beetle infested trees, and salvage logging following natural disturbances (Melin et al. 2021). In addition, proactive management strategies, such as increasing tree species diversity, aim to maintain bark beetle populations below outbreak thresholds by reducing the availability of suitable host trees (de Groot et al. 2023; Jactel et al. 2026). Besides whole trees, other brood material for bark beetles include felling residues like large branches, tree tops, wood slides, slash, and logs (Kacprzyk 2012). Such residues are usually generated during sanitary or salvage operations and through regular silvicultural operations. Felling residue management in European forests is practiced as part of maintaining "forest hygiene" in managed forests to reduce potential sources for proliferation of pests, particularly bark beetles. In some instances, though, felling residues are also preserved to protect against soil erosion and to promote biodiversity, whilst in other cases it is removed to make space for regeneration, to increase accessibility for recreation, and for bioenergy.

To maintain good forest hygiene, several approaches have been used to handle felling residues. Brash can be piled, often above stumps, where the thicker branches are placed in the center of the pile and thinner branches are placed towards the outer edges. Branches inside the pile are generally less densely colonized by facultative saproxylic beetles depending on fresh material (Hedin et al. 2008), andthis trend has been observed for potential pest bark beetles such as *P. chalcographus* (Kacprzyk and Bednarz 2015) and *I. typographus* (de Groot et al. 2025); however, piling does not completely eliminate the risk of bark beetle colonisation. Other ways of managing felling residues are to mulch the branches or to remove them from the forest (Udali et al. 2025). Felling residues can, on the other hand, have positive

effects on the forest ecosystem by providing breeding substrate for many saproxylic insect species (de Groot et al. 2025; Ranius et al. 2018). This is why some countries have recommendations on the quality and quantities of felling residues that should be retained in the forest to conserve biodiversity (Egnell et al. 2001). Also, the forest certification schemes such as the Programme for the Endorsement of Forest Certification (PEFC) and Forest Stewardship Council (FSC) have restrictions on removal of felling residues for securing soil quality and nutrition as well as supporting biodiversity. Both schemes, however, mention forest protection requirements as justified exceptions (e.g., FSC Deutschland 2024; PEFC Austria 2025).

Considering that felling residue management is a fundamental part of forestry practices in Europe, it is important to understand whether residue management strategies differ between countries and regions. To our knowledge, no such comparison between countries exists. It is critical to understand the factors driving any differences in management practices, especially in the context of climate change. Knowledge about the effectiveness of methods used in Central Europe for forest protection can, for example, help inform management in northern European countries, where *I. typographus* has increased in outbreak intensity relatively recently (Gohli et al. 2024; Kärvemo et al. 2023; Trubin et al. 2022). The specific aim of this study was to provide an overview of the felling residue management strategies used in Europe in the context of forest protection in managed forests. We have compiled information about the practice, legal basis, and purpose of felling residue management from 20 European countries to provide an overview of how residues are dealt with in different regions. Therefore, we gathered a group of forest protection experts from these countries with good connections to forest practice and forest authorities in their country for this study to compile relevant information. Our research questions were: (1) Do residue management strategies and their legal basis differ between countries? (2) Is bark beetle control the primary purpose for managing felling residues? (3) For which tree species and bark beetle species are these approaches used? and (4) What are the most commonly used methods for residue management? We investigate these main questions and discuss residue management approaches in the context of each country's geographic location and intensity of bark beetle outbreaks.

Materials and methods

Area description

Our study involves forested areas across the temperate and boreal zones of Europe, thus excluding Mediterranean forests. The investigated area included 20 different countries or regions, namely Austria, Belgium, Bosnia and Herzegovina, Croatia, Czechia, England, Estonia, France, Finland, Germany, Hungary, North-East Italy, Lithuania, Norway, Poland, Romania, Slovakia, Slovenia, Sweden, and Switzerland (Kanton Zürich). These countries have different approaches to forest management – from intensively managed forests, to close-to-nature forest management – and different dominant forest types and tree species.

Survey protocol

For the survey on felling residue management, the involved forest health experts (the authors of this study) compiled information on the practice of felling residue management as well as the legal basis in the country they represent. To better structure the information, a questionnaire was prepared to be completed by all partners. This was typically done after consultation of forest practitioners and people working for forest authorities in their networks. One consensus answer was given per country. The experts collected information from literature and personal contacts and aggregated it to general statements for the represented country. The questionnaire was answered during the period from January to April 2025. In total, eight questions about the management of felling residues in each country were asked to understand (*i*) how residue management was implemented in forestry practice, (*ii*) what the reasons for its implementation were, and (*iii*) on which tree species it was focused (Table 1). Finally, we asked for "other comments regarding felling residue management in your country", where the experts could add context to the answers or provide other comments. Multiple answers were possible except for questions 1 and 2 (see Table 1). To review the legal situation, all experts screened the forest legislation in their country for regulations concerning felling residue management and consulted with representatives of forest authorities concerning implementation. The legal sources were provided and regulations summarized.

Data analysis

The analysis was performed separately for each question. The answers were analyzed using descriptive statistics because of the questionnaires were filled out per country and we had a relatively low number of countries included. For questions 5 to 8, data was only included if felling residue management was mentioned in the legislation or if it was used in practice (despite not being in the legislation). Answers to question 7 were only analysed if the answer to question 6 (purpose of management) was "prevention of bark beetle outbreaks".

