European Environment Agency

Nature-based solutions for fire-resilient European forests

Briefing | Published 29 Oct 2025 | Modified 29 Oct 2025

This briefing outlines the potential of nature-based solutions (NbS) to reduce fire risk and increase overall climate resilience across Europe's forests. It is based on a review of forest management case studies across Europe and available literature, and is published in the context of the EU adaptation strategy and the forest strategy for 2030.

Key messages

- Fire is a natural part of the Earth system. However, the frequency, intensity and impacts of wildfires in Europe are increasing. Between 2000 and 2024, an average of 3,770km^2 of land was subject to fires annually in the EEA member countries.
- Climate change, urban expansion and land abandonment in rural areas are increasing the occurrence of fire-prone conditions. The interface between wildland and urban environments, where the risk of wildfires is especially high, is estimated to cover 7.4% of the land surface in the EEA33.
- NbS like adaptive forestry, green corridors, agroforestry, rewetting and rewilding can play key roles in transitioning from fire suppression to fire management. NbS can also increase the resilience of forests to other climate change threats, including pest outbreaks.
- The most suitable NbS will depend on site-specific biophysical, socio-economic and governance conditions. Early stakeholder involvement is essential for avoiding conflicts, for example with economic interests and nature conservation objectives.

Policy context

Forest management in Europe is essential. It helps to preserve biodiversity, support the provision of all forest-related ecosystem services (for example, timber production) and it also mitigates climate change and degradation of biodiverse habitats (Lier et al., 2022). The need for actions that increase the resilience of forests to climate change is recognised in the European Green Deal and the EU's forest strategy for 2030. More resilient forests can contribute to achieving the EU's climate commitments and the objectives of the Land Use, Land-use Change, and Forestry (LULUCF) Regulation, thus strengthening synergies between climate mitigation, adaptation and environmental protection. Although they have not yet been systematically assessed, Nature-based Solutions (NbS) (EC, 2015) are encouraged by EU policies, which include the EU adaptation strategy and the Nature Restoration Regulation. Actions encouraged through these policies can provide a multitude of benefits, including the reduction of risk and better protection from natural hazards and disasters.

The increasing risk of wildfires in European forests

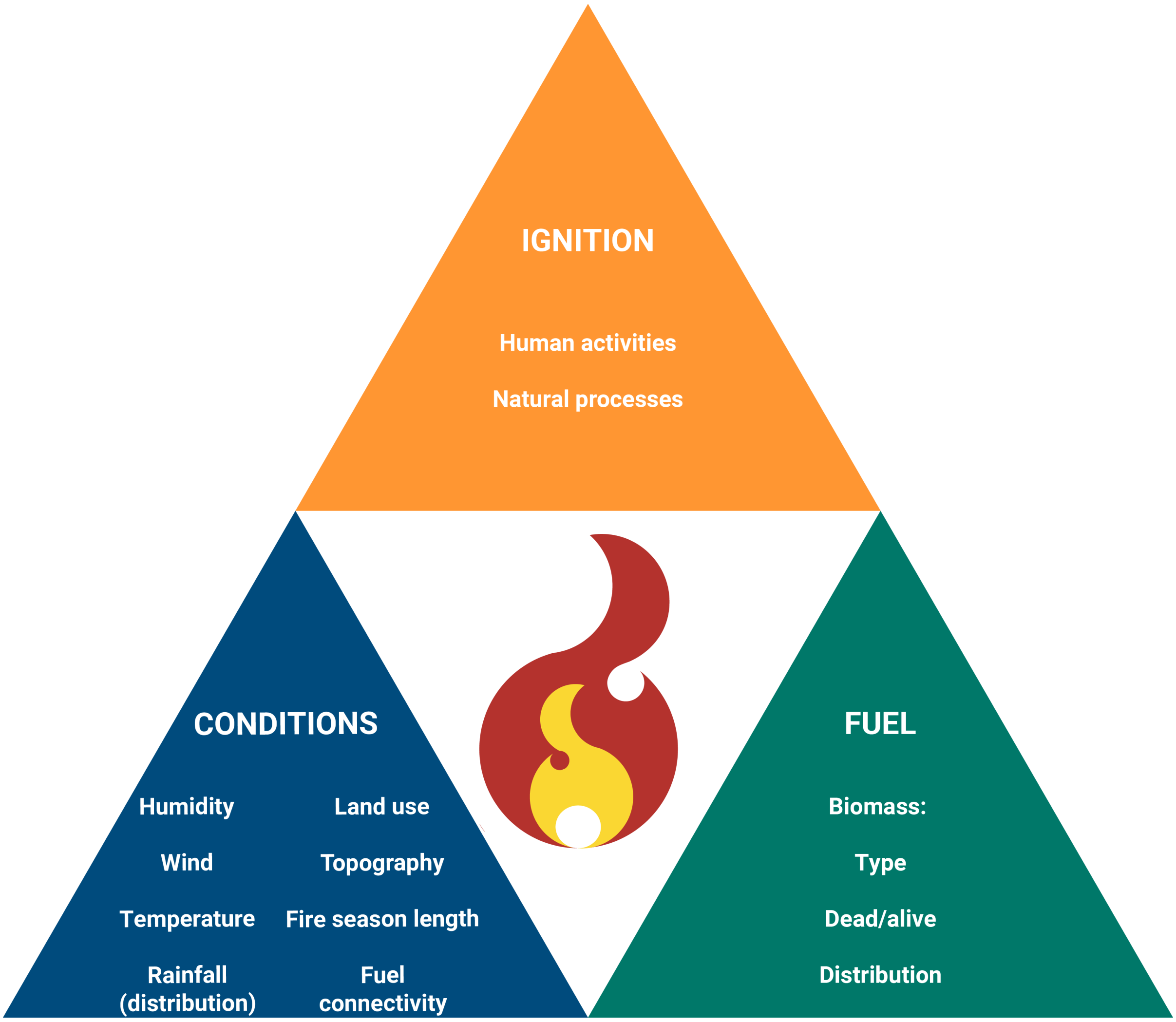
Climate change and shifts in land use are changing the conditions under which wildfires occur; their potential extent and severity are increasing. Higher temperatures, prolonged droughts and increased fuel loads caused by the accumulation of combustible material in forests, are helping to create more days each year subject to a high risk of wildfires. Land use and management practices such as large-scale land abandonment and monoculture forestry exacerbate the increased risk from natural causes. Fire-prone areas like the Mediterranean now face extreme, prolonged fire seasons, while regions such as north-west Europe, previously less affected, now also experience more frequent and intense wildfires (Galizia, 2021). Furthermore, fires are now often occurring out of their regular season.

