G20 Study on Restoration of Forest Fire impacted Areas for Recovering the Natural Biodiversity

Country Profile – Germany

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Mandated by
German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection – in cooperation with German Federal Ministry of Food and Agriculture

Introduction

The G20 nations acknowledge the commitment to accelerate progress on the implementation of the UN-SDGs and to support combating land degradation. The G20 harbors about two-thirds of the world population, twenty largest economies in the world and premier forum for international economic cooperation. The Forum brings together 19 countries and the European Union and is committed to the global economy, financial stability, climate change and sustainable development. India holds the G20 presidency in 2023 under the motto "One Earth – One Family – One Future". The Indian Institute of Forest Management, an autonomous Institution under the Ministry of Environment Forest and Climate Change, Government of India, has been entrusted to develop a study "Restoration of fire-impacted areas for recovery of natural biodiversity". This publication will provide a current state of knowledge on the subject and provide a roadmap for the G20 countries to share and collaborate in the coming years.

One chapter of the study will provide an overview of restoration of fire-affected areas in G20 countries. In this chapter, each of the 19 G20 countries and European Union shall be covered. In every country standard items such as forest types and ecosystems, forest fire occurrence, area impacted annually by forest fires, causes and losses, restoration approaches for natural biodiversity recovery including nature based solutions etc. are covered. Historical evidence of community / indigenous fire management practices are incorporated, where applicable, in recognition of the significant learning available from such traditional fire use in managing ecosystems.

Mandated by the German Federal Ministry for the Environment, Nature Conservation, Nuclear Safety and Consumer Protection – in cooperation with German Federal Ministry for the Food and Agriculture – the country chapter for Germany has been authored by the Global Fire

Monitoring Center (GFMC) / Fire Ecology Research Group, Max Planck Institute for Chemistry and Freiburg University.

With regard to the terminology and the structure, the chapter largely follows the standards as prescribed by the overall outline of the study exempt a few adjustments. Thus, this national report does not cover the entire activities and measures taken in landscape fire management in Germany.

1. Germany – Overview of forest fires

1.1 Forest area

The country profile for Germany will focus on forests and forest fires. However, since non-forest lands are also affected by fire, including fire-sensitive and fire-dependent ecosystems of high conservation value, examples of non-forest ecosystems are included.

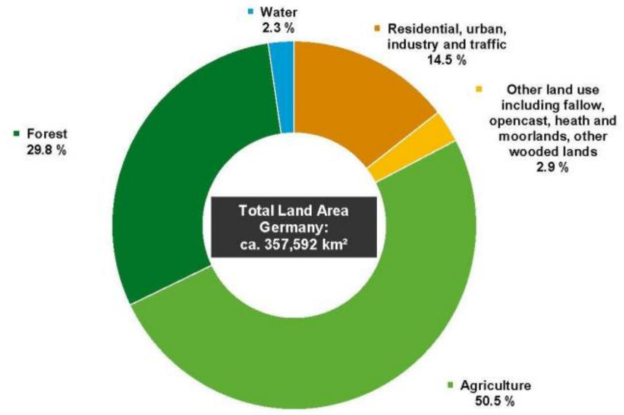

Figure 1. Land use in Germany 2022. Source: German Federal Environment Office (Umweltbundesamt)[1]

Figure 1 shows the share of land-use and land cover categories, including water bodies, in Germany. The forest cover of 29.8% of the total land area corresponds to 11.4 million hectares (ha). Since 2016, other wooded lands as well as high-value conservation areas, which are bearing significant biodiversity outside of forests, including heathlands and moorlands, are included in the category "other land use". Agricultural lands are covering 16.7 million ha. The total area of heathlands and moorlands is 148,700 ha. Out of the 8,878 protected areas on land and sea, a total of 1.42 million ha terrestrial conservation sites are established, corresponding to 4% of the land cover of Germany.[2]

Half of the German forest lands are privately owned (48%). One-fifth is owned by municipalities, cities and other public bodies (19%). One third belongs to the federal states (29%) and the federal government (4%). The total forest area consists of 54.2% conifers and 43.2% deciduous trees; the remaining area constitute open spaces. About 47% of the forest lands are classified as protected landscape areas.[3]

The federal government's current "National Strategy on Biological Diversity" aims at establishing wilderness areas. Wilderness areas are sufficiently large, (largely) undivided,

[1] Source (URL, April 2023): Umweltbundesamt
[2] Source (URL, April 2023): Bundesamt für Naturschutz
[3] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft

unused areas that serve to ensure that natural processes can run unaffected by humans long term. Natural processes are particularly important for many species and habitats and their protection or reintroduction is therefore a key goal of nature conservation. This is reflected by the Federal Nature Conservation Act, in which the protection of natural developments in National Parks is expressively stated as the central goal for this type of protected area. In this way, nature should develop according to its own laws on at least 2% of Germany's land area. This goal is to be achieved primarily through large-scale wilderness areas. The wilderness areas are also to be integrated into the transnational biotope network. In addition, forests should be able to develop naturally on 5% of the forest area.[4]

More than 1.1 million people are employed in the forestry and timber industry (1.7% of the German work force). The annual turnover of forestry and forest industries is €132 billion, representing 1.2% of the national gross value added.[5]

1.2 Area under forest fire

Wildfire statistics are available for forest areas. Statistical data of fires affecting agricultural lands and other open landscapes are not collected. Fire statistics of protected areas are available if the area burned is classified as forest. Forest fire statistics are collected by the 16 Federal States, and evaluated and published annually by the German Federal Agency for Agriculture and Food (Bundesanstalt für Landwirtschaft und Ernährung). After reunification of Germany in 1990, coherent and consistent statistical data are available since 1991.[6]

In the following, extracts of statistical evaluation are provided for the 30-years period 1991 to 2021. The evaluation of forest fire statistics of 2022 cannot yet be included as they will be available only by mid-2023. Figure 2 shows the annual area burned and number of fires between 1991 and 2021. Figure 3 shows the average forest area burned per fire (green columns) and damages (purple line) in Germany 1991 to 2021. Figure 4 shows the share of area burned classified as coniferous forests and deciduous stands in the same 30-years period. Figure 5 displays the causes of forest fires in Germany in 2021 – representative for long-term averages.

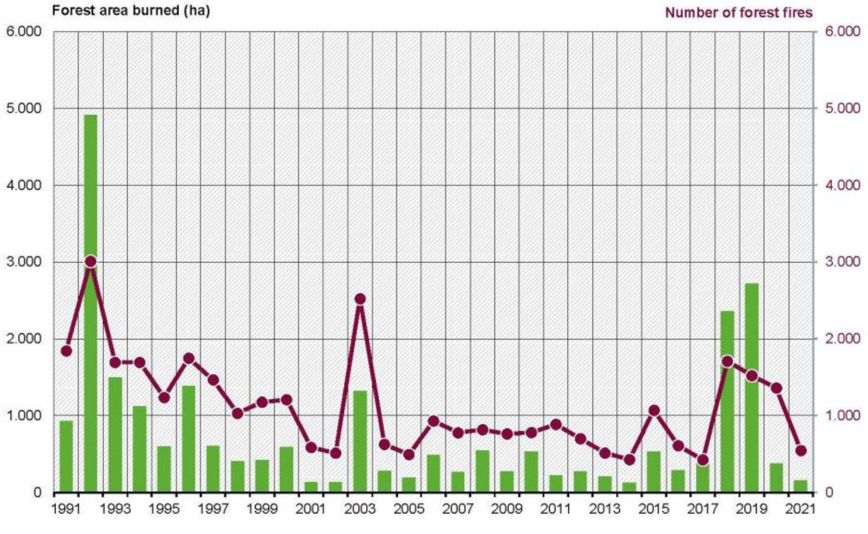

Figure 2. Forest area burned (ha) (green columns) and number of fires (purple line) in Germany 1991 to 2021. The total forest area affected in 2022 is currently estimated to exceed 4300 ha.

[4] Source (URL, April 2023): Bundesamt für Naturschutz
[5] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft
[6] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft and Umweltbundesamt

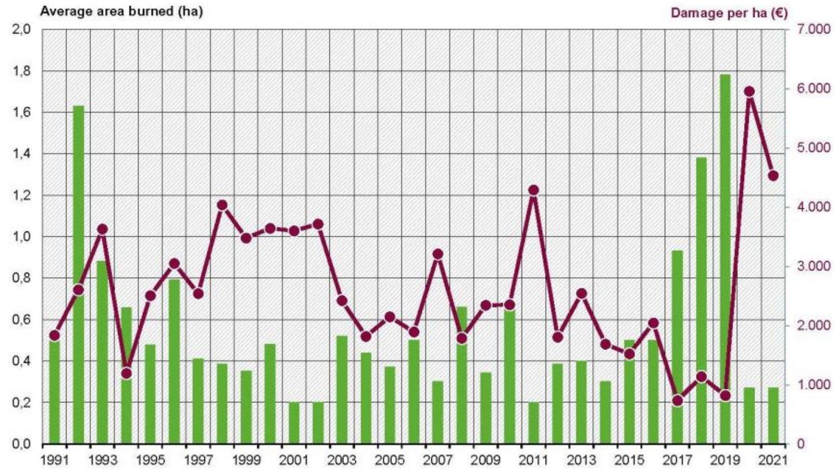

Figure 3. Average forest area burned per fire (ha) (green columns) and damages per ha (purple line) in Germany 1991 to 2021. The average area burned per fire in the 30-years period is 0.6 ha.