Table 1 Questions asked to forest health experts in 20 different European countries

Question no	Question	Possible answers
1	Do you have the management of felling residues in the national legislation?	Yes (send the translated text of the legislation) No
2	Do you take care of felling residues in practice, even if it is not in the legislation?	Yes No
3	If no, why not?	Felling residues are not a problem for bark beetle outbreaks Other reasons (fill in the reason)
4	What is thought under felling residues in your country?	Branches Tree top Stump Others (add other possible residues)
5	If taking care of felling residues, for which tree species is this done?	*Picea abies* *Abies alba* *Pinus* spp. Other species (add species names)
6	What purpose of taking care of felling residues?	Prevention of bark beetle outbreaks Biodiversity Other reason (add reason)
7	For which bark beetle species is this done?	*Ips typographus* for *Picea abies* *Pityogenes chalcographus* for *Picea abies* *Pityokteines* spp. for *Abies alba* *Tomicus* spp. for *Pinus* spp. Other species (add pest or other insect species names and for which tree species)
8	What are the ways of management that your country is using to take care of felling residues?	Put them in piles Leave them on the ground Take the residues out of the forest Other methods
9	Other comments regarding felling residue management in your country	

The provided legislation texts were checked and categorized by whether pest management was included, whether the texts contained detailed descriptions (of either the definition of felling residues or the methods of management), and whether pest management was directly linked to residue management.

Results

Of the 20 surveyed countries, 14 (70%) reported that they have felling residue management in the legislation (Figs. 1a, 2a), and furthermore 8 out of the 20 countries (40%) have detailed laws on felling residues where management method, type of residues, purpose of management, etc., are mentioned (Table 1; lists the legal sources and summarizes relevant regulations).Some countries, such as Austria, Germany, and Switzerland, do not explicitly mention residue management in their forest laws. The laws do, however, in very general terms require forest owners to implement forest protection measures against harmful pests. This enables forest authorities to prescribe specific measures when there is an increased risk of bark beetle proliferation. In Finland, the legally required removal of potential breeding material for bark beetles applies only to roundwood with a diameter above 10 cm, thus the law mostly excludes felling residues. Special legislation is in effect, when quarantine pests are concerned. This is the case with the pine wood nematode (*Bursaphelenchus xylophilus*) in France or *I. typographus* in England. Due to federal constitutions, the legal situation may be different in different regions of a country. In Belgium, e.g., residue management is regulated in Wallonia but not in Flanders and Brussels. Germany has a national Plant Protection Act that regulates principles of pest control; specific forest management regulations are laid out in forest acts of the states. Also in Italy, national forest law provides a frame, which is complemented by regional legislation (Table 2).

Responses showed that 19 of the 20 countries practice felling residue management nationwide, regionally or locally (Figs. 1a, 2a). Austria, Belgium, England, Poland and Sweden indicated that they practice residue management, but that the application differs among regions within the country or among forest owners (Fig. 2a). In Poland, e.g., principles governing the management of felling residues are based primarily the Forest Act. In forests managed by the State Forests National Forest Holding (over 77% of the forested area), residue management follows a highly structured and system-based approach. Residue management in private forests is considerably less formalized and allows greater flexibility for forest owners. Only the respondent of Norway reported that they do not practice residue management (Fig. 2a).

The definition of felling residues varied between countries, but all definitions included branches (Fig. 1b). Tree tops were recognized by 18 of the 20 countries, stumps by 5 out of 20 countries, and other material by 10 out of 20 countries (i.e. bark, stem wood, chopped wood, stems of small trees with diameter < 6 cm or height < 1.3 m, underwood and bushes) (Figs. 1b, Table 3).

Most of the countries that practice felling residue management, or have it in their legislation, focus their management on Norway spruce (*Picea abies*) (19 of the 20 countries), followed by *Pinus* spp. (17 of the 20 countries). Only 9 of the 20 countries reported residue management for silver fir (*Abies alba* Mill.) (Figs. 1c, Table 3). This tree