Changing conditions (temperature, drought, heavier rains and increasing storminess) also make forests more vulnerable to insect disturbances and diseases, which affect over 10,000km^2 annually (Forzieri et al., 2023). Since 2018, due to the prolonged number and severity of drought events experienced in central Europe, forest tree health has deteriorated, leading to severe bark beetle infestation and increased tree mortality (EEA, 2023). The resulting dead trees are more flammable and are at greater risk of catching fire during the first years after dying (Hartmann et al., 2022). However, this risk is temporary. Once fallen trees decay, fire risk declines, partly because large lying deadwood in the higher stages of decay absorbs and holds water and so poses no higher threat, potentially even lowering fire risk (Larjavaara et al., 2023). Deadwood is also an important carbon store and a habitat for biodiversity (Bauhus et al., 2018).

Fire plays a natural role in the Earth's ecosystems (Rodrigo-Comino et al., 2024). It aids regeneration, controls pests and cycles nutrients. Some species have adapted to fire or even need fire events to reproduce. Small fires can actually reduce the risk of large-scale fires by burning through accumulated fuel in forests (Ascoli et al., 2023). However, large and/or uncontrolled fire events can cause serious direct and indirect impacts: production loss, economic damages, habitat loss and the loss of lives. Fire-damaged ecosystems are also more prone to secondary disasters, such as soil erosion, water runoff, floods, ecological droughts and pest outbreaks.

Wildfire risk is a product of the possibility of fire occurrence and the potential impacts of the fire on people and the environment (for further framing see Oom et al., 2022). Therefore, fire risk depends not just on where a fire may occur, but also on how society manages the possibility of a fire happening and how to respond. Management is key to risk mitigation. Figure 1 shows the interaction between the three main elements determining fire occurrence: conditions, fuel and ignition.

Figure 1. Elements determining fire occurrence, intensity and spread



In general, a Mediterranean climate is conducive to fires, because prolonged droughts, elevated temperatures and low humidity during summer are typical. Because of climate change, these conditions are becoming more common and are also experienced further north in Europe (Fernandez-Anez et al., 2021). Fire needs a continuous source of fuel to keep burning and landscape configuration is therefore important for fire management. Fire breaks can be designed specifically for this, but agricultural land can, under specific conditions, also form a barrier that helps to reduce the risk of fire spread. Land abandonment in southern Europe is one reason for the increased fire risk in this region. Diverse and deciduous forests are less prone to fire, while monoculture practices, especially coniferous tree plantations, are more flammable. There is also a high risk of outbreaks from pests in monoculture forests, which can lead to trees dying, sometimes in large numbers. The resulting deadwood can become extremely flammable. Transitioning monoculture plantations and forests into mixed species stands can make them more resilient to current and future climate conditions, provided this is done in accordance with the requirements of local habitats.

The majority of fires are sparked by human activity (Oom et al., 2022). The wildland-urban interface (WUI), i.e. the zone where human settlements are in or near areas of fire-prone wildland vegetation, covered about 7.4% of Europe in 2020 (Bar-Massada et al., 2023). Increased tourism and urban sprawl increase the wildland-urban interface (WUI), where the risk of fires and their impacts are heightened.

Nature-based solutions for mitigating wildfire risks and impacts

Most EU fire management strategies traditionally focused on emergency responses and fire suppression. The primary objective was to reduce burned areas rather than address fire prevention or post-fire recovery. This focus on the acute response can lead to homogeneous landscapes with high fuel loads that actually increase the risk of wildfires in the long term (Oliveras Menor et al., 2025). Fire management will be increasingly ineffective in the future if it prioritises emergency response over risk reduction or recovery (Fernandez-Anez et al., 2021; Oliveras Menor et al., 2025; Tedim et al., 2016). NbS can play a key role in transitioning from fire suppression to longer-term risk reduction and restoration as an integral part of forest management strategies that are fit for future climate conditions (FAO, 2006; UNDRR, 2020).

NbS are not yet fully mainstreamed in forest management practices and policy making, limiting their funding and deployment at scale (Smeenk et al., 2024). However, they are gaining momentum, with research on NbS for fire management having increased from just a few publications per year around a decade ago to approximately 40 per year in 2021-2023 (Keesstra et al., 2024). The increased use of NbS in forests calls for the standardisation of implementation and monitoring practices, and stronger integration of NbS in regional and national adaptation and forest management plans.