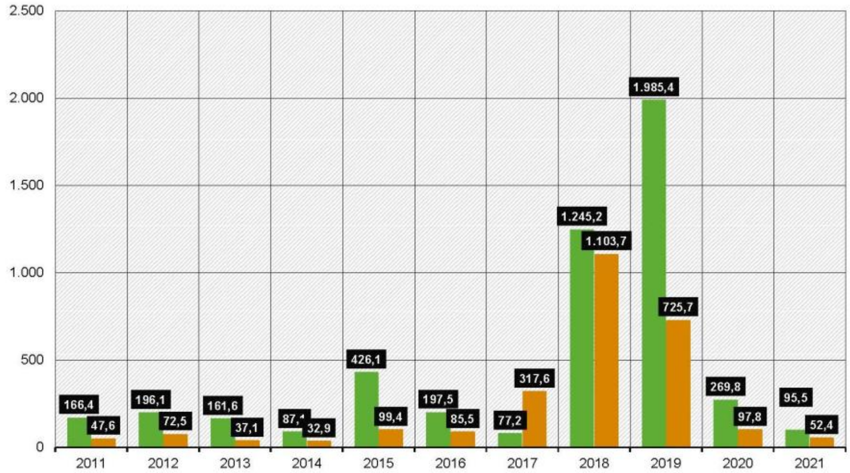

Figure 4. Share of area burned classified as coniferous forests (green columns) and deciduous stands (ochre columns) in Germany 1991 to 2021.

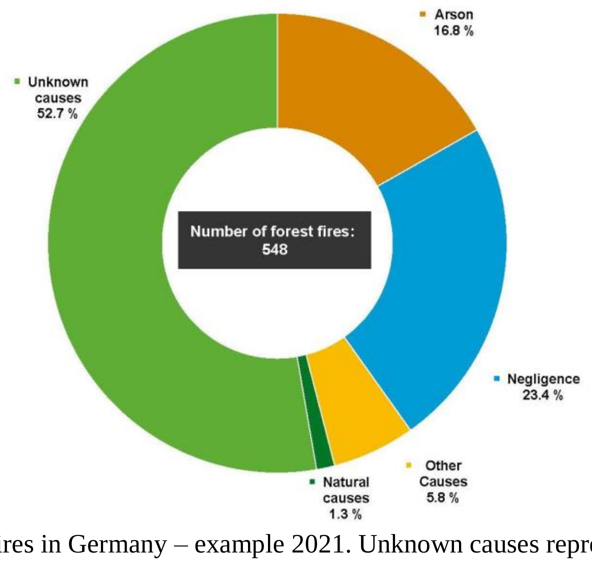

Figure 5. Causes of forest fires in Germany – example 2021. Unknown causes represent human-caused fire of which the origin or intent could not be identified. Natural causes refer to thunderstorm / lightning-caused fires. The 30-years averages (1991-2021) show that around 4% of fires are of natural origin and 96% of fire starts are human caused – thereof 20 % arson, 24% negligence, 9% other causes, 43% unknown causes.

Since 2018 Germany is experiencing increasing occurrence and severity of dry spells / droughts, some associated with heat waves, which have significant impacts on forest ecosystem, i.e. lowered water tables, reduced soil moisture, increased dryness of forest microclimate and forest fuels (combustible materials), forest dieback with consequences on secondary stresses such as pests and diseases, notably bark beetle infestations, and thus an overall increased flammability and susceptibility to fire.

Thus, long-term average statistical data such as the averages 1991 to 2021 reflect the environmental conditions and forest health under historic climate. The climate crisis is posing unprecedented wildfire risks to the natural and cultural landscapes of Central Europe including Germany.

The following assessments and deliberations intend to reflect the *status quo ante* as well as uncertainties of future development of and the role of fire in forest and non-forest landscapes in light of the climate crisis.

1.3 Key ecosystems susceptible to wildfires

Plantation forests of Scotch pine (*Pinus sylvestris*), many of them stemming from reforestation after World War II, are bearing the highest risk and susceptibility to wildfires. However, in 2022 it became evident that in principle, all forests of the country are susceptible / vulnerable to wildfires as they are becoming increasingly subjected to drought. As highlighted in Section 2.3, the drought and heat stress of the recent years have resulted in crown defoliation of coniferous and deciduous forest stands. Opening of the canopy layer, associated with lack of precipitation, lowered upper soil moisture and ground water level (cf. Fig. 9).

For the first time in 2022, protected areas like Saxon Switzerland National Park (Nationalpark Sächsische Schweiz)[7] and Harz National Park[8] have been affected by wildfires. Wildfires in these and other protected forests, which are managed by “close-to-nature principles”, have resulted in fire behavior, which was not observed before. The concept of development of wilderness areas (cf. Section 1) and “close-to nature” forest management is aiming, among other, at increasing biodiversity and terrestrial carbon storage. However, there are a few controversial implications: Protected or non-managed forests are becoming less accessible for firefighting and burning of larger amounts of deadwood is resulting in fires of higher intensity and severity. This led to a controversial public debate during and after the 2022 fire season.

In this scientific discourse about future forest and fire management concepts, the Global Fire Monitoring Center (GFMC) / Fire Ecology Research Group, attempted to clarify the role and consequences of deadwood on fire behavior and fire impacts, which will also have implications on post-fire restoration / rehabilitation of fire-affected forests.[9]

Among the non-forested ecosystems, organic terrain (peatlands) are vulnerable to fire. In 2018 a major wildfire affected a moor near Meppen, State of Lower Saxony, on the terrain of a military site and the Tinner Dose-Sprakeler Heide Nature Reserve. Caused by missile tests of the German Army, the fire affected an area of ca. 1200 ha and considerably impacted the flora, fauna, air quality and carbon storage.[10]

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[7] Source (URL, April 2023): Wikipedia and Online news
[8] Source (URL, April 2023): Wikipedia and Online news
[9] Source (URL, June 2023): GFMC
[10] Source (URL, April 2023): Wikipedia and Second Wikipedia

Peat soils make up about eight percent of the agriculturally used area in Germany. Most recently, around 53 million tons of CO_2 emissions and thus around 6.7 percent of German greenhouse gas emissions were emitted from the decomposition of peat soils through drainage measures and peat use. With the target agreement, the federal and state governments are now creating the basis for area-effective moorland protection. By 2030, greenhouse gas emissions from moorland are to be reduced annually by five million tons of CO_2 equivalent. The most important measure for saving emissions is the rewetting of previously drained peat soil. Together with the federal states, we ensure enormous savings in emissions, because intact moors are considered carbon sinks. On 9 November 2022, the National Peatland Conservation Strategy was adopted in the cabinet. The federal government will implement effective incentive programs for peatland protection on peatlands used for agriculture on the basis of the federal-state target agreement.[11]

2. Important concerns linked to wildfires

2.1 Land degradation

The forest fire statistics of Germany reveal that the average area burned by a wildfire during the period 1991-2021 was 0.58 ha (cf. Fig.3). Compared to the fire statistics of other G20 nations, this magnitude of average fire sizes allows the conclusion that the legal provisions and measures of post-fire management are appropriately addressing rehabilitation and reforestation and thus avoiding land degradation (cf. Section 4.1).

Individual fire events, such as the aforementioned moorland fire in Lower Saxony in 2019, may affect several hundred or more than one thousand ha. Special attention is given to the rehabilitation or reforestation of larger-scale areas burned.

2.2 Biodiversity, including invasive species

Small-scale sites disturbed by fire are offering opportunities for recolonization of species, which otherwise would not find suitable habitats in densely stocked forest ecosystems.

Given the aforementioned small size of average area burned has prompted forestry and conservation agencies to take advantage of small-scale disturbances events such as fire, drought, insect infestations or extreme wind events (storms) causing wind break or wind fall.

In Baden-Württemberg State, prescribed fire has been used to create disturbance sites, which meet the habitat requirements of an endangered forest bird species – the capercaillie (*Tetrao urogallus*).[12] In 2022, the forestry administration of Baden-Württemberg State established a Working Group on Nature Conservation in Forestry, which aims at integrating aforementioned disturbances in a broader concept of biodiversity conservation (cf. Section 4.1).

The cultural landscapes of Germany – similar to neighboring countries of Europe – are hosting biodiversity-rich ecosystems that have been shaped by land use and other ecological disturbances including the use of fire in land management or fires stemming from activities such as military exercises.