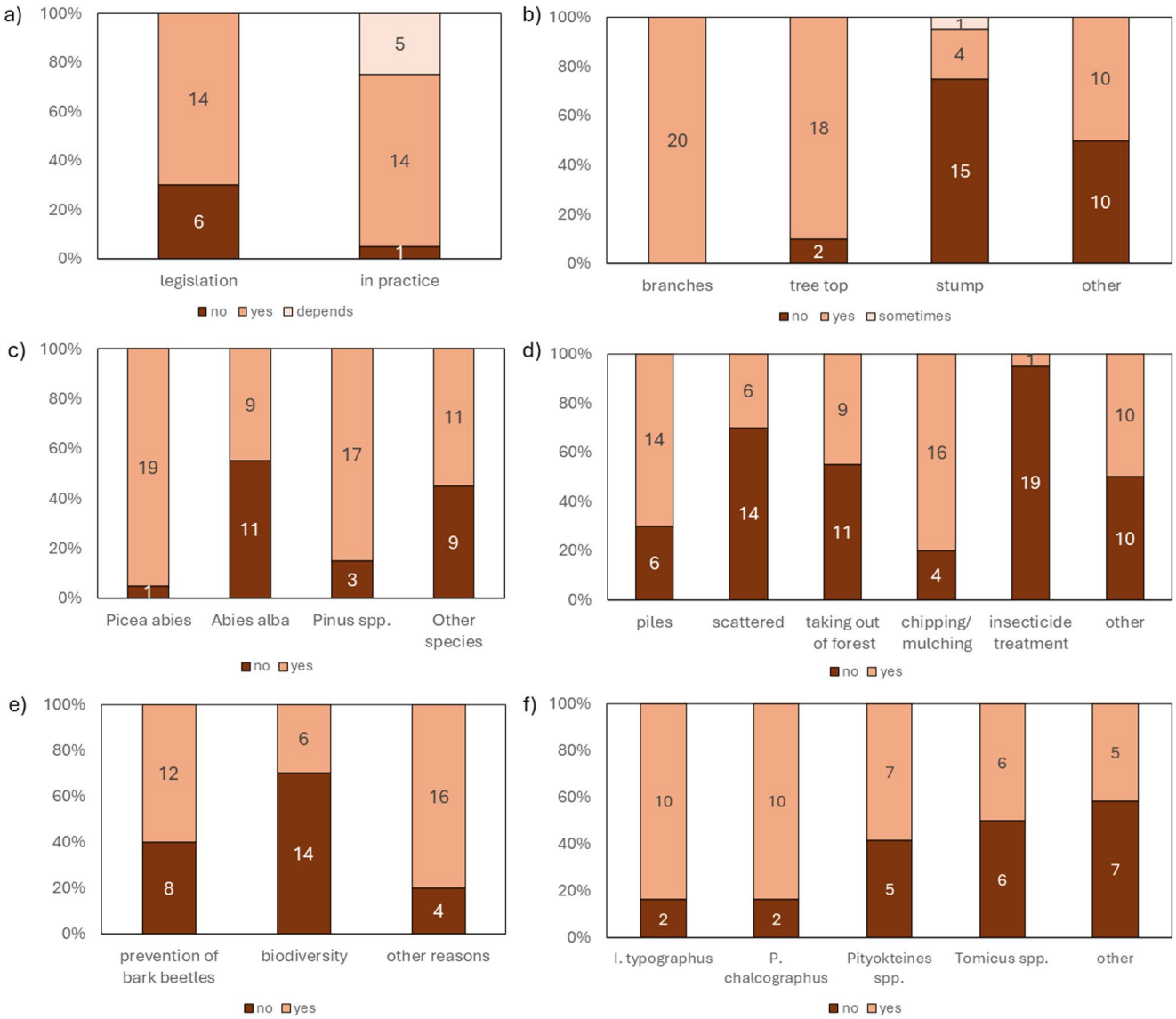

Fig. 1 Management of felling residues in Europe as surveyed by a questionnaire: **a** Are felling residues included in the legislation or used in practice? **b** Which tree parts are considered as residues? **c** Which tree species is the residue management applied to? **d** What are the methods used for felling residue management? **e** For what reasons is the felling residue management applied? **f** Which bark beetle species is the felling residue management aimed to prevent?. Panels a to e are based on all the countries (N = 20). Panel f is based on the countries which apply residue management to prevent bark beetles (N = 12). The option "depends" refers to the answer "Difference in practice between enterprises/regions"

species is not present in the Nordic region, and some Central European countries do not consider the species for residue management. In Sweden, Estonia, Romania and Lithuania, residue management is mandatory for all tree species according to the legislation, however in Sweden, it is mainly applied to *Picea abies*, *Pinus* spp. and birch (*Betula* spp). In Finland, the law on removal of breeding material for bark beetles (including weakened trees) generally only applies to *Picea abies* and species of *Pinus*, and not to deciduous tree species. Residue management was also reported for oak (*Quercus* spp.: Poland, Slovakia, Germany), Douglas fir (*Pseudotsuga menziesii* (Mirb.): Slovenia), ash (*Fraxinus* spp.: Slovakia, Germany), European larch (*Larix decidua* Mill.: Slovakia, Slovenia, Germany) and elm (*Ulmus* spp.: Germany, Slovenia).

Different methods for the management of felling residues were reported (Figs. 1d, Table 3). Most commonly, residues are put in piles or chipped/mulched, followed by removal from the forest and scattering. Only one country (Slovakia) also reported the use of authorized insecticides, but at a low frequency. Ten countries indicated other types of management, such as burning (outside the fire hazard