NbS can support both fire risk management and post-fire restoration. Close-to-nature forest management can greatly reduce wildfire risk by reducing the fuel load in a forest, for example through grazing, agroforestry, deadwood management and prescribed fires (related to fuel management, see Figure 1). Close-to-nature forestry also aims to have diverse species, age and forest structure, which makes the forest more resilient and less fire prone. Post-fire management requires comprehensive forest restoration that includes natural or assisted natural regeneration, reforestation with diversified species, soil rehabilitation and hydrological rehabilitation. The diversification of landscape and of tree species can also increase forest resilience to other climate change threats, including pest outbreaks. Table 1 gives examples of NbS in forests focusing on fire management. These include promoting species diversity, assisting natural regeneration and expanding protected areas; these approaches help enable forests to adapt to climate change while maintaining ecological and economic functions. The selection of specific measures should consider future proofing, for example by prioritising native tree species that are also suitable for the expected future local climatic conditions.

Table 1. Examples of NbS for fire-resilient landscapes

NbS	Description	Relevance for fire risk	Sources
	Fire risk reduction and management		
Rewilding	Allowing nature to return to a wilder, more diverse landscape, including restoring natural biodiversity and the (re-)introduction of large herbivores; not to be mistaken for land abandonment, which increases fire risk.	Naturally diversified forests are more resilient to fire risks. Bringing back grazing by wild animals can be effective to keep fuel under control.	Johnson et al., 2018; Bauhus et al., 2018
Prioritising fire-resistant vegetation	Planting (possibly native) vegetation less prone to fire risk, e.g. introducing broadleaved species into forests dominated by conifers. May also include planting fire-resistant crops and using hedgerows and other natural barriers to slow fire spread (agroecology and land stewardship).	Planting fire-resistant vegetation halts or slows down the spread of wildfire.	Zuazo and Pleguezuelo, 2009

NbS	Description	Relevance for fire risk	Sources
Green infrastructure, green firebreaks and buffer zones	Strategically planted strips of low-flammability species that act as buffers around urban areas and critical infrastructure.	These structures act as firebreaks by establishing high-moisture (and therefore lower flammability) vegetation and by creating a shaded wet environment, thus acting as a break to reduce windspeed and rate of fire spread.	Curran et al., 2018 ; Marshall et al., 2024
Close-to-nature and adaptive forestry	Managing the establishment, growth, composition, health age and quality of forests on a sustainable basis. Practices include various measures like conversion from monoculture (e.g. fire-prone eucalyptus) to polyculture, selective thinning and favouring mixed stands of trees (diverse species and age composition).	Reduce fuel connectivity and the creation of diversified forests more resilient to fire risks.	Larsen et al., 2022; Mutterer et al., 2025.
Agroforestry	Land management strategy where trees, shrubs and hedges are planted in combination with either livestock, pasture or agricultural crops. This approach enhances soil quality, provides habitats for wildlife and helps increase yields.	Agroforestry creates barriers in forest landscapes and reduces the understory layer of biomass that is usually found in forests.	Damianidis et al., 2021; Wolpert et al., 2022.
Grazing management	Optimising wild and domestic grazing pressure of domestic animals (see also **Agroforestry** and **Rewilding**).	Grazing helps reduce vegetation density, lowering the amount of combustible material (fuel load) in fire-prone areas. After a fire, fencing off forest regeneration areas helps forest recovery (see also **Natural and assisted natural regeneration**).	Oikonomou et al., 2023; Nuijten et al., 2021; Union civil protection knowledge network, 2024.
Rewetting and hydrological restoration	Various measures to restore natural water yield and flow (rewetting dried wetlands, restoration of streams, wetlands and grasslands, building small dams or various water retention structures).	Rewetting helps reduce peat oxidation and hence the risk of fire. Restored ecosystems create natural firebreaks by creating moist areas. Through post-fire restoration, aquatic habitats recover, water quality improves and soil erosion decreases.	Sirin et al., 2020.
Dead biomass management	Optimising dead and residual biomass.	Careful removal of dead biomass from forested stands influences fuel dynamics and fire potential.	Larjavaara et al., 2023. Silva et al., 2025 ; Bauhus et al., 2018.
Prescribed fire	Use of fire under specific controlled conditions.	Prescribed controlled fire reduces the occurrence of large and/or uncontrolled fire events.	Heikkala et al., 2014 ; JRC., 2023; EC, 2021.
	Post-fire management		

NbS	Description	Relevance for fire risk	Sources
Reforestation and afforestation with native and diverse species	Planting (possibly native) tree species in areas severely impacted by fires or storms to restore forest cover, stabilise soils and promote biodiversity. This approach also involves keeping control over alien species (see also **Prioritising fire-resistant vegetation**).	Planting native and diverse species helps restore forest cover after damage has occurred. Fire-resistant species can enhance future resilience.	Cerdà and Robichaud, 2009.
Natural and assisted natural regeneration	Protecting natural regrowth of native species, young seedlings and controlling invasive species to support the natural regrowth of forests affected by large, damaging fires. This approach may also include keeping the ungulate population low during the initial recovery phase (see also **Grazing management**).	Preserving natural regeneration accelerates recovery of forests after significant fire damage has occurred.	Cerdà and Robichaud, 2009; FAO: Assisted natural regeneration.
Soil erosion control and stabilisation	Includes contour log terracing (placing logs or other natural barriers across slopes to slow water and sediment runoff to reduce landscape connectivity), mulching and ground cover (e.g. applying organic materials like straw or wood chips to burned areas).	These strategies protect from soil erosion and overland flow. Mulching and ground cover can also retain soil moisture and protect seedlings.	Cerdà and Doerr, 2008; European NWRM+ platform, A10-traditional terracing.
Soil microbial restoration	Biotechnological strategies that introduce native or external micro-organisms. Application of biochar can improve organic matter in soils.	Plant growth promoting rhizobacteria (PGPR) can help the improvement of plant growth, plant nutrition, root growth pattern and responses to external stress factors. Microbial application creates a cohesive layer that covers the soil surface to protect fragile soil surfaces.	Wittenberg and Stober-Zisu, 2023; Nazarov et al., 2023.