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[11] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft
[12] Source (URL, June 2023): GFMC EU Life I and GFMC EU Life II

Since the 1990s, the use of prescribed fire in maintaining biodiversity-rich habitats is increasingly used in the management of open-land ecosystems. Fundamental experiments and literature is available on the online repository of the Eurasian Fire in Nature Conservation Network, which is hosted by the GMFC and provides references including experiments, conferences, reports and publications from Germany and the temperate-boreal ecosystems of Eurasia.[13] Particular reference is given to the "White Paper on Use of Prescribed Fire in Land Management, Nature Conservation and Forestry in Temperate-Boreal Eurasia" (2010) and the expertise of Prescribed Burning in Russia and Neighbouring Temperate-Boreal Eurasia.[14] [15]

Most challenging is the management of high-value conservation sites that are created by military operations during and after World War II, many of the contaminated by unexploded ordnance (UXO). These sites are posing a major challenge to the fire services because of the threat of UXO explosions affecting firefighters.[16] Special protected fire management systems are required to manage ammunition-contaminated nature reserves. A best practice example is given in the Annex.

2.3 Climate Change

Three observations provide evidence of increasing wildfire risk – (1) the long-term series of meteorological forecasts of grassland and woodland fire danger, (2) the trend of groundwater level lowering and (3) the annual assessments of forest conditions as affected by droughts and other disturbances.

2.3.1 Meteorological Fire Danger Rating

The German Weather Service (Deutscher Wetterdienst – DWD) provides grassland and woodland (forest) fire danger forecasts for Germany during the season March to October. These forecasts are updated daily and published online by DWD as well as by various other public websites. The indices use hourly data of air temperature, relative humidity, wind speed, precipitation, incoming short- and longwave radiation, as well as, at the beginning of the fire season, the daily snow depth measured in the morning. They are based on a fuel-moisture model which is the central element for calculating fire behavior. Using the micro-meteorological energy-balance and water-budget principles allow the estimation of vapor adsorption and desorption, dew formation, absorption of intercepted water, and evaporation.

- **The grassland fire index (GLFI)** describes the fire danger of cured grasslands in temperate climates in open flat terrain and is based on a single-layer model.[17]
- **The Woodland Burning Index (WBI)** model on the other hand has two intra-canopy source layers, one in the overstory at tree-crown level and the other in the understory at

[13] Source (URL, June 2023): GFMC

[14] Goldammer, J.G. (ed.). 2013. White Paper on Use of Prescribed Fire in Land Management, Nature Conservation and Forestry in Temperate-Boreal Eurasia. In: Prescribed Burning in Russia and Neighbouring Temperate-Boreal Eurasia (J.G. Goldammer, ed.), 281-313. Kessel Publishing House, 326 p. (ISBN 978-3-941300-71-2). See also: https://gfmc.online/wp-content/uploads/EFNCN-White-Paper-2010-1.pdf

[15] Goldammer, J.G. (ed.) 2013. Prescribed Burning in Russia and Neighbouring Temperate-Boreal Eurasia. A publication of the Global Fire Monitoring Center (GFMC). Kessel Publishing House, 326 p. (ISBN 978-3-941300-71-2).

[16] Goldammer, J.G., E. Brunn, S. Hartig, J. Schulz, and F. Meyer. 2016. Development of technologies and methods for the application of prescribed fire for the management of *Calluna vulgaris* heathlands contaminated by unexploded ordnance (UXO): Problems and first experiences gained in a research and development project in Germany. Naturschutz und Biologische Vielfalt 152, 87-122. DOI 10.19213/973152; ISBN 978-3-7843-4052-4.

[17] Source (URL, April 2023): Deutscher Wetterdienst

the forest-floor litter layer. In addition, soil moisture is taken into account by the model and evaporated by the vegetation.[18]

Three fire danger classes are considered depending on the region. The respective model parameters for litter and canopy represent pine forests, mixed forests and deciduous forests. At times of high litter moisture or leaf wetness and low wind speed, the risk level is low, whereas at times of low litter moisture and high wind speeds the risk level is high.

Figure 6 (a-d) displays the comparison of the average number of days with a Forest Fire Danger Index (WBI) 4 and above for the 30-years periods 1961-1990 and 1991-2020, and the individual years 2021 and 2022. The last 30 years show an average increase of days with WBI >=4 days as compared to the period 1961-1990. The year 2021 shows a nationwide distribution of elevated WBI days similar to the average of 1991-2020. The year 2022 shows a significant increase of days with WBI >=4.

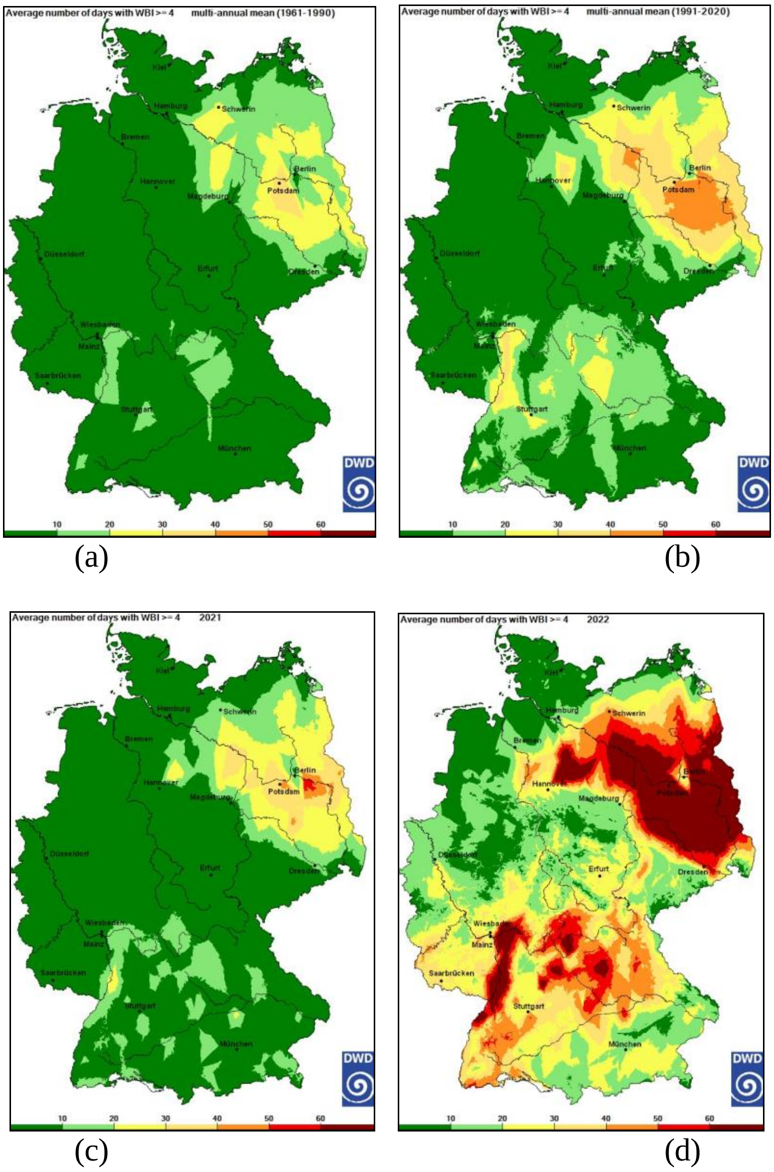

Figure 6. (a) Average number of days with a Forest Fire Danger Index WBI >=4 for the 30-years periods 1961-1990 and (b) 1991-2020, and the individual years (c) 2021 and (d) 2022. Source: DWD and German Federal Agency for Cartography and Geodesy (Bundesamt für Kartographie und Geodäsie).

[18] Source (URL, April 2023): Deutscher Wetterdienst

Figure 7 shows the average annual days of WBI 4 and above for the period 1961-2022 as well as the averages for the 30-years periods 1961-1990 and 1991-2020 as well as the linear trend 1961 to 2022.

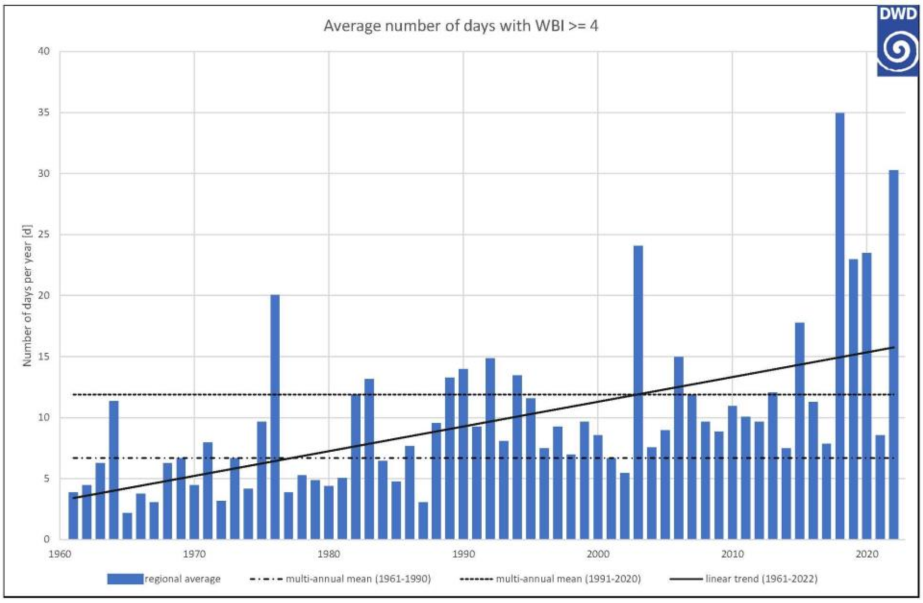

Figure 7. Average annual days of WBI Forest Fire Danger Index WBI >=4 for the period 1961-2022 as well as the averages for the 30-years periods 1961-1990 (- · - · -) and 1991-2020 (- - - -) as well as the linear trend 1961 to 2022 (──). Source: German Weather Service (DWD).