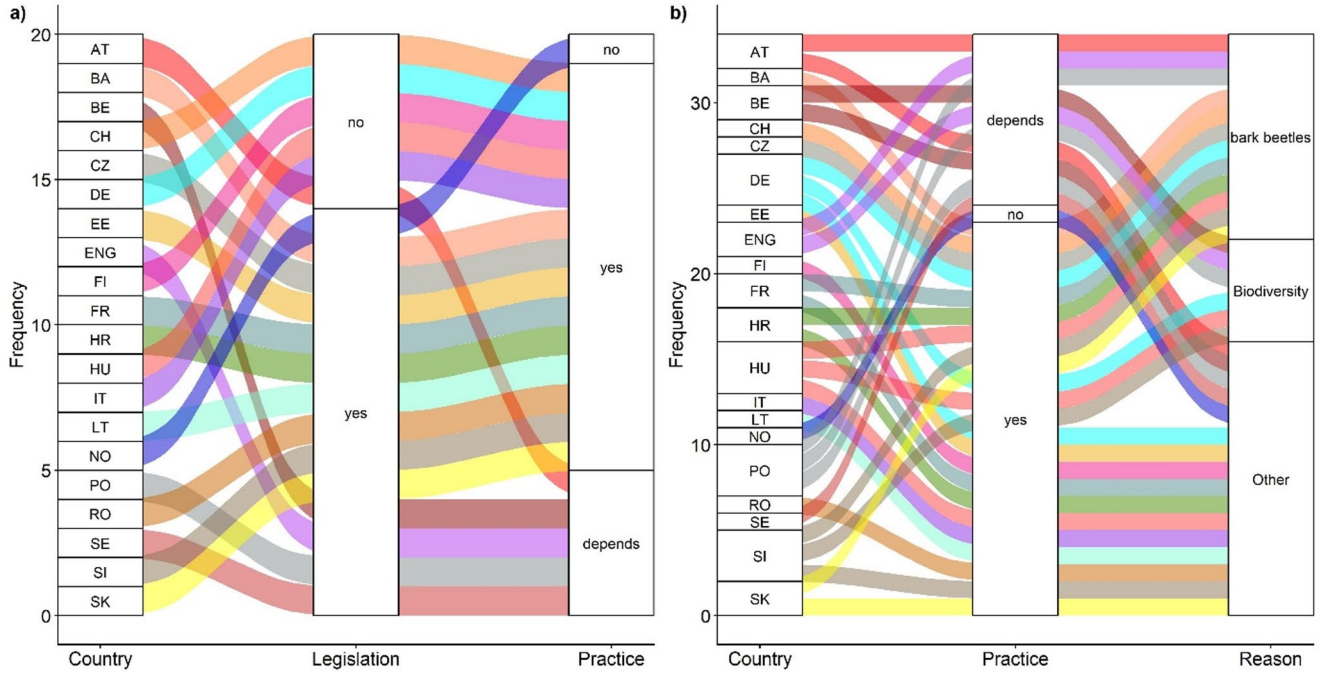

Fig. 2 Alluvial diagram showing for every country the relationship between **a** legislation (question 1: Do you have the management of felling residues in the national legislation?) and practice (Question 2: Do you take care of felling residues in practice, even if it is not in the legislation?) and **b** practice and rationale for felling residue management. In the column "Practice", the option "depends" refers to the answer "Difference in practice between enterprises/regions". In the column "Reason", the option "bark beetles" refers to the answer "Prevention of bark beetles". AT = Austria, BA = Bosnia and Herzegovina, BE = Belgium, CH = Switzerland, CZ = Czechia, DE = Germany, EE = Estonia, FI = Finland, HR = Croatia, HU = Hungary, IT = Italy, LT = Lithuania, NO = Norway, PL = Poland, RO = Romania, SE = Sweden, SI = Slovenia, SK = Slovakia, ENG = England

period) or cutting residues/branches into smaller pieces with a chainsaw.

The reasons for managing felling residues differed among countries. Twelve of the 20 countries apply residue management to prevent bark beetle outbreaks, while 6 of the 20 countries apply it to foster biodiversity by keeping the felling residue (Figs. 1e, 2b). Other reasons included using residues for bioenergy production (4 of the 20 countries), keeping the forest floor open for natural regeneration or planting, facilitating recreational access (e.g., hiking and skiing), reducing fire hazard, mitigating the risk of large pine weevil, *Hylobius abietis* (L.), attacks on seedlings, reinforcing drag roads with residues, enhancing soil nutrition and depth, and improving work safety and organization. A few countries indicated that felling residues are not assumed to increase the risk of bark beetle outbreaks (Estonia, Norway, and Belgium), whereas England practice felling residue management in demarcated areas where *I. typographus*—a quarantine species in the UK—has recently been discovered (Blake et al. 2024).

When felling residue management is implemented to control bark beetle infestations, management mostly focuses on *P. chalcographus* and *I. typographus* (in 10 countries, for both species), followed by *Tomicus* spp. and *Pityokteines* spp. (six and seven countries, respectively) (Fig. 1f, 2d). Countries in the southeastern or central part of Europe tend to focus on *I. typographus,* while northern and northeastern countries mainly target other bark beetle species (Table 3). *Pityogenes chalcographus* is a target species in countries that also target one of the other bark beetle species. In addition to the species mentioned above, the following beetles and host tree species were also reported: *Scolytus intricatus* (Ratz.) and *Agrilus* spp. for *Quercus* spp., *H. abietis* and *Hylastes* spp. for coniferous hosts, *Hylesinus* spp. for *Fraxinus* spp., *Ips acuminatus* (Gyll.), *Ips sexdentatus* (Börner, 1776), and *Pityogenes bidentatus* (Herbst) for *Pinus* spp., *Ips cembrae* (Heer) for *Larix decidua*, *Scolytus scolytus* (Fabr.) and *S. multistriatus* (Marsham)—vectors of Dutch elm disease—for *Ulmus* spp., and *Ernoporicus fagi* (Fabr.) and *Taphrorychus bicolor* (Herbst) for *Fagus* spp..

Discussion

This synthesis highlights that felling residue management is applied in forestry practice in managed forests in many European countries, even in countries where it is not mandated by legislation. However, the rationale for felling

Table 2 Legislation of the selected countries that includes directly or indirectly felling residue management