Effective implementation of NbS across different European forest ecosystems

Selection of the most suitable NbS for adaptive fire management necessitates a thorough understanding of the site-specific biophysical, socio-economic and governance conditions and contexts.

Europe can be divided into five ecoregional clusters (van Hattum et al., 2023). Each of these regions experiences different conditions and types of fire risks, meaning that the most effective NbS to apply may differ notably between regions. Figure 2 shows key challenges facing each region, alongside suitable NbS that align with these regional characteristics and constraints. The analysis is based on a literature review and the analysis of case studies. Five of these case studies are provided in the Annex; two examples are highlighted below (Boxes 1 and 2).

Figure 2. Distribution of different forest ecosystems and NbS applied, based on review of literature and case studies

Case studies

1. Southern Italy	A community of practice for the sustainable management of forests surrounding the Occhito Lake. Located in the ecoregional cluster 5. South (Mediterranean region)	More info
2. Northern Spain	Sustainable forestry for increasing climate change resilience of forests in Soria. Located in the ecoregional cluster 5. South (Mediterranean region)	More info
3. Southern Netherlands	Wildfire risk reduction by landscape diversification in Deurnse Peel. Located in the ecoregional cluster 2. West (Atlantic and North Sea regions)	More info
4. North Rhine-Westphalia, Germany	Large-scale forest restoration solutions for resilience to multiple climate stressors. Located in the ecoregional cluster 3. East (Continental region)	More info
5. Eastern Finland	Introducing mixed species to reduce the risk of spruce bark beetles in North Karelia. Located in the ecoregional cluster 1. North (Arctic and Boreal regions)	More info

Ecoregional clusters

1. North (Arctic and Boreal regions)

2. West (Atlantic and North Sea regions)

3. East (Continental region)

4. Central (Alpine and Pannonian regions)

5. South (Mediterranean region)

Van Hattum, T., Van Buuren, M., De Rooij, B., Nel, J. Reinhard, S., Baptis Jones-Walters (2023). Imagining a nature-based future for Europe in 2 solutions at the heart of a visionary approach for accelerating the trans resilient and nature-positive future. Wageningen University & Researcl 1566-7197.

Box 1. Occhito Lake, southern Italy: a community of practice for sustainable forest management

Due to climate change and rural land abandonment, forests that surround the Occhito Lake in southern Italy are increasingly exposed to wildfire. A forestry management plan was set up alongside a formalised forest agreement that aimed to facilitate implementation of the plan by combining public and private funding. The forest agreement is a public-private forest management model which entities that manage and operate in the Occhito area can join voluntarily. The agreement adopts a nature-based approach to preserve and enhance the resilience of forest ecosystems, consolidate slopes and prevent fire risks and pest outbreaks. In addition, it also stimulates the circular economy and revival of local communities. Use of prescribed/controlled fires was tested in a pilot area. The full-scale applicability in the region has been discussed and brought to the attention of local and regional administrations to fill in the existing legislation gap.

Image 1. View of Occhito Lake, southern Italy.

Sources: Climate-ADAPT case study; PABLO project.

Box 2. North Karelia, south-east Finland: introducing mixed species to reduce tree death and fire risk

In North Karelia, Finland, the main NbS used is the diversification of tree species. Increasing summer temperatures cause large scale tree mortality in single-species forests due to bark beetle outbreaks and increasing fire risk caused by the build-up of highly flammable dead biomass in the first years after trees die. NbS addressing this risk include reforestation with native and diverse species, including broadleaf species to increase biodiversity soil health and nutrient cycling (Key et al., 2022). These practices help regional forests attract more tourists and leisure visitors. They also sustain forest industries, which play an important role in forest management implementation along with the governmental forest entities that actively promote this style of sustainable forest governance and provide guidance to landowners.

Image 2. Managed forest in North Karelia, Finland.

Source: North Karelia Living Lab case study.

Success and limiting factors for implementing and upscaling NbS

Public institutions, private owners, conservation groups and industry often have differing priorities when managing forests (e.g. wood production versus biodiversity conservation; forest cover versus other land uses; recreation versus strict nature conservation). Conservation objectives in Natura 2000 sites need to consider future climate-driven changes in the distribution of tree species (Reichmuth et al., 2025). For example, NbS that reduce forest fuel in the short term to mitigate overall, longer term wildfire risk may be seen to conflict with carbon storage objectives (Herbert et al., 2022). In rewilding cases, the increased presence of ungulate[1] animals could cause concerns about overgrazing. Grounding NbS in local knowledge and traditional close-to-nature practices, such as grazing and agroforestry (Prats et al., 2022), can help align adaptation with sustainable development objectives. Local communities must also be actively involved in NbS implementation, particularly for solutions that involve visible landscape changes, such as prescribed burns.

Forest management approaches are determined by forest owners' decisions and by national and regional policy frameworks. About 55% of forests are privately owned across EEA member countries, with large variations in the proportion of forest habitats in public and private ownership (UNECE, 2020). Public owners of large, forested areas (state, or subnational authorities) mainly follow unified nationally defined goals for forest management, typically resulting in forests with higher biodiversity than found in comparable private forests (Mölder et al., 2021). Local public forest owners tend to respond to the needs of local communities for multifunctional forests (UNECE, 2020). Most private forests in Europe are small scale and family owned. These owners often have more constrained economic and technical knowledge resources, but they do have an increasing awareness of conservation goals (Tiebel et al., 2024; Weiss et al., 2019; Weiss et al., 2021; Pulla et al., 2013). Fragmented and small-scale ownership is to some extent associated with absentee ownership and land abandonment, which can increase forest vulnerability to fires and pests. Well-managed forest owner associations or cooperatives (Hrib et al., 2024; Thorning, 2024), networks among practitioners (Tiebel et al., 2024) or among actors along the timber value chain (Zafra-Calvo et al., 2024) could be entry points for disseminating the necessary knowledge and changing management practices.