2.3.2 Groundwater Level Trends

As a consequence of droughts, the ground water level in Germany is affected significantly. Compared to the long-term mean, the frequency of months with low groundwater levels below-average is on the increase. In particular, precipitation deficits occurring several years in a row, lead to falling groundwater levels or reduced spring flows.[19]

In order to obtain an overview of the development of groundwater levels in Germany, 136 groundwater measuring points and spring flow points were selected across all federal states and hydrogeological environments, for which data are available from 1971 onwards; in respect of 96 measuring points the observation time series even date back as far as 1961. All these measuring points are in the uppermost aquifers and they are, as far as possible, unaffected by anthropogenic influences. Looking at the entire time series, it becomes clear, as shown by the mean value of all measuring points observed, especially in the course of the past decade, that there has been an increase in the occurrence of extremely low groundwater levels and very little spring flow. The number of months per year in 1971 to 2000 in which the mean of lowest groundwater levels or spring flows measured were not reached, has increased significantly since 1961. At the same time, the number of months in which the mean of the highest groundwater levels or spring flows measured long-term were exceeded, has decreased (Fig. 8). Statistically speaking, however, this trend is not significant. It is also evident that owing to weather conditions there were cyclical changes in groundwater levels at least as late as the 1990s. Such changes can no longer be found to the same degree since the 1990s.

[19] Source (URL, April 2023): Umweltbundesamt

Developments vary across Germany even though the patterns show similarities. A particularly strong trend can be seen towards low groundwater levels in the low-precipitation areas of Northeast Germany, i.e. in areas where annual precipitation amounts to less than 700mm. This situation prevails especially in the states Brandenburg, Sachsen-Anhalt and Mecklenburg-Vorpommern. However, even in regions with particularly high precipitation (annual precipitation of more than 900mm), i.e. in the uplands and in the alpine regions, it can be said that groundwater levels were clearly low. These findings would seem to require further research. Groundwater levels and spring flows were conspicuously low in the years 2013 to 2017. In view of a distinctly dry period, the data for 2018 point to the likelihood of a similar, presumably even more extreme situation arising.

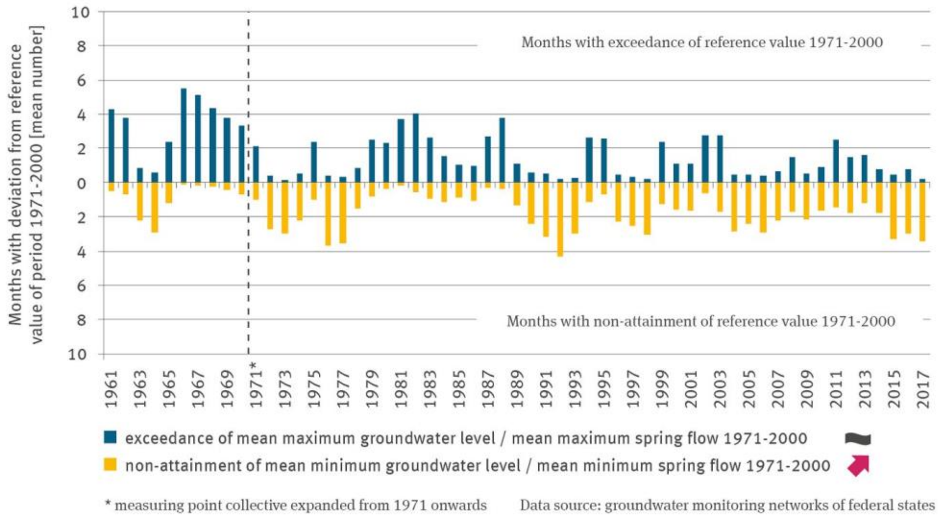

Figure 8. The column graph above the 0-axis shows the mean number of months in which the mean highest groundwater level or the mean highest spring discharge has been exceeded since 1961. The trend analysis was carried out for the time series from 1971 onwards, as the full set of measuring points is only available from then on. There is no significant trend, the development is cyclical. Below the 0-axis, the undershoot of the mean lowest groundwater level or the mean lowest spring discharge is plotted from 1961 onwards. Here there is a significantly increasing trend towards a larger number of months with undershoots. Source: Groundwater monitoring networks of federal states published by Federal Environment Office (Bundesumweltamt)

2.3.3 Forest condition inventories: Indications of change

Drought and heat stress are impacting forest health and microclimate. The crown condition of German forests is evaluated in annual random surveys. This allows changes and risks to be recognized and important decisions to be made to protect the forest. The results of the last evaluated survey of 2021 are summarized as follows:

The persistent drought in the growing seasons 2018-2020 led to widespread premature leaf drop (crown defoliation). In the case of spruce, it favored further mass proliferation of bark beetles. Compared to the previous year, the mortality rate increased again. Trees over 60 years old are particularly affected. After this bark beetle and drought damage, around 380,000 ha have to be reforested since 2018. The state of crown defoliation of forest trees is considered an important indicator of their vitality. In many tree species it improved slightly in 2021 compared to the previous year, but there is still a high level of crown thinning in all species. The proportion of clear crown defoliation and that of medium crown defoliation has fallen slightly compared to the previous year. Average crown defoliation fell from 26.5% to 25.7% for all tree species. As in 2020, the proportion of all trees with no crown defoliation is 21.3%. Oaks, for example, protect themselves from severe drought by actively shedding fine twigs, so that the tree thins out its crown and thus requires less water. When the drought is over, the tree grows new twigs.

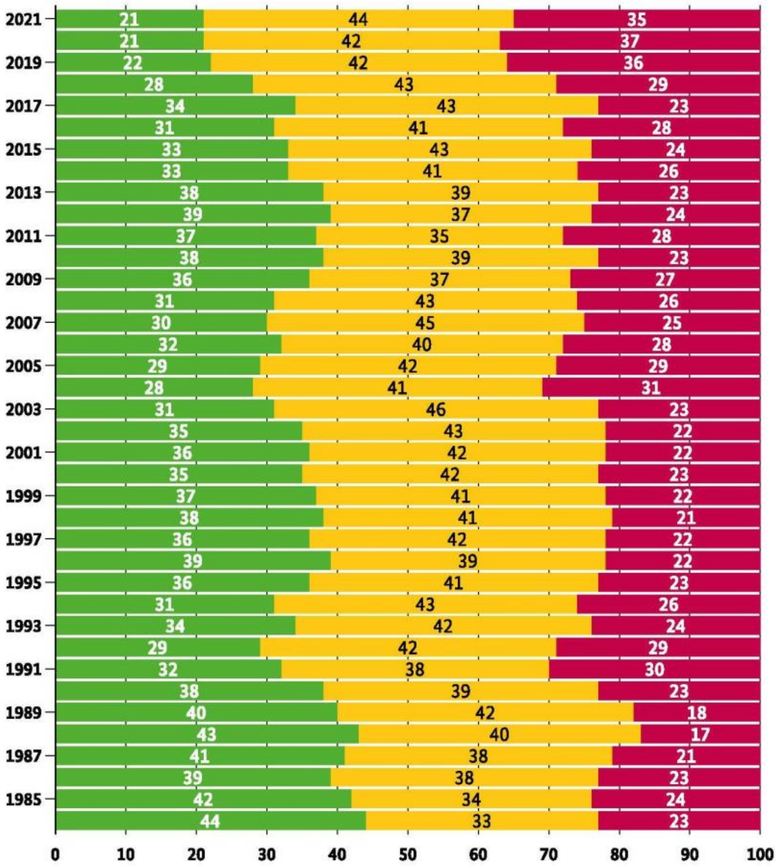

Figure 9. Evaluation of crown conditions of all tree species of German forests by annual random surveys 1985-2021 (until 1989 without new federal states). Legend: Left (green) = no crown damage; center (yellow) = alert stage; right (purple = significant crown defoliation. More details on coniferous and deciduous trees, including detailed reports by the federal states, are available in the 2021 survey. Source: Federal Ministry for Food and Agriculture 2022. Ergebnisse der Waldzustandserhebung 2021.[20]

Crown defoliation is affecting forest health and microclimate and may constitute an important factor for increasing wildfire risk.