Country	Law	Relevant text parts
Felling residues explicitly addressed in legislation		
Bosnia	Act on Forests (Official Gazette of the Federation of Bosnia and Herzegowina, No. 20/02) https://www.fbihvlada.gov.ba/bosanski/zakoni/2002/zakoni/13%20hrv_zakon%20o%20sumama.htm	Branches as well as bark of conifers must be stacked in piles
Croatia	Forest Act NN 68/18 i 115/18 https://narodne-novine.nn.hr/clanci/sluzbeni/2018_07_68_1392.html Regulation on Tree Designation, Forest Products, Transport Documentation and management of Feeling residues 71/19 https://narodne-novine.nn.hr/clanci/sluzbeni/2019_07_71_1506.html	Procedures and actions carried out in a forest stand to ensure the regular management of the forest, particularly for its cultivation, protection against fires, plant diseases, and pests, as well as to fulfill all general beneficial functions of forests and to preserve biodiversity
Czechia	Forest Act No. 289/1995 Coll https://www.zakonyprolidi.cz/cs/1995-289 Decree No. 101/1996 Coll. on Measures for Forest Protection https://www.zakonyprolidi.cz/cs/1996-101	Forest owners are obliged to implement measures for forest protection against harmful agents (which includes handling materials generated during logging); Removing material suitable for insect pest reproduction
England	(1) UK Forestry Standard (2023) https://www.gov.uk/government/publications/the-uk-forestry-standard (2) Guidance Eight-toothed spruce bark beetle (*Ips typographus*) https://www.gov.uk/guidance/eight-toothed-european-spruce-bark-beetle-ips-typographus#map	(1) To reduce the amount of suitable habitat for specific pests and diseases, inspect the deadwood of host tree species for damage after storms or drought and remove it from site if necessary (2) No spruce harvesting residue greater than 8 cm diameter can be left on site within the demarcated area (note: *I. typographus* is quarantine pest in UK) following felling operations, unless authorisation to stack this material has been granted
Estonia	(1) Estonian Forest Act https://www.riigiteataja.ee/en/eli/503012025001/consolide (2) Forest Management Regulations https://www.riigiteataja.ee/akt/113062025014	(1) Regeneration cutting areas must be cleaned of slash; minister in charge of the policy sector will establish the manner of and procedure for cleaning cutting areas of slash by the rules of forest management (2) Forests to be managed in a way that does not allow spread of fungus diseases or pests; regeneration cutting areas shall be cleaned of slash (e.g., rotting or burning of slash collected into piles, burning slash, chopping and spreading, removal); If undried, unbarked coniferous timber other than slash exceeds 10 solid cubic metres per hectare, it must be transported out of the forest by 1 June if cut between 1 September and 30 April; or within one month of cutting if cut between 1 May and 31 August
France	(1) Forestry Code, article L. 131–10—131–16 https://www.legifrance.gouv.fr/codes/texte_lc/LEGITEXT000025244092/ (2) EUR-Lex—02012D0535-20180423—EN—European Union https://eur-lex.europa.eu/eli/dec_impl/2012/535/2018-04-23/eng	(1) Brush-clearing carried out in accordance with the obligations set out in this section of the forestry code constitutes public interest work aimed at preventing the risk of fire, with a view to safeguarding public health and safety and protecting forests (2) Under emergency measures to prevent the spread within the Union of Bursaphelenchus xylophilus (the pine wood nematode), wood waste produced at the time of felling of susceptible plants which is left on site shall be chipped into pieces of less than 3 cm thickness and width
Lithuania	(1) Order of the Minister of Environment of the Republic of Lithuania on the Approval of the Rules on Forest Felling (Chapter VI – Requirements for the Carrying Out of Final Felling and for Cutting-Area Cleaning Operations) https://www.e-tar.lt/portal/en/legalAct/TAR.4A966C7D30EB/xefWFNWPqY (2) Order of the Minister of Environment of the Republic of Lithuania on the Approval of the Rules on Forest Sanitary Protection (Chapter VI – Forest Sanitary Protection Requirements in Cutting Areas) https://www.e-tar.lt/portal/fr/legalAct/TAR.BA9557DAF396/XhbZUxrQOl	(1) Felling sites shall be arranged in order to create favorable conditions for forest restoration, rational use of forest felling residues, ensure fire safety and forest sanitary protection; permitted to remove felling residues, load them into strip road network or piles, spread them after crushing; burning on site is prohibited; in open fellings, at least 5 m^3/ha of forest felling residues or an additional number of trees important for biodiversity corresponding to this volume must be left (2) From 1 April to 1 October, green conifer logging residues with bark cannot be left in cutting areas if they are more than 8 cm in diameter at the thickest part and longer than 1 m, except where they are intended for fuelwood preparation or other purposes and are stacked in piles not higher than 1.5 m, as well as for individual branches up to 0.1 m^3/ha
Norway	Regulations on Sustainable Forestry https://lovdata.no/dokument/SF/forskrift/2006-06-07-593/KAPITTEL_4#KAPITTEL_4	Forest owner is responsible for ensuring that treatment of felling waste carried out in such a way that there is no risk of insect damage or other damage to the forest. Felling waste must be cleared away from streams, rivers and water, and from commonly used ladders, tracks and other thoroughfares

Table 2 (continued)

Country	Law	Relevant text parts
Poland	(1) Forest Act of 28 September 1991 (Journal of Laws 1991 No. 101, item 444, as amended) (2) Forest Protection Instruction. Annex to Directive No. 109 of the Director General of State Forests of 5 December 2023	(1) Provisions collectively imply the requirement for the rational utilization of timber resources, including post-harvest residues, while maintaining ecological balance and soil productivity; (2) Forest hygiene principles, including detailed procedures for handling post-harvest residues
Romania	Instructions dated June 3, 2011, regarding the deadlines, procedures, and timeframes for the collection, removal, and transport of timber (Ministry of the Environment and Forests) https://legislatie.just.ro/Public/DetaliiDocumentAfis/241354	Clearing of the forest from felling residues by holders of exploitation permit: collected in rows (ridges) or compact piles
Slovakia	Forest Act No. 326/2005 Coll https://www.zakonypreludi.sk/zz/2005-326	Prevent the spread of harmful agents to the surrounding forest plots by removing the logging residues and transporting such stored wood or by taking another appropriate measure to prevent the spread of the harmful agent
Slovenia	(1) Regulations on the Conduct of Logging, the Handling of Logging Residues, and the Harvesting and Stacking of Forest Timber, Uradni list RS, št. 55/94, 95/04, 110/08 in 83/13 https://pisrs.si/pregledPredpisa?id=PRAV2997 (2) Forest Protection Regulations, Uradni list RS, št. 114/09, 31/16, 52/22 in 125/22 – popr https://pisrs.si/pregledPredpisa?id=PRAV9492 (3) Forest Act https://pisrs.si/pregledPredpisa?id=ZAKO270	(1) Regulates maximum stump heigt; logging residues must not be stacked or left in the beds of streams and torrents, in ditches, on the grazing grounds of wild animals, on forest roads, etc.; branches and tops of conifers have been cut and stacked in piles, or in the case of mechanical logging, also placed along the logging roads; logging residues are stacked so as not to hinder the growth of young trees (2) It must be ensured that, taking into account the risk of pest proliferation in the forest, an average of at least 3% of deadwood remains relative to the timber stock in the forest; logging residues larger than 0.2 m^3 are also considered (3) Exceptionally permits burning in the forest for the purpose of controlling overpopulated insect populations and forest tree diseases
Sweden	Forest Conservation Act (1979:429) and Forest Conservation Ordinance (1993:1096) https://www.riksdagen.se/sv/dokument-och-lagar/dokument/svensk-forfattningssamling/skogsvardslag-1979429_sfs-1979-429/	Regulation of removal of forest fuel in form of branches, tops, stumps; no blocking of publicly used paths by logging residues; not allowed to have more than 5 m^3 of fresh conifer wood/ha thicker than 10 cm in diameter in the forest (that size of the wood is usuallay not regarded as logging residues)
Felling residues explicitly addressed in legislation in parts of the country		
Belgium	Decree of 15 July 2008 on the Forest Code, Wallonia https://environnement.wallonie.be/files/eDocs%20Environnement/legis/dnf/forets/foret025.htm Walloon Government Decree [WGD] of 27 May 2009 on the implementation of the Decree of 15 July 2008 https://wallex.wallonie.be/eli/arrete/2009/05/27/2009027164	Burning of residues only under certain circumstances; definition of residues is given Note: The three regions in Belgium have different regulations; only Wallonia regulates management of residues
Felling residues not explicitly addressed in legislation, but implicitly covered		
Austria	Forest Act 1975 https://www.ris.bka.gv.at/GeltendeFassung.wxe?Abfrage=Bundesnormen&Gesetzesnummer=10010371	Take precautionary measures against the risk of dangerous damage to the forest by forest pests and effectively combat forest pests which are already increasing in a threatening fashion; it is prohibited to encourage the imminent danger of an increase in forest pests by action or neglect; wood which may serve as a breeding ground for such pests, should be treated in good time