Implementing NbS strategies such as mixed forests and efforts to increase biodiversity inevitably involves some economic and financial trade-offs; good management requires significant initial investment and extends turn-over time of investments in forest management. This is something that many small forest owners cannot afford, so NbS are less attractive to commercial investors. Market constraints are also important: in forests managed for timber production, selective harvesting increases costs. New markets for non-timber products or ecosystem services provided by forests, including alternative carbon markets, are underdeveloped. Improved knowledge and awareness of the long-term benefits of forest management for resilience are needed, alongside specific incentives to support the transition, in particular in the case of reforestation after fire. The role of insurance in recognising the value of forest fire resilience is still untapped (Martinez et al., 2021).

NbS implementation requires long-term strategies with aligned objectives that translate into coherent governance frameworks, including certification schemes and regulations regarding forest management planning and monitoring. Existing regulations should be supported both by efficient law enforcement and by easier access to support programmes for landowners and forest managers. Integrating NbS impact assessments into consistent forest monitoring frameworks could help scale these solutions and support evidence-based policy and funding decisions.

Reducing risks from wildfires requires a multipronged approach that must incorporate efforts to increase awareness about the risks of wildfires and encourage preparedness by emergency services, authorities and local communities. In Portugal, the Safe Villages Programme (SVSP) aims to involve local communities in awareness-raising campaigns against risky behaviour, encourage self-protection measures, create refuges and conduct evacuation drills. A comprehensive benefit-cost analysis was conducted to understand the potential benefits of the programme and support the prioritisation of areas for implementation.

Identifiers

Identifiers for EEA Briefing 14/2025:

Title: **Nature-based solutions for fire-resilient European forests**

HTML: TH-01-25-030-EN-Q - ISBN: 978-92-9480-736-6 - ISSN: 2467-3196 - doi: 10.2800/8810870

References

Ascoli, D., et al., , 2023, ‘Fire-smart solutions for sustainable wildfire risk prevention: Bottom-up initiatives meet top-down policies under EU green deal’, *International Journal of Disaster Risk Reduction* 92, p. 103715.

Bar-Massada, A., et al., 2023, ‘The wildland – urban interface in Europe: Spatial patterns and associations with socioeconomic and demographic variables’, *Landscape and Urban Planning* 235, p. 104759 (DOI: 10.1016/j.landurbplan.2023.104759).

Bauhus, J., et al., 2018, ‘Dead wood in forest ecosystems’, *Advances in Ecological Research*, 15 (DOI: 10.1093/obo/9780199830060-0196).

Cerdà, A. and Doerr, S. H., 2008, ‘The effect of ash and needle cover on surface runoff and erosion in the immediate post-fire period’, CATENA 74 (3), pp. 256-263 (DOI: 10.1016/j.catena.2008.03.010).

Cerdà, A. and Robichaud, P. R. (eds), 2009, *Fire effects on soils and restoration strategies*, CRC Press, Florida, United States.

Climate-ADAPT, 2025, *Prescribed fire and grazing as integrated approach to make forests climate resilient in Viseu Dão Lafões, Portugal*, European Environment Agency (https://climate-adapt.eea.europa.eu/en/metadata/case-studies/prescribed-fire-and-grazing-as-integrated-approach-to-make-forests-climate-resilient-in-viseu-dao-lafoes-portugal) accessed 7 April 2025.

Curran, T. J., et al., 2018, ‘Managing Fire and Biodiversity in the Wildland-Urban Interface: A Role for Green Firebreaks’, *Fire* 1 (1), p. 3 (DOI: 10.3390/fire1010003).

Damianidis, C., et al., 2021, ‘Agroforestry as a sustainable land use option to reduce wildfires risk in European Mediterranean areas’, *Agroforestry Systems* 95, pp. 919-929.

EC, 2015, *Towards an EU Research and Innovation policy agenda for Nature-Based Solutions & Re-Naturing Cities,* final report of the Horizon 2020 expert group on ‘Nature-based solutions and re-naturing cities’, Publications Office of the European Union, Luxembourg.

EEA, 2023, *The European biomass puzzle. Challenges, opportunities and trade-offs around biomass production and use in the EU*, EEA Report No 08/2023, European Environment Agency.

FAO, 2006, *Fire Management: Voluntary Guidelines - Principles and strategic actions*, Food and Agriculture Organization of the United Nations, Rome.

Fernandez-Anez, N., et al., 2021, ‘Current wildland fire patterns and challenges in Europe: A synthesis of national perspectives’, *Air, Soil and Water Research* 14 (DOI: 10.1177/11786221211028185).

Forzieri, G., et al., 2021, ‘Emergent vulnerability to climate-driven disturbances in European forests’, *Nature Communications* 12 (1), p. 1081.

Galizia, L.F., et al., 2021, ‘Understanding fire regimes in Europe’ *International Journal of Wildland Fire* 31 (1), pp. 56-66.

Hartmann, H., et al., 2022, ‘Climate change risks to global forest health: emergence of unexpected events of elevated tree mortality worldwide’, *Annual Review of Plant Biology* 73 (1), pp. 673-702.

Heikkala, O., et al., 2014, 'Effects of retention level and fire on retention tree dynamics in boreal forests', *Forest Ecology and Management* 328, pp. 193-201 (DOI: 10.1016/j.foreco.2014.05.022).