2.4 Effect on livelihoods of resource-dependent communities

In Germany the impacts wildfires on livelihoods of resource-dependent communities is limited to forest owners and the tourism sector.

2.4.1 Forest owners

As shown in Figure 3, the average area burned per fire in the 30-years period 1991-2021 was 0.6 ha. In 2021, around 40% of forest area burned was private forest. Average economic damages of all forest fires in Germany (all categories of ownerships) were around €4,500/ha; in 2020 the average damages amounted €6,000/ha.

The Joint Task "Improvement of Agricultural Structures and Coastal Protection" (Verbesserung der Agrarstruktur und des Küstenschutzes [GAK]) is the most important national funding

[20] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft

instrument for supporting agriculture and forestry, developing rural areas and improving coastal and flood protection. The following measures for converting drought- and fire-sensitive monoculture forest stands to fire-resilient mixed forests – including rehabilitation of burned forests – are financially supported by grants:[21]

- up to 70% of expenses for mixed cultures with at least 30% deciduous trees and silver fir
- up to 85% of expenses for deciduous tree cultures with up to 20% conifers as well as natural regeneration methods.

Federal states provides additional subsidies for post-fire rehabilitation, e.g. Bavaria.[22] In Brandenburg State the state forest law regulates subsidies for private and communal forests as well as for forest management associations up to 80% of the reforestation / rehabilitation costs.[23]

2.4.2 Tourism sector

In July/August 2022, a wildfire burning three weeks in the National Park *Sächsische Schweiz* (total area 9,350 ha) covered about 115 ha mountainous protected areas. Apart of the tentative damages and suppression costs of ca. €10 million (not yet confirmed), the fires had a significant impact on the tourism sector. Between 26 July and 7 August 2022, the whole National Park was closed. Ecotourism tours, hotels and restaurants had to shut down and experienced economic losses. Most of them were compensated by a €2 million aid program for the tourism sector.[24]

3. Key Institutions involved in forest fire prevention and management

3.1 Fire danger rating

The German Weather Service (Deutscher Wetterdienst – DWD) provides forest fire danger forecasts for Germany and a 60-years archive of forest fire danger ratings, which allow to identify long-term trends of changes (cf. Section 2.3).

3.2 Forest fire prevention

Owners and managers of forests, protected areas and agricultural lands are responsible for fire prevention. National federal laws and laws of the federal states regulate the use of fire and prohibitions, respectively. In general, the use of fire inside forests, along the interface of forests and surrounding lands is regulated and widely restricted by state laws on forestry, conservation, waste disposal and emissions.[25]

After the large-scale forest fires in Germany of 1975 and 1976, many pine (*Pinus sylvestris*) forest stands, which had been established as monocultures on clearcut areas after World War II, have been successfully enriched by understory planting with deciduous trees, notably by

[21] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft
[22] Source (URL, April 2023): Bayerisches Staatsministerium für Ernährung, Landwirtschaft und Forsten
[23] Source (URL, April 2023): Land Brandenburg, Forst
[24] Source (URL, April 2023): Online News I, Online News II and Online News III
[25] Goldammer, J.G., E. Brunn, A. Held, A. Johst, S. Kathke, F. Meyer, K. Pahl, A. Restas, and J. Schulz. 2012. Kontrolliertes Brennen zur Pflege von Zwergstrauchheiden (*Calluna vulgaris*) auf munitionsbelasteten Flächen: Problemstellung, bisherige Erfahrungen und geplantes Vorgehen im Pilotvorhaben im Naturschutzgebiet „Heidehof-Golmberg" (Landkreis Teltow-Fläming). Naturschutz und Biologische Vielfalt 127, 65-95 and
Goldammer, J.G., E. Brunn, S. Hartig, J. Schulz, and F. Meyer. 2016. Development of technologies and methods for the application of prescribed fire for the management of *Calluna vulgaris* heathlands contaminated by unexploded ordnance (UXO): Problems and first experiences gained in a research and development project in Germany. Naturschutz und Biologische Vielfalt 152, 87-122. DOI 10.19213/973152

beech (*Fagus sylvatica*), aiming at changing microclimate, increasing upper soil and litter moisture and thus flammability.

Through the above-mentioned Joint Task "Improvement of Agricultural Structures and Coastal Protection" (GAK) the following additional measures in forest fire prevention and suppression preparedness can be subsidized:[26]

- Expenses for the purchase of suitable material resources
- Establishment of fire protection corridors by planting fire-resilient tree species
- Establishment and maintenance of fire breaks and fuel breaks
- Establishment of ponds and other water supply installations for firefighting

Mecklenburg-Vorpommern State is an example of federal state level regulations. The State provides similar subsidies and additionally supports the construction of forest roads for accessing water supply points.[27]

In 2021, a total of €6 million has been invested in forest fire prevention measures in Germany.[28] A new financial support instrument "Climate-adapted Forest Management" provides financial subsidies for forest owners for adjusting forests to changing climate conditions. Financial subsidies of up to €900 million will be available until the end of 2026.[29]

3.3 Forest fire suppression

The responsibility for fire protection in Germany lies with the 16 Federal States, out of which the three city States Berlin, Bremen and Hamburg have a rather limited wildfire risk.

In the 13 Federal States, which are covering large areas of rural space including forests and protected areas, the responsibility of firefighting lies with the local communities in 294 counties and 107 independent cities. In the independent cities, 110 professional fire and rescue services are providing the backbone for fire protection and disaster management. The rural communities and counties, respectively, are protected by 22,000 voluntary fire services. The voluntary firefighting work force comprises more than one million volunteers. The total workforce of voluntary, professional and youth fire service personnel amounts to 1.3 million persons.[30]

After the major wildfire in the 1970s, Germany experienced more than four decades of limited occurrence of large wildfires. This could be attributed to the prevailing temperate climate and to the generally rapid response of local fire services to a reported fire – especially in forest areas that have a dense forest road network suitable for timber transport vehicles and thus suitable for operating urban / structural firefighting vehicles.

This situation changed with the onset of extended droughts and larger and longer-lasting wildfires in 2018, especially on terrain contaminated by UXO. Since then, new efforts are underway to prepare the fire services for the increasing occurrence and likely increasing intensities and difficulties to control. A parliamentary hearing in the German Bundestag,

[26] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft
[27] Source (URL, April 2023): Mecklenburg-Vorpommern Forst
[28] Source (URL, April 2023): Bundesministerium für Ernährung und Landwirtschaft (cf. national forest fire statistics 2021)
[29] Source (URL, April 2023): Fachagentur Nachwachsende Rohstoffe
[30] Source (URL, April 2023): Deutscher Feuerwehrverband (Status: 2020)

Commission for Internal Affairs and Community, was conducted on 17 April 2023, in which experts provided recommendations for future approaches in landscape fire management.[31]

In addition to the professional and voluntary fire services, specialized volunteer teams are available, e.g. the non-profit organization **@fire**, which has a history of more than 20 years, from the founding idea to a recognized and internationally active aid organization with several hundred members, most of them professionally working in forestry and fire services.[32]

4. Restoration practices for biodiversity recovery in fire affected areas

4.1 After wildfires

Responsibilities for forest fire prevention and control are regulated by forestry laws of the Federal States.[33] Obligation of forest owners to restore fire-damaged forest stands are regulated by State laws (Tab.1).

Table 1. Permitted maximum sizes of areas without tree stocking and deadlines for post-fire forest restoration in the Federal States of Germany (Status: June 2020). Source: Agency for Renewable Resources (Fachagentur für Nachwachsende Rohstoffe – FNR)

Federal State	Permitted Maximum Sizes of Areas without Tree Stocking	Reforestation Deadline
Baden-Württemberg	1.0 ha	-
Bayern	0 ha	3 years
Berlin	0 ha	individual decision
Brandenburg	2.0 ha	3 years
Bremen	0 ha	5 years
Hamburg	0.5 ha	adequate time period
Hessen	0.5 ha	6 years
Mecklenburg-Vorpommern	2.0 ha	3 years
Niedersachsen	1.0 ha	3 years
Nordrhein Westfalen	2.0 ha	2 years
Rheinland-Pfalz	0.5 ha	5 years
Saarland	1.0 ha	adequate time period
Sachsen	1.5 ha	3 years
Sachsen-Anhalt	2.0 ha	3 years
Schleswig-Holstein	0.3 ha	5 years
Thüringen	0 ha	6 years

[31] Source (URL, April 2023): Deutscher Bundestag
[32] Source (URL, April 2023): @fire (English)
[33] Source (URL, April 2023): Waldwissen Net

In 2022, a Working Group "Forest Nature Conservation and Disturbance" was established by Baden-Württemberg State.[34] The Working Group aims at addressing dual questions:

- **Use of disturbance events to increase biodiversity through effective forest conservation**: Disturbance areas have great ecological potential because they initiate changes in the forest and can create deficient structures in the permanent forest. Disturbance events accelerate the natural dynamics of forest development and thus contribute to the preservation and increase of forest biodiversity. At the same time, the burden on forest owners from disturbance events and the associated economic losses is great. Therefore, an attempt should be made to establish a relief for a treatment of disturbed areas that is geared to forest nature conservation goals. To this end, the path for advice and implementation should be designed as simply as possible and contain financial incentives for forest owners. A catalog of risks and measures is to be developed, which is geared to practice and shows various management options for dealing with disturbed areas to increase biodiversity.