Table 2 (continued)

Country	Law	Relevant text parts
Germany	(1) Plant Protection Act Germany https://www.gesetze-im-internet.de/pflschg_2012/PflSchG.pdf (2) State Forest Acts, e.g., State Forest Act Baden-Württemberg https://www.landesrecht-bw.de/bsbw/document/jlr-WaldGBWrahmen	(1) To protect plants, particularly cultivated plants, from harmful organisms and non-parasitic damage; maintaining the health and ensuring the quality of plants and plant products through a) preventive measures, b) preventing the introduction or spread of harmful organisms, c) repelling or controlling harmful organisms, d) promoting natural mechanisms for controlling harmful organisms (2) The forest owner is obligated to manage the forest in a sustainable, careful and planned manner, and to take into account environmental protection considerations Careful management includes, in particular … preventing the risk of significant damage to the forest caused by natural events, forest fires, and animal and plant forest pests; combating animal and plant forest pests in a timely and adequate manner …
Italy	Italian National Law No. 34 of April 3, 2018, "Law on Forests and Forestry Sectors" https://www.normattiva.it/uri-res/N2Ls?urn:nir:stato:decreto.legislativo:2018-04-03;34	State and regions promote sustainable forest management through the fundamental contribution of forestry; to recognize social and cultural role of forests, protect and enhance forestry heritage, territory, national landscape, strengthening forestry supply chains and ensuring multifunctionality and diversity of forest resources, environmental protection, fight against and adaptation to climate change, and socio-economic development
Switzerland	Swiss Forest Act https://www.fedlex.admin.ch/eli/cc/1992/2521_2521_2521/de	Swiss Forest Act stipulates: Newly identified pests must be eradicated in a timely manner; Established pests must be contained if the expected benefits outweigh the control costs; To protect the forest, pests must also be monitored, eradicated, or contained outside the forest area
Felling residues not addressed in legislation		
Finland	Forest Damage Prevention Act https://www.finlex.fi/en/legislation/translations/2013/eng/1087	No more than 10 solid m^3 per ha of spruce wood with diameter > 10 cm and no more than 20 m^3 per ha of pine wood must be left in the stand after felling. (Hence, residue < 10 cm is not considered under the Forest Damages Prevention Act.)
Hungary	–	–

residue management varies among countries. The most common rationale is prevention of bark beetle damage (12 out of 20 countries), but felling residues are also managed for bioenergy production, and forest restoration purposes. The potential function of felling residues for biodiversity conservation is also often considered. Different regulations apply to nature reserves and other set-aside woodlands where often no harvesting is done at all and hence no residue management occurs; these unmanaged areas were outside the scope of our study. The main bark beetle species of concern were *I. typographus* and *P. chalcographus,* which both attack spruce. The most frequently reported felling residue management methods involved putting felling residues into piles, and chipping/mulching them.

The United Kingdom, Switzerland and Italy were only partly assessed, specifically England, Canton Zurich and the region of Friuli-Venezia Giulia. In the UK, each administration (England, Scotland, Wales, and Northern Ireland) has its own responsibility for forest policy and legislation, following the UK Forestry Standard (UKFS) as the technical standard for sustainable forest management (UKFS 2023). Despite having devolved administrative responsibilities, they collaborate on plant health issues under the umbrella of the UK Plant Health Service to ensure a consistent, cross-border approach to biosecurity. Switzerland consists of 26 cantons, which are practically sovereign states regarding most areas of policy (other than those governed by federal law). However, the forest legislation, policies, and practices of Canton Zurich are generally representative of Switzerland as a whole. The principles of sanitation following bark beetle outbreaks are similar throughout the country. For example, the Swiss Forest Act stipulates that newly identified pests must be eradicated in a timely manner, and established pests must be contained if the expected benefits outweigh the control costs. Differences within Switzerland are mainly due to topography (e.g., sanitation felling in mountainous areas may not be logistically possible) and the availability of human labour. Although only a small part of Switzerland and the United Kingdom was assessed, these specific areas have their own legal requirements particularly in the context of bark beetle outbreaks, and can therefore be more easily evaluated in the context of felling residues. Furthermore, they are representative of the whole country and other administrations will collaborate in the same manner in regard of forest pest management.