Hrib, M., et al., 2024, 'The potential of small-scale owners' associations for sustainable forest management: the case of the Czech Republic', *Scandinavian Journal of Forest Research* 39 (6), pp. 328-343 (DOI: 10.1080/02827581.2024.2409111).

Johnson, C. N., et al., 2018, 'Can trophic rewilding reduce the impact of fire in a more flammable world?', *Philosophical Transactions of the Royal Society B: Biological Sciences* 373 (1761), p. 20170443 (DOI: 10.1098/rstb.2017.0443).

Keesstra, S., et al., 2024, *Nature-based Solutions to address forest disturbances under climate change: the case of fire and pests*, ETC CA Technical Paper No 1/2024, European Topic Centre on Climate Change Adaptation and LULUCF (ETC CA).

Key, I. B., et al., 2022, 'Biodiversity outcomes of nature-based solutions for climate change adaptation: Characterising the evidence base' *Frontiers in Environmental Science* 10, p. 905767.

Larjavaara, M., et al., 2023, *Deadwood and Fire Risk in Europe - Knowledge Synthesis for Policy*, JRC Report No JRC134562, JRC, Publications Office of the European Union, Luxembourg (DOI:10.2760/553875).

Larsen, J.B., et al., 2022, *Closer-to-Nature Forest Management*, in: From Science to Policy, European Forest Institute (DOI: 10.36333/fs12).

Lier, M., et al., 2022, 'The new EU Forest strategy for 2030: a new understanding of sustainable forest management?', *Forests* 13 (2), p. 245.

Marshall, E., et al., 2024, 'Can green firebreaks help balance biodiversity, carbon storage and wildfire risk?', *Journal of Environmental Management* 369, p. 122183 (DOI: 10.1016/j.jenvman.2024.122183).

Mölder, A., et al., 2021, 'On the Interplay of Ownership Patterns, Biodiversity, and Conservation in Past and Present Temperate Forest Landscapes of Europe and North America', *Current Forestry Reports* 7 (4), pp. 195-213 (DOI: 10.1007/s40725-021-00143-w).

Mutterer, S., et al., 2025, 'Beetles, wind, and fire: Effects of climate change and close-to-nature forestry on disturbance predisposition and ecosystem service trade-offs', *Forest Ecology and Management* 586, p. 122690 (DOI: 10.1016/j.foreco.2025.122690).

Nazarov, A., et al., 2023, 'Microbial. Preparations Combined with Humic Substances Improve the Quality of Tree Planting Material Needed for Reforestation to Increase Carbon Sequestration', *Sustainability* 15, p. 7709 (DOI: 10.3390/su15097709).

Nuijten, D., et al. (eds), 2021, *Land-based wildfire prevention – Principles and experiences on managing landscapes, forests and woodlands for safety and resilience in Europe*, European Commission DG ENV, Publications Office of the European Union, Luxembourg (DOI: 10.2779/695867).

Oikonomou, D., et al., 2023, Grazing as a Management Tool in Mediterranean Pastures: A Meta-Analysis Based on A Literature Review', *Land* 12, p. 1290 (DOI: 10.3390/land12071290).

Oliveras Menor, I., et al., 2025, 'Integrated fire management as an adaptation and mitigation strategy to altered fire regimes', *Communications Earth & Environment* 6 (1), p. 202.

Oom, D., et al., 2022, *Pan-European wildfire risk assessment*, JRC Report No JRC130136, JRC, Publications Office of the European Union, Luxembourg (DOI: 10.2760/9429).

Prats, S. A., et al., 2022, 'Effectiveness of community-based initiatives for mitigation of land degradation after wildfires', *Science of The Total Environment* 810, p. 152232 (DOI: 10.1016/j.scitotenv.2021.152232).

Pulla, P., et al., 2013, *Mapping the distribution of forest ownership in Europe*, EFI Technical Report No 88, European Forest Institute EFI, Joenessu, Finland (https://efi.int/sites/default/files/files/publication-bank/2018/tr_88.pdf) accessed 29 September 2025.

Reichmuth, A., et al., 2025, 'Forested Natura 2000 sites under climate change: effects of tree species distribution shifts', *Web Ecol.* 25, pp. 59-89 (DOI: 10.5194/we-25-59-2025).

Rodrigo-Comino, J., et al., 2024, *Introduction: FIRElinks, a Community for Society and Science*, in: Fire Hazards: Socio-economic and Regional Issues, Springer International Publishing, Cham, Switzerland.

Silva, R.G., et al., 2025, 'Sustainable Harvest/Collection Optimization of Residual Agro-Forestry Biomass including Wildfire Risk', *Procedia Computer Science* 253, pp. 3037-3048.

Sirin, A. A., et al., 2020, 'Multispectral satellite based monitoring of land cover change and associated fire reduction after large-scale peatland rewetting following the 2010 peat fires in Moscow Region (Russia)', *Ecological Engineering* 158, p. 106044 (DOI: 10.1016/j.ecoleng.2020.106044).

Smeenk, A., et al., 2024, Summary of the webinar on nature-based solutions for integrated Wildfire risk management (https://firelogue.eu/pdf/webinar290524/Nature_based_solutions_for_integrated_wildfire_risk_management.pdf) accessed 29 September 2025.

Tedim, F., et al., 2016. A wildfire risk management concept based on a social-ecological approach in the European Union: Fire Smart Territory. International Journal of Disaster Risk Reduction, 18, pp.138-153.

Thorning, A., 2024, 'Co-operative forest owner associations - harmonized values for sustainable development?', *Forest Policy and Economics* 164 (DOI: 10.1016/j.forpol.2024.103237).

Tiebel, M., et al., 2024, 'Understanding small-scale private forest owners is a basis for transformative change towards integrative conservation', *People and Nature* 6 (1), pp. 337-353 (DOI: 10.1002/pan3.10579).