- **Make forests more resilient to natural disturbances, which will increase due to climate change**: The forest of the future should be prepared for climate change and, in the course of this, made more resilient to disturbance events. More resilient forests and forest conservation are not mutually exclusive, but can complement each other. In this way, forests with a long habitat tradition are to be identified and preserved in order to preserve or enrich CO_2 storage there, as well as to enable a spreading effect on disturbed areas. Furthermore, a greater age spread of the forests, the design of functional forest edges, a choice of tree species adapted to climate change and the avoidance of fragmentation can preserve the forest reservoir for as long as possible. The *Fach-AG Biotopverbund* has taken on the aspect of fragmentation. However, the previously mentioned topics have so far been underrepresented in the GK WNS and should therefore be considered in future revisions.

4.2 Using fire as restoration method

In the history of land-use in temperate-boreal Eurasia fire has been an important element in forestry, agriculture and pastoralism. The use of fire has contributed to shape landscape patterns of high ecological and cultural diversity, e.g. heathlands, open grasslands, meadows, and swidden (shifting) agriculture sites. In the Nordic countries historic natural fires caused by lightning and burning practises have also significantly influenced the composition and structure of forest ecosystems

The rapid socio-economic changes in the past five decades led also to a change of land-use systems and landscape patterns, resulting in abandonment of traditional land-use including burning practises. Laws and regulations of government administrations as well as the prevailing public view of fire as destructive agent of ecosystem stability and biodiversity, led to imposing of fire bans in most European countries. Air quality standards also contributed to reducing application of fire in land management.

However, since the late 1990s it has become evident that the abandonment of traditional land-use methods including historic burning practices have resulted in the elimination of disturbances, which have characteristically shaped many valuable landscape types and ecosystems. Changing paradigms in ecology and nature conservation have replaced fire-

[34] Ongoing: Results are not yet published

exclusion policies (prohibition of fire use in nature conservation, forestry and landscape management) by integrated fire management systems (cf. Section 2.2).

Since the 1990s, the application of fire in the conservation of endangered biodiversity habitats has shown successful results, notably in maintaining dwarf-shrub heathlands (e.g., *Calluna vulgaris*) and other open landscape elements. The targeted application of small-sized management fires for creating mosaic- or edge-rich habitat structures for endangered bird species, e.g. Black Grouse (*Tetrao tetrix*), capercaillie (*Tetrao urogallus*) and Hazel Grouse (*Tetrastes bonasia*), has been demonstrated (cf. Sections 2.2. and 4.1).

In Western Europe, the targeted application of small-sized fires for creating mosaic- or edge-rich habitat structures is common in the management of endangered bird species, e.g. Black Grouse (*Tetrao tetrix*), capercaillie (*Tetrao urogallus*) and Hazel Grouse (*Tetrastes bonasia*). Capercaillie habitat management by fire has been proven successful in Scottish pine-heath forests. In Germany, capercaillie populations increased in some sites of the Black Forest (Germany) that were disturbed by hurricane *Lothar* in 1999. Wind throws and wind falls, partially salvage-logged but with snags remaining, resulted in the formation of edge-rich habitat structures preferred by capercaillie. The populations began to disappear with the onset of regeneration of spruce (*Picea abies*) and the development of succession towards dense forest. Small-scale, mosaic-rich prescribed burns were used to control abundant regeneration of spruce (*Picea abies*) to maintain general openness, to create vegetation-free areas (mineral soil exposed) as refuge areas.[35] [36]

5. Role of research and academic institutions in generating relevant knowledge

In Germany, fire research projects and publications are documented since around a century. In 1979 the Fire Ecology Research Group was established at the Faculty of Forest Sciences of Freiburg University. Since then fundamental research on fire ecology and impacts in forest and non-forest ecosystems in Germany provided the necessary scientific evidence for fire management planning and decision making. Since the early 1980s the research group expanded its international work to the tropics (Latin America, Asia and Africa) and to the boreal zone with focus on Central and Eastern Eurasia. In 1990 the research group transited to the Max Planck Institute for Chemistry and remained at Freiburg University, Faculty for Environment and Natural Resources.[37]

With the support of the German Foreign Office, the Global Fire Monitoring Center (GFMC) was established as an additional function of the Fire Ecology Research Group, aimed at providing an interactive science-policy interface with countries and international organizations worldwide. In 2004, the GFMC established the UNISDR Wildland Fire Advisory Group and the Global Wildland Fire Network, and is serving since then as coordinator and facilitator.[38] This global voluntary network is providing advisory services for the development of national fire management policies, and science and technology transfer to enable nations to:

- Reduce the negative impacts of landscape fires on the environment and humanity.
- Advance the knowledge and application of the ecologically and environmentally benign role of natural fire in fire-dependent ecosystems, and sustainable application of fire in land-use systems.

[35] Source (URL, April 2023): GFMC I and GFMC II
[36] cf. Section 2.2
[37] Source (URL, April 2023): GFMC Homepage
[38] Sources (URL, April 2023): UNISDR Inter-Agency Task Force and Global Wildland Fire Network

In 2019, the Federal Ministries for Food and Agriculture (BMEL) and for the Environment, Nature Conservation and Nuclear Safety (BMU) reacted to the increasing risk of forest fires. Starting in May 2020, a total of 22 research and pilot projects are funded with a volume of €11.3 million funded by the jointly financed forest climate fund (Waldklimafonds – WKF). Most of these projects are currently in the final phase.[39] Information for the public is displayed on a dedicated website of the information and communication platform *waldwissen.net*, which is currently operated jointly by four research institutes of Austria, Germany and Switzerland and provide a special section of easy-to-read information on forest fires.[40]

6. Community involvement and engagement

The backbone of firefighting in the rural space is in the responsibility of local communities and counties (cf. Section 3.3). The total of 22,000 voluntary fire services are organized at local community level and comprise more than one million volunteers. The members of the local volunteer fire services are recruited from the population of towns and villages, as well as from scattered farmsteads. The volunteers provide best knowledge of local conditions of infrastructures, private communal assets, critical infrastructures at risk, and road networks and communication means.

The tasks for the prevention and control of forest fires traditionally lie with the forest owners and managers on the one hand and the fire brigades on the other. However, it has been recognized that sharing of joint responsibilities will facilitate the effectiveness, efficiency and safety of firefighting. In 2012, the city of Freiburg (Baden-Württemberg State) has initiated a model of sharing personnel and resources of the forest department and the local fire and rescue service with its professional fire brigade and ten voluntary fire brigades. Two voluntary teams are forming the "Task Force Landscape Fire".[41] Training, exercises and initial wildfire response are shared with forestry personnel. Forestry personnel provides the in-depth knowledge of the terrain and characteristics of burnable vegetation resources, forest road access, natural and technical infrastructure. In addition, skilled by joint field training with fire service personnel, the forestry personnel is equipped with hand tools, allowing to confine a starting fire until the fire service will intervene on site.

The interface between rural villages and individual houses and the adjoining forest is bearing a risk to private and public assets and to human health and security. In Beelitz, a town located in Brandenburg State, the application of a new model of wildfire prevention is underway to analyze and map wildfire risk and to establish wildfire protection corridors along the forest-residential interface.[42] This will include intensive thinning of corridor forests, removal of debris (removal or mechanical treatment of downed fuels and understory) and prescribed grazing.[43]

[39] Source (URL, April 2023): Fachagentur für Nachwachsende Rohstoffe (details of projects objective and implementing institutions)
[40] Source (URL, April 2023): Waldwissen Net
[41] Source (URL, April 2023): GFMC (Germany profile)
[42] Source (URL, April 2023): Online Media
[43] Source (URL, April 2023): Brandherde

7. Capacity building initiatives

Besides the institutions and groups aforementioned in Sections 3.3 and 5, a number of initiatives have been launched since 2018. Most initiatives are focusing on wildfire suppression. Local initiatives for landscape management and restoration include involvement of volunteers. However, post-fire reforestation is generally performed by forest owners in accordance with the rules as outlined in Section 4.