Table 3 Participant responses for each country for which tree parts that are considered felling residuals, which tree species that felling residue management is applied to, which management methods that are applied, and which bark beetle species that are targeted. For country abbreviations, see Fig. 2

Questions	Answers	AT	BA	BE	CH	CZ	DE	EE	ENG	FI	FR	HR	HU	IT	LI	NO	PO	RO	SE	SI	SK
What is thought under felling residues in your country?	Branches	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Tree top	X		X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Stump													X	X			X	X		X
	Others—Comment				X	X	X	X		X				X	X		X	X		X	
If taking care of felling residues, for which tree species is this done?	*Picea abies*	X	X	X		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
	Abies alba		X		X		X				X	X		X			X	X		X	
	Pinus spp.		X	X		X	X	X		X	X	X	X	X	X	X	X	X	X	X	X
	Other species (add species names)					X	X	X			X			X	X		X	*X*	X	X	*X*
For which bark beetle species is this done?	*Ips typographus* for *Picea abies*	X	X				X		X		X	X	X				X			X	X
	Pityogenes chalcographus for *Picea abies*	X	X	X	X	X	X	X				X	X				X			X	X
	Pityokteines spp. for *Abies alba*		X		X		X				X	X					X			X	
	Tomicus spp. for *Pinus* spp.						X					X	X			X	X			X	X
	Other species (add pest or other insect species and for which tree species)						X				*X*				X		X			X	*X*
What are the ways of management that your country is using to take care of felling residues ?	Put them in piles	X	X	X		X		X		X		X	X	X	X			X	X	X	X
	Scatter the branches equally on the ground so they will dry faster			X				X				X	X						X	X	
	Taking the residues out of the forest	X			X		X	X			X				X		X			X	X
	Chipping/mulching	X			X	X	X	X	X	X	X	X	X	X	X		X		X	X	X
	Insecticide treatment																				X
	Other methods			X	X	X	X	X							X		X		X	X	X

Interestingly, even most countries without any specific regulation in the forest law perform felling residue management in practice. Among countries with an explicit legislation on management of felling residues, some have detailed prescriptions for piling residues (e.g. Romania, Slovenia, Bosnia, and Herzegovina), while others list various options (e.g., Lithuania and Estonia). In France, the Forestry Code considers residue management in the context of prevention of fires. In Norwegian and Slovakian laws, measures to prevent the spread of bark beetles and other damaging agents are obligatory. Other countries have general obligations of forest owners to implement forest protection measures against harmful pests but without explicitly addressing felling residues (e.g. Switzerland, Germany, and Austria). In Austria, for instance, the forest authorities in some federal provinces have guidelines for the enforcement of residue management. Swedish law regulates the removal of residues in the context of bioenergy production, and harvesting of residues is recommended to be restricted, especially for certain wood qualities and on certain soil types (Drott et al. 2019). There are recommendations from the Forestry Board on sites and situations where felling residues should not be extracted to conserve site conditions, prevent erosion or conserve biodiversity. In some countries, breeding of bark beetles in logging residues is not perceived as a major forest protection problem and therefore no management measures are applied. In Scandinavian forestry, the residues left after felling generally have too small diameter (< 10 cm) to be useful for *I. typographus*. Although such dimensions to be suitable for *P. chalcographus,* this species is not able to kill fully vital trees under Scandinavian conditions, even in experiments where population levels were enhanced by supplying extensive breeding material or pheromones (Hedgren 2004; Hedgren et al. 2003; Schroeder 2008). The perceived threat from bark beetles is also reflected in differences in residue management among regions and/or forest owners within countries. The actual strategy used appears to depend on the current bark beetle situation and is based on previous experience. Climatic conditions probably also play a role (particularly through effects on beetle voltinism and the suitability of the residues), but the intensity, objectives, and tradition of bark beetle management are also important in determining if and how residue management is implemented.

A special case is England, where *I. typographus* is a quarantine pest under eradication (EPPO 2025) and current guidelines state that "no spruce harvesting residues greater than 8 cm diameter can be left on site within the demarcated area following felling operations, unless authorization to stack this material has been granted" (Forestry Commission 2025). In outbreak areas of the pine wood nematode, *B. xylophilus* (Steiner & Bührer) Nickle, a priority quarantine pest in the EU, wood waste produced at the time of felling of susceptible plants shall be chipped into pieces < 3 cm (Commission Implementing Decision 2012/535/EU). This illustrates that residue management can become crucial in eradication efforts against invasive pests, where all potential breeding materials for the pest should be removed.

Although bark beetle prevention is the focus of residue management in most surveyed countries, other functions of residues are also considered. The importance of residues for nutrient cycling in the forest is reflected in the legislation of many northern countries, as well as in recommendations for practice in Central Europe (e.g. Forster et al. 1998; Kölling et al. 2007; Zimmermann et al. 2022). In addition to nutrients (Achat et al. 2015; Špulák and Kacálek 2020; Wall 2008), felling residues also affect forest carbon pools, soil physical properties, forest regeneration and protection against soil erosion (Achat et al. 2015; Udali et al. 2025). Achat et al. (2015) found that removing the felling residues decreased the amount of total and available nutrients and therefore reduced the tree growth of 3–7%. Udali et al. (2025) showed that felling residues can reduce soil temperature, maintain soil moisture, sediment production and erosion. The residues can also reduce soil disturbance when undertaking salvage logging on skidrows (Udali et al. 2025). Furthermore, conservation of felling residues increases biodiversity (Johansson et al. 2007; Lassauce et al. 2012; Nittérus et al. 2004; Ranius et al. 2018; Thorn et al. 2014), especially of saproxylic species which are attracted to and breed in these residues. In addition, predatory Cleridae such as *Thanasimus formicarius* (L.) are attracted to these residues (de Groot et al. 2025), and can be important natural enemies of bark beetles (Wegensteiner et al. 2015). Hence, removal of felling residues to reduce bark beetle risk can have negative effects on other forest functions (de Groot et al. 2025; Hiron et al. 2017). Risks and benefits of residue management for forest protection should thus be carefully weighed against each other. Some specific treatments of felling residues such as putting branches in piles, have been shown to potentially increase forest biodiversity while not strongly increasing bark beetle numbers (de Groot et al. 2025; Kacprzyk 2012). However, further research is needed regarding the effects of residue piling on bark beetle reproduction and microclimatic conditions (de Groot et al. 2025).