UNDRR, 2020, *Evolving Risk of Wildfires in Europe*, E-STAG (https://www.undrr.org/publication/evolving-risk-wildfires-europe-thematic-paper-european-science-technology-advisory) accessed 29 September 2025.

UNECE, 2020, *Who Owns our Forests? Forest Ownership in the ECE Region* (https://www.un-ilibrary.org/content/books/9789210048286) accessed 29 September 2025.

van Hattum, T., et al., 2023, *Imagining a nature-based future for Europe in 2120 : nature-based solutions at the heart of a visionary approach for accelerating the transition to a climate resilient and nature-positive future*, Wageningen University & Research, Wageningen, The Netherlands (DOI: 10.18174/637123).

Weiss, G., et al., 2019, 'Forest ownership changes in Europe: State of knowledge and conceptual foundations', *Forest Policy and Economics* 99, pp. 9-20 (DOI: 10.1016/j.forpol.2018.03.003).

Weiss, G., et al., 2021, 'Innovation governance in the forest sector: Reviewing concepts, trends and gaps', *Forest Policy and Economics* 130, p. 102506 (DOI: 10.1016/j.forpol.2021.102506).

Wittenberg, L. and Shtober-Zisu, N., 2023, 'Restoring fire-affected soils: The potential of nature-based solutions', *Current Opinion in Environmental Science & Health* 36, p. 100520.

Wolpert, F., et al., 2022, 'Collaborative agroforestry to mitigate wildfires in Extremadura, Spain: land manager motivations and perceptions of outcomes, benefits, and policy needs', *Agroforestry Systems* 96 (8), pp. 1135-1149.

Zafra-Calvo, N., et al., 2024, 'Identifying key actors, barriers and opportunities to lead a transition towards sustainable forest management: an application to the Basque Country, Spain', *Trees, Forests and People* 18 (DOI: 10.1016/j.tfp.2024.100727).

Zuazo, V. H. D. and Pleguezuelo, C. R. R., 2009, 'Soil-Erosion and Runoff Prevention by Plant Covers: A Review', in: Lichtfouse, E., et al. (eds), Sustainable Agriculture, Springer Netherlands, Dordrecht.

Notes

Climate-ADAPT case studies:

- A community of practice for the sustainable management of forests surrounding the Occhito Lake in Puglia, Italy
- Sustainable climate change adaptation of forestry in the province of Soria, Spain

Relevant Climate-ADAPT pages:

- Nature-based Solutions
- Adaptation in the forestry sector

Related EEA briefings:

- Preparing society for climate risks in Europe - lessons and inspiration from Climate-ADAPT case studies
- Scaling nature-based solutions for climate resilience and nature restoration

Footnotes

1. A hoofed typically herbivorous quadruped mammal. ↵

Annex

Overview of case studies

Case study	Climate and non-climate challenges	Implemented solutions	Suitability factors for scaling
1. A community of practice for the sustainable management of forests surrounding the Occhito Lake, southern Italy **Sources:** PABLO project Climate-ADAPT case study	Fire risk. Decreasing population. Agricultural land abandonment. Disorganised silviculture. Lack of a common forest management objective.	**Prescribed fire** Tested in pilot areas. **Close-to-nature and adaptive forestry** Preparation of a forestry management plan. **Development of a Forest Agreement** Voluntary public-private partnership for implementing the management plan).	**Biophysical conditions:** • Mediterranean pine forest. • Dominating species Aleppo pine (*Pinus halepensis* and Arizona cypress (*Cupressus arizonica*). **Socio-economic conditions**: • Small, scattered villages surrounding the lake. • Forest used for timber production and recreational activities. • The subscribers of the Forest Agreement are both beneficiaries and financial contributors. **Governance conditions:** • Presence of a mosaic of state, municipal and private properties. **Success (+) and limiting (-) factors:** • (+) Increased safety from fire risk. • (+) Circular economy implementation (marketing of wood residues). • (+) Positive impact on local economies (short supply chain) and rural development. • (+) Various environmental co-benefits of NbS, including biodiversity enhancement, slope consolidation and reducing plant diseases originated by pests. • (+) Forest shared by two neighbouring regions (Molise and Puglia), allowing scalability. • (+) High interest from several municipalities. • (-) Initial scepticism towards prescribed fires. • (-) Regional legislation gap (addressed during the project) for scaling the prescribed fire technique.

Case study	Climate and non-climate challenges	Implemented solutions	Suitability factors for scaling
2. Sustainable forestry for increasing climate change resilience of forests in Soria, northern Spain **Sources:** LIFE Soria ForestAdapt Climate-ADAPT case study	Fire risk. Pest outbreaks. Changing the growth patterns of trees and suitability of species.	**Close-to-nature and adaptive forestry** Establishing mixed species composition. **Prioritising fire-resistant vegetation** Introduction of broadleaved forest species into large coniferous forest stands. **Grazing management** Managed grazing through alternating fenced off areas. **Pheromone traps** Monitoring presence of insects, e.g. pine processionary moth. **Natural and assisted natural regeneration** • Animals are kept away to allow natural regrowth. • Early detection of fires, based on watchtowers with guards, thermal cameras, smoke detection and visible camera. • Forest fire crews for continuous fire prevention.	**ophysical conditions:** Mixed tree composition of conifers and deciduous species Dominant species: *Pinus sylvestris* (Scots pine), *Pinus pinaster* (maritime pine), *Pinus nigra* (black pine), *Juniperus thurifera* (Spanish juniper), *Fagus sylvatica* (European beech), *Quercus ilex* (holly oak), *Quercus faginea* (Portuguese oak) and *Quercus pyrenaica* (Pyrenean oak) **Socioeconomic conditions:** • High economic value of the forest. • Natural space for recreational activities. **Governance conditions:** • Mosaic of private, public, industry and educational institutes. • Forest managed by a group of owners (Montes des socios). **Success (+) and limiting (-) factors:** • (+) Preserved forest wood and non-wood products, including resin production, mushrooms, truffles, hunting and extensive domestic livestock. • (+) Presence of the Association of Forest Owners of Soria (ASFOSO) to save mountains from abandonment and facilitating contact between private owners and the administrative authorities. • (-) Presence of agricultural areas bordering the forest (competing interests). • (-) Lack of formal organisation of the shared ownership, left without a management body to make decisions.