At international level, Germany actively contributes to the UN Decade for Ecosystem Restoration – "Preventing, Halting and Reversing Loss of Nature".[44] The agenda of the German contribution to the Decade includes a broad suite of projects.[45] The project "Restoration of near-natural forests in the Berchtesgaden National Park through natural disturbance dynamics" addresses Germany's only national park in the Alps, in which only remnants of the mixed mountain forests with beech and fir, which originally covered extensive parts of the landscape, have been preserved due to centuries of cultivation. Instead, poorly structured stands of spruce dominate today over a large area. While the forest development in the core zone is completely left to natural development, the national park in the buffer zone implements innovative forest conversion measures to restore near-natural mixed mountain forests. In the frame of the project, restoration measures follow the natural forest dynamics by using naturally occurring disturbances in the canopy (e.g. caused by wind and bark beetles) as starting points for forest conversion.[46]

Similarly, the GFMC has been conducting capacity building in using prescribed fire as a substitution tool for restoring historic cultural activities disturbances. Capacity building included personnel of the Federal German Forest Service, which is responsible for managing forests and other lands under the auspices of the Federal government, including active and abandoned military training areas.[47]

In March 2023, a coalition of voluntary groups, academic institutions and private entrepreneurs founded the "Fire Management Advisory and Support Group", which is offering capacity building for advanced fire management and support of public bodies in responding to wildfire emergencies.[48]

[44] Source (URL, April 2023): UN Decade on Ecosystem Restoration
[45] Source (URL, April 2023): UN-Dekade zur Wiederherstellung von Ökosystemen
[46] Source (URL, April 2023): Wiederherstellung von naturnahen Wäldern im Nationalpark Berchtesgaden durch natürliche Störungsdynamik (UN-Dekade zur Wiederherstellung von Ökosystemen)
[47] Source (URL, April 2023): GFMC
[48] Source (URL, April 2023): GFMC announced at Bundestag Hearing (17 April 2023)

8. Success stories

Note: In the outline of the G20 study, member states had been requested to document at least one success story on restoration example of fire-affected area. For Germany it was decided to provide two examples

8.1 Germany – Success Story I
Restoration of the forest burned in 2018 near Fichtenwalde, Brandenburg State

a. Introduction to the area

In 2018, a wildfire burned 35 ha of pine forests (*Pinus sylvestris*) near Fichtenwalde, Potsdam-Mittelmark County, located about 25 km south of Potsdam, the capital of Brandenburg State. With a share of 37% forest cover, Brandenburg State is one of the federal states with the highest proportion of forest in Germany and has the highest proportion of pine forests.

The forests of Northeast German lowlands are shaped by the last ice age, dating back 20,000 years ago. The forest areas between Fichtenwalde and the town of Beelitz are characterized by poor brown earth and sandy soils with low nutrient availability and annual precipitation between 500-600 mm. The forests are primarily characterized by the anthropogenically created pine forests.

b. Nature and occurrence of forest fires

The peculiarities of the forest fires in the South of Brandenburg are above all the extensive artificial pine afforestation, resulting of the reparation clearcuts after the 2nd World War. Large areas of these forest lands are contaminated by unexploded ordnance (UXO) stemming from WWII and the military exercises during the Cold War. The threats by fire-induced explosions of UXO play a decisive and limiting role in responding to wildfires.

After the number and area of forest fires in Brandenburg State fell sharply during the early 2000s, this changed in 2018.[49] Around Beelitz alone, 12 forest fires occurred. The largest forest fire, which occurred in June 2018 near Fichtenwalde, covered 35 ha.

c. Assessment of biodiversity

The biodiversity of tree, shrub and herb species in the pine forests, which are located adjacent to the burned area and which were not affected by the fire in 2018, is rather low. Two years after the fire, an MSc thesis in 2020 conducted an inventory on the burned area, which had been prepared for restoration. A total of 83 plant species were identified on the burned area, including 11 woody, 66 herbaceous and six moss species. In particular, the high number of species of herbaceous plants on the forest fire area differed statistically highly significantly from reference areas. A BSc thesis in 2021 followed-up the development on the same research plots and revealed a change of plant species, i.e. a shift from light-demanding towards shade-tolerant species as a consequence of increasing crown closure of pioneering tree cover.

[49] Source (URL, April 2023): Land Brandenburg, Ministerium für Landwirtschaft, Umwelt und Klimaschutz (forest fire statistics for Brandenburg State 2002-2021)

d. Technical approach to restoration

Following a mass outbreak of bark beetles (*Ips typographus*) the burned and infested stand was salvage-logged (clearcut). Reforestation started in spring 2019 by sowing pine on 70% of the area. Originally, it planting the inner and outer forest edges with hardwood species (30% of the total area) was planned. The pine seed was sown in April 2019 using a strip plowing and seed drill. The area was fenced off to reduce browsing by wildlife.

e. Challenges and limitations in achieving restoration

Following heavy rain events and heat records in summer 2019, a large part of the pine seed dried up. Parallel to the reforestation, the succession of deciduous pioneer trees with poplar (*Populus tremula*) and silver birch (*Betula pendula*) began. Due to the fast-growing deciduous trees and their degree of coverage, an emerging natural regeneration of pine was further dammed, so that the pine only accounts for a very small proportion of the regeneration.

The deciduous trees developed much faster than expected. From an economic and silvicultural point of view, it was considered to what extent further tree species could be integrated in the succession. However, these considerations were not implemented due to the effort needed in reducing the regeneration of poplars and birches. In the coming years the share of poplar will be reduced in favour of birch and black locust (*Robinia pseudoacacia*) – with interspersed pine and oak (*Quercus petraea*).

f. Replicability of the restoration in G-20 nations

As stated by the responsible local forester: “From the experiences of the natural reforestation of the forest fire area Fichtenwalde it can be concluded that we should give nature more trust and patience in the development – the process is a teaching example of the self-healing powers of nature". In accordance with the principles of “close to nature” forestry (Naturgemäße Waldwirtschaft), the post-fire natural regeneration and reforestation, respectively, will receive more attention opposite planting as was done in earlier years.

g. Illustrations

Figure 1. The mature pine stand, freshly burned in 2018. Due to post-fire mass outbreak and infestation by bark beetles, the stand needed to be clearcut some weeks after the fire.

Figure 2. The first step – planting pine seeds on the cleared forest fire area

Figure 3. View of the development of the rehabilitated area 2019 (left) and 2020 (right). After the dying-off of pine regeneration, pioneer deciduous trees (aspen, birch) became dominant

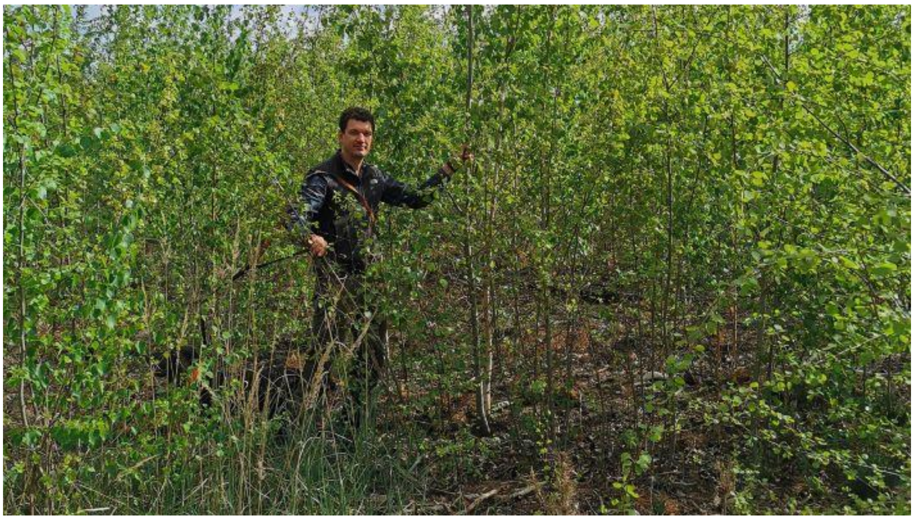

Figure 4. Succession four years after the fire (2022): The natural regeneration is taking off.

8.2 Germany – Success story II

Restoration of biodiversity on heathland conservation area contaminated with unexploded ordnance (UXO) in Brandenburg State

a. Introduction to the area

Active and abandoned military training areas in Germany, some of them in use for more than a century, have been subjected to disturbances caused by movements of military vehicles and tanks, and the direct and indirect impacts of artillery shooting and bombing exercises, often associated with wildfires started by explosive ordnance. These training areas provide valuable habitats and refugia for endangered species and open land ecosystems. Abandoned or reduced disturbances by military training have resulted in plant succession towards forest formation, resulting in losses of habitats for endangered species dependent on open-land ecosystems, notably the *Calluna vulgaris* heathlands. In some areas the desired effects of meanwhile abandoned military activities and wildfires are substituted by targeted grazing, mechanical treatment or prescribed fire.

With regard to the occurring Habitat Types (HT) of Annex I of the EU Habitat Directive, the State of Brandenburg has a nation- and EU-wide significance, particularly with European dry heaths (HT Code 4030). Abandoned military training areas in Brandenburg State cover a total area of ca. 71,000 ha Natura 2000 sites consisting of 38 Special Areas of Conservation (SAC) and nine Special Protection Areas (SPA).