Although the surveyed countries sometimes differed in how they defined felling residues, most definitions included the tree parts that are most suitable for bark beetle reproduction. Treetops and branches, for instance, can provide abundant breeding material for *P. chalcographus* in particular (Maňák and Jonsell 2017; Schroeder 2013). In contrast, tree stumps, that are usually left in the forest, are not considered a major source of breeding substrate for bark beetles. Most research on the effect of stumps on beetles has been done for

other beetle species like *H. abietis* on Scots pine (Elton et al. 1964; Långström and Day 2004), which causes problems throughout Europe by girdling conifer saplings. The beetle breeds in larger roots (Långström and Day 2004), and previous studies have shown a positive relationship between the number of stumps and damage to saplings (Rahman et al. 2015).

Many countries report that bark fallen from infested trees can be important residual brood material that may increase bark beetle numbers, especially the number of overwintering beetles (Schroeder et al. 2025). A larger proportion of *I. typographus* individuals can be found overwintering in fallen bark at lower compared to higher altitudes and latitudes, and this affects the importance of managing this type of felling residue (Kasumovic et al. 2019).

In the present study, *I. typographus* (with its main host *P. abies*) was clearly the bark beetle species of most concern in the context of felling residue management. As it is the most important and widely distributed outbreak species in Europe, it is typically the main focus of bark beetle management (Hlásny et al. 2019). *Ips acuminatus* and other species that attack pines with thinner diameter have less impact and are therefore less important for forest management, even though their impact has increased in recent years (Papek et al. 2024). We are aware that our questionnaire might have been biased towards bark beetles and particularly the species of most concern. However, the focus of certain bark beetle species reflects their importance as forest damaging agents. Hlásny et al. (2025) reported that *I. typographus* accounted for 85.8% of total recorded insect-caused forest disturbance in the last two decades in 15 European countries. Other bark- and wood boring species clearly lagged behind; *P. chalcographus* being the second most important species with 4.1%.

A variety of methods for felling residue management were reported in this study. The two most frequently reported methods were piling and chipping of residues, which was then followed by mulching and removing the materials from the forest. The harvesting technique used tends to determine how the felling residues are treated. With cut-to-length harvesting methods, residues are produced at the felling site, and it requires little effort to leave the residues scattered on the forest floor. With whole-tree harvesting methods, residues are usually produced next to a forest road (Ghaffariyan 2023), and this reduces the effort required to take residues out of the forest. Similarly, cable yarding in mountainous terrain also often involves the latter method as it is more efficient (Böhm and Kanzian 2023). Emphasis on the ecological importance of logging residues will often be a motivation for leaving the residues on or near tree processing sites, whereas a high demand for bioenergy can, in contrast, be a motivation for removing residues from the forest.

Insecticide treatment is not considered to be an option for residue management in most countries, and few registered products are available for this purpose. Some countries and forest areas have a general ban on the use of insecticide in the forest. Only Slovakia indicated that insecticides could be used for residue management. In Austria, insecticides are allowed but are very rarely used. Only one federal province in Austria recommended insecticide treatment of residues in their guidelines, and then only for exceptional cases when there is very high risk of damage by *P. chalcographus* and when mulching is not feasible. Burning of residues was a common practice in the past in Europe. However, clean air policies and the risk of forest fires often restrict the use of this practice nowadays. In our study, burning was reported as an additional method from Poland, Czechia, Slovakia and to some extent from Switzerland, yet under strict regulations to minimize wildfire risks. In some European countries, certification rules require that some forest cuttings are burned to restore the ecosystem, as fires are an important part of the natural dynamics (FSC 2000).

A large range of measures are used for felling residue management in Europe. Although we did not test this directly, the choice of methods seems to be guided by differences in political and climatic conditions in the different countries. In countries that have large problems with bark beetle outbreaks due to climate change, such as in Central Europe, residue management is practiced regardless of whether it is in the legislation or not. For example, in Austria where there are regional differences in felling residue management, residue management is most rigorous in the areas that are experiencing most bark beetle outbreaks. In boreal areas, where conditions still are less conducive to large-scale beetle outbreaks, management of felling residues is not yet seen as vital. From a practical point of view, managing felling residues is considered to reduce the risk of bark beetle outbreaks, but this effect is context-dependent. Due to climate change, felling residue management will probably become more important in the future, particularly in areas where bark beetle outbreaks are not yet that intensive. It is therefore recommended to fill important knowledge gap regarding the effectiveness of different residue management approaches that would reduce the number of attacks by bark beetles.

Conclusion

Felling residue management is widely used in Europe, mainly to prevent bark beetle outbreaks but also for bioenergy production. In many cases, consideration is given to the role of felling residues supporting biodiversity and nutrient cycling on the sites. Practices vary by country, legislation,

and regional bark beetle risk. While removing residues can reduce pest risk, it may affect ecosystem functions, so management should balance forest protection with ecological benefits. Climate change is likely to increase its importance, highlighting the need for further research on effective residue management strategies.

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Declarations

Conflicts of interest The authors declare no competing interests.

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