Case study	Climate and non-climate challenges	Implemented solutions	Suitability factors for scaling
3. Wildfire risk reduction by landscape diversification in Deurnse Peel, southern Netherlands **Sources:** LIFE Climate Forest SUPERB Project	Fire risk. Pest outbreaks.	**Green infrastructure, green firebreaks, green corridors and buffer zones** Ecological corridors with deciduous/broadleaved forests. **Reforestation and afforestation with native and diverse species** In areas hit by pests. **Close to-nature and adaptive forestry** Creating diverse mixed forests on landscape scale - broadleaved species and pine trees.	**Biophysical conditions:** • Dry sandy soils, poor of nutrition. • Pine/fir/Douglas/Lork and different species of broad-leaved deciduous trees. **Socioeconomic conditions:** • Forests both managed as investment assets and public forests. • Forest used for recreational activities. **Governance conditions:** • Different types of property regimes, including small-scale private owners and consortia of small-scale owners. **Success (+) and limiting (-) factors:** • (+) Various environmental benefits of NbS related to the increase of biodiversity (insects, birds, mammals, vegetation). • (+) NGO (de Bosgroep) supporting owners for forest management. • (+) Forest owners are obliged to reforest areas hit by pests. • (+) The state authorities as well as national authorities provide subsidies for reforestation of areas destroyed by pest infestation. • (+) Reforestation must consider suitability of single species under different future climate regimes • (+/-) Strict conservation regimes for reforesting some natural areas. • (-) No forest transformation is possible without the consent of the owner. • (-) Lack of funds for implementing measures.

Case study	Climate and non-climate challenges	Implemented solutions	Suitability factors for scaling
4. Large-scale forest restoration solutions for resilience to multiple climate stressors in North Rhine-Westphalia, Germany **Source:** SUPERB Project	Wind, drought and subsequent European spruce bark beetle (*Ips typographus*) outbreaks. Spruce forests no longer suitable due to changing climate.	**Reforestation and afforestation with native and diverse species** According to the "four tree species principle", i.e. suitable compositions of tree species according to the site typology and future climate suitability. **Natural and assisted natural regeneration** Deer management.	**Biophysical conditions:** • Dominating spruce stands following the demand for pit timber in the 19th century. • Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) replaced previously existing beech and mountain beech forests. **Socioeconomic conditions:** • Wood harvesting and hunting are the two main economic activities. **Governance conditions:** • Different types of forest owners, ranging from public (state and local authorities), to church and private owners. **Success (+) and limiting (-) factors:** • (+) Preservation of various ecosystem services delivered by the forest (climate regulation; water regulation and supply; erosion control; habitat provision and recreation). • (+) Expected increase in wood harvest (tangible only in 30 years or beyond). • (+) All restoration measures are developed in cooperation with the landowners or the forest managers representing the landowners. • (+) Legal obligation for reforestation, supported by subsidies. • (-) Resource shortages (planting materials, skilled personnel, etc.) are challenging a full and timely reforestation. • (-) Many forest owners are financially unable to manage reforestation and lack income from forests. • (-) Large deer populations cause heavy browsing, which affects restoration success. • (-) Rigid rules apply to conservation sites, with conflicting restoration objectives in Natura2000 area.

Case study	Climate and non-climate challenges	Implemented solutions	Suitability factors for scaling
5. Introducing mixed species to reduce the risk of spruce bark beetles in North Karelia, eastern Finland **Source:** North Karelia Living Lab	Increasing risk of pest outbreaks (increasing summer temperatures and longer growing season of bark beetle). Significant damage caused by fire, storms and drought.	**Reforestation and afforestation with native and diverse species** Introducing broadleaved tree species to promote resilience and biodiversity. **Close-to-nature and adaptive forestry** Sustainable forest management and biodiversity enhancement. **Dead biomass management** Reduce the availability of habitat for bark beetles and improve habitats for predators.	**Biophysical conditions:** • Norway spruce (*Picea abies*) and Scots pine (*Pinus sylvestris*) forming varying mixtures with birch (Betula sp.). **Socio-economic conditions:** • Important nature destination. • Several forest industry companies, such as forest machinery and wood logistics companies, pulp and paper mills, and sawmills dispersed throughout the region. Major wood construction companies also play significant roles. **Governance conditions:** • Private, state, other public owners and companies accounting for 55%, 19%, 5% and 21%, respectively. Finnish Forest Centre is a crucial entity in forest governance, actively promoting the forestry sector and providing guidance to landowners. **Success (+) and limiting (-) factors:** • (+) More biodiversity. • (+) Enhanced soil fertility. • (+) Improved nutrient cycling and soil health.

Acknowledgements

The European Environment Agency (EEA) would like to thank its partners from the European Environment Information and Observation Network (the EEA member countries (with comments from Hungary, Belgium, Poland, Croatia, Germany) and European Topic Centre on Climate change adaptation and LULUCF (ETC CA)), as well as the European Commission's directorates-general for the environment (ENV), climate action (CLIMA) and European Civil Protection and Humanitarian Aid Operations (ECHO) for their valuable contributions and input.