The project „Development and Tests of Methods for Heath Management on UXO-contaminated Sites by Prescribed Burning in Heidehof-Golmberg Nature Reserve (Teltow-Fläming County)“ was between 2010 and 2014

The nature reserve and Natura 2000 site "Heidehof-Golmberg" is located 50 kilometers South of Berlin in Teltow-Fläming County and is a part of the abandoned military training area "Jüterbog Ost". The project site is characterized by a continental climate with an average annual precipitation of 530 mm, average temperature of 8.7°C, relatively warm and dry summers and winters with persistent frost periods.

b. Nature and occurrence of forest fires

The military use of the site started in the 19th century. From 1945 until 1992, the site was used as an artillery and air force shooting range by the Soviet armed forces. The site includes also ammunition dumped at the end of World War II, including tracer ammunition containing phosphor that are now corroding and easily igniting by high summer daytime temperatures or by fire. As part of the research and development project, the question had to be answered how the use of controlled fire for heathland management can be applied on UXO contaminated areas with sufficient safety.

Details of the historic occurrence of fires as result of military activities, which have contributed to create the high conservation value of the nature reserve, are unknown. However, it is assumed that fires have affected the terrain annually while confined to small sizes. The objective of the project included the feasibility of armored technology for setting prescribed fire by protecting the involved ground personnel and to investigate the impact and rehabilitation of heath vegetation and selected faunistic species.

c. Assessment of biodiversity

The project was accompanied with an intense ecological monitoring programme consisting of the following parts:

- Analysis of habitat and vegetation structures including Natura 2000 habitat types
- Age structure of *Calluna vulgaris*
- Post-fire vegetative and reproductive regeneration of *Calluna vulgaris*
- Biomass storage and fire-induced mass exports
- Nutrient element balance
- Mapping of key faunistic taxa, such as spiders, grasshoppers and birds
- Photo monitoring

The study design consisted of different plots covering burned as well as non-managed (reference) plots, where various parameters were measured and mapped before, during and after the use of fire.

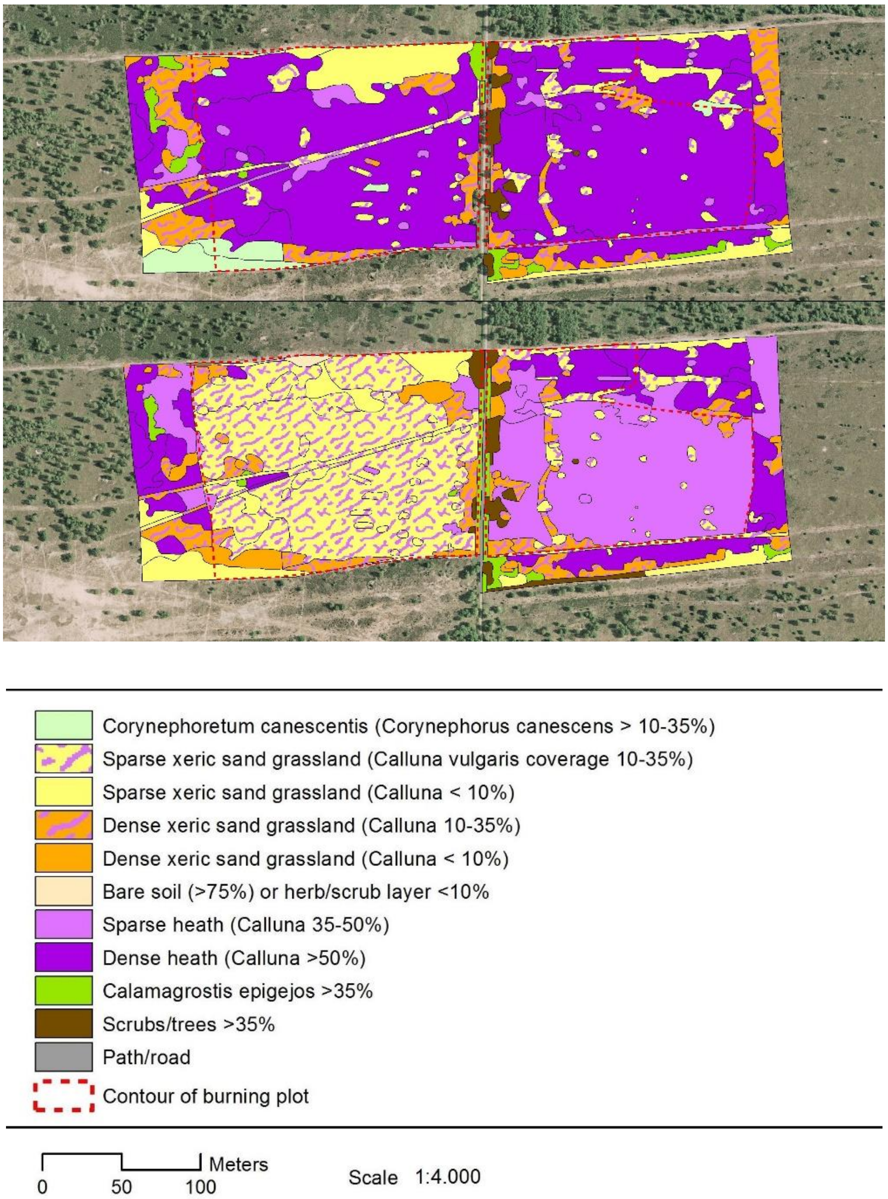

Figure 1. Habitat structure of burnt plots before (2010 – above) and after burning (2013 – below). Ten years later (2023) the vigour of heath is fully restored.

Selected key findings:

- After prescribed fire, *Calluna vulgaris* is resprouting from roots and germinating from the seed bank – in some parts of the plots a process with different pace, consequently the formation of mosaic-rich structures of micro habitats.
- Coverage of competing grasses, above all *Deschampsia flexuosa*, increases after burning and it is supposed that an effective suppression of such competing species can only be reached by high fire intensities. *Calamagrostis epigejos* did not show distinct changes in its frequency.
- A boost growth of trees and scrubs as a result of the increased bare soil ratio did not take place, so that the initial concerns are unwarranted.
- Prescribed burning led to the export of 15.2 to 25.7 tons of biomass per ha
- The amount of total nitrogen (N) was quantified as 209 or 193 kg/ha at two different plots. Here, the application of prescribed fire led to an export of 73% of the original N amount, i.e. an average of 145 kg/ha. Assuming a 15-year management cycle, this amount is almost sufficient to compensate for more than half of the annual atmospheric N intake of 15 kg/ha, as determined for this part of Germany.
- Fire management, when practiced in late winter, has a very positive effect on invertebrate communities, especially on target species of *Calluna* heathlands and sand dunes that are often highly endangered. Development of species and individual numbers are almost indistinguishable between burnt and reference plots immediately after burning, but a higher increase is seen in the burnt sites subsequently. The resulting strong elevation of arthropod densities evidently benefits the prey supply for reptiles and birds.

d. Technical approach to restoration

A protected fire ignition vehicle needed to be designed and constructed. It was decided to use a decommissioned light non-armed command tank of type BMP OT-R5. The steel armor thickness between 12 and 20 mm is able to protect the personnel against shrapnel and bomb splinters. Two types of ignition technologies were tested and successfully applied (a) The BMP is equipped with a Pyroshot Green Dragon®. The device is an automated ground-launcher designed and engineered for use in forestry and wildfire management applications such as back burning or prescribed burning; and (b) an ATV drip torch, which is used to ignite prescribed fire or back burning from off-road vehicle. For controlling (confining) prescribed burnings, a firefighting tank SPOT 55 with capacity of 11,000 liters and high-pressure monitors. With this armored equipment the prescribed fire technique can be applied on terrain contaminated by UXO. Monitoring and decision-support during the prescribed burning operation was conducted by drones.

e. Challenges and limitations in achieving restoration

The limitations for using prescribed fire in maintaining or restoring biodiversity on terrain contaminated by unexploded ordnance has been overcome with the development of fire ignition and control system allowing safe ignition, monitoring and control.

f. Replicability of the restoration in G-20 nations

The use of prescribed fire for maintaining or restoring of biodiversity in ecosystems that require fire and other disturbances can be extended to high-conservation value sites of similar characteristics as in Germany.

g. Illustrations

The Heidehof-Golmberg Nature Reserve is characterized by open dwarf-shrub *Calluna vulgaris* cover, in which birch and pine trees are increasingly invading (left), and intermixed with open sand sites and dunes (right).

Former military command tank converted to ignition tank with ignition sphere launcher and ATV. Controlling / confining of the prescribed fire by a SPOT-55 firefighting tank.

High-intensity fire resulting in exposure of UXO, which can be safely disposed after the burn.

Removal of invading trees (pine, birch) and vigorous restoration of heath after the fire.

Source and further reading:

Goldammer, J.G., E. Brunn, S. Hartig, J. Schulz, and F. Meyer. 2016. Development of technologies and methods for the application of prescribed fire for the management of Calluna vulgaris heathlands contaminated by unexploded ordnance (UXO): Problems and first experiences gained in a research and development project in Germany. Naturschutz und Biologische Vielfalt 152, 87-122. DOI 10.19213/973152; ISBN 978-3-7843-4052-4. Online: https://gfmc.online/wp-content/uploads/GFMC-Publication-RX-Burning-UXO-Terrain-2016.pdf

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