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Adaptation to Climate Change in Sustainable Forest Management in Europe

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Introduction

Climate change is ongoing and, besides the global warming trend (current global temperatures are already more than 1 degree above the pre-industrial levels), it is particularly worrying that extreme events are amplified, resulting in extended periods of hot spells and drought. The years 2018 and 2019 were exceptionally warm and dry in large parts of Europe. For example, the temperatures during the growing season 2018 deviated twice as much from the average climate compared to previous hot years (Rahmstorf 2018). With continuing climate warming, the current extreme weather patterns may soon become common and the future will probably bring even more extreme temperatures and drought spells. In recent years, European forests have been affected by severe droughts, widespread wildfires, a series of severe windstorms, and rapidly expanding bark beetle infestations, in some places accompanied by new invasive pests taking advantage of the weakening of trees through the aforementioned disturbances. Evidence is increasing that these events have become much more frequent and more threatening because of ongoing climate change. What makes this situation different from the past is not only the number of disturbances but also the extent of damage, the number of human fatalities (e.g. the Attica fire in Greece 2018 killed 100 people), and the fact that in a single year, severe disturbances occurred all over Europe, often in locations that have not experienced similar events before. It is also noteworthy that observed impacts exceeded the expectations from past impact projections (Lorenz et al. 2019), which challenges sustainable forest management (SFM) in Europe and makes adaptation to climate change necessary. Adaptation to climate change refers to adjustments in ecological, social and economic systems in response to its effects. There are various approaches to climate-change adaptation and many supporting measures need to be considered. Effective adaptation policies must be responsive to a wide variety of economic, social, environmental and political circumstances. The forestry community, as well as the public, need to understand the effects of climate change on forests and determine which adaptive actions could be taken now and in the future to respond to this threat. A high priority should be given to the coping with and adapting to forest disturbances while maintaining and enhancing the diversity and resilience of forest ecosystems.

The need for strengthening the resilience of European forests and enhancing their protection against natural hazards and human induced threats associated with climate change was highlighted by European ministers at the 7th FOREST EUROPE Ministerial Conference on the Protection of Forests in Europe in 2015.

Therefore, one of the action areas in the subsequent FOREST EUROPE Work Programme 2016-2020 focused on the protection of forests in a changing environment and their adaptation to climate change.

A group of experts nominated by signatory countries and the EU assisted the Liaison Unit Bratislava (secretariat of FOREST EUROPE in 2016-2020) in the implementation of the planned actions, namely conducting two surveys and the organisation of workshops.

Based on the work done, the Expert Group, coordinated by the Liaison Unit Bratislava, developed a set of policy recommendations for integration of adaptation measures into SFM in Europe. These recommendations form Part I of this publication.

Part II summarises the work done by FOREST EUROPE and signatory countries in this field. Results of the surveys on the existing adaptation strategies and measures implemented by countries are analysed and the publication provides country examples of adaptation-related measures and policies. Furthermore, it briefly summarizes main approaches and know-how in the field of adaptation of forests to climate change and presents main conclusions of the workshops organized by FOREST EUROPE in this work area.

Part I.

Photo: E. Hermanowicz/European Forest Institute

Policy Recommendations of the FOREST EUROPE Expert Group on Adaptation of Forests to Climate Change

Considering that European forests are increasingly impacted by recent natural disturbance developments, such as extreme weather events, outbreaks of pests and diseases, there is a need for a broader framework for climate change adaptation and pro-active disturbance-risk management. The present rate and magnitude of climate change exceeds the natural migration and adaptation capacity of tree species. Sustainable forest management (SFM) practices need to be adapted to these changing conditions by enhancing the adaptive capacity and resilience of managed as well as some currently unmanaged forests and other wooded land. Appropriate measures to support this (e.g. by increasing genetic diversity in forest regeneration, assisted migration or adopting silvicultural systems favouring structural diversity) and disturbance risk prevention should be selected based on robust scientific evidence combined with practical experience and knowledge of particular site conditions and species' requirements.

At international and national levels, legal frameworks and policies may hamper the possibility of adapting SFM practices to the changing climatic conditions, e.g. by limiting proactive forest management or transfer of forest reproductive material. Governments and institutions at all levels should establish favourable conditions for adaptation to climate change through appropriate revision of their policies (e.g. national forest programmes), guidelines for forestry practice and legislation. For example, the Pan-European operational-level guidelines for sustainable forest management (PEOLG) endorsed by European countries in 1997 would deserve an update related to climate change adaptation needs. In addition, national/international guidelines and/or legislation regulating transfers of forest reproductive material should be revised to allow assisted migration and selection of suitable provenances considering the recent and projected changes in climate.

A changing climate, accompanied with more frequent and extreme disturbances, requires a longer time horizon for the planning of adaptation measures. The efforts of governments and all stakeholders in implementation of forward-looking adaptation measures should be further intensified, taking into account projected climate change over the time horizon of rotation periods. Possible support schemes should reflect forest owners' longer-term commitments.

Governments and institutions at all levels should continue to revise, if appropriate, their policies and legislation, to allow pro-active approaches and management measures in different types of forests. In this respect, cross-sectoral coordination of policies is inevitable as climate change intensifies the extreme disturbance events that will affect all forests, including those in protected areas or protective forests, and only well-adapted and resilient forests may contribute to the achievement of policy objectives set by various policy domains.

Multi-stakeholder involvement is equally important as, for example, high ungulate population densities may hinder successful implementation of adaptation measures such as forest stand conversion. Wildlife and hunting policies, therefore, need to be adjusted to enable the development of well-adapted and resilient forests. Efficient hunting strategies, ungulate density limits and reliable game monitoring will have to be implemented, otherwise the potential of natural regeneration and a diversified tree species composition in European forests would not be achieved.

Game management should be accompanied by informing the public on the role of hunting in the SFM.

Another example is cross-sectoral land use planning aimed at the development of fire-smart landscapes e.g. through establishing natural firebreaks between fire-prone areas, managing the vegetation on abandoned land, reducing fuel load (e.g. understorey, grass layer, excessive small dimension deadwood) and optimising forest structures and vegetation mosaics in the landscapes. Cooperatives could also improve management of small and fragmented properties in this respect.

Sustainable pro-active forest management is crucial especially in disturbance-risk prevention (e.g. managing the fuel load in fire-prone areas or favouring species mixtures to mitigate insect outbreaks). To cope with large-scale disturbances, governments should continue their efforts towards advanced coordination of human and other resources (including infrastructure, machinery, etc.) cross-sectorally within countries and between countries, cooperating also with stakeholders along the whole timber supply chain.

Traditional disturbance-risk management measures often focus on emergency responses. If not coupled with appropriate prevention measures, effectiveness of such risk management is increasingly questioned (by both scientists and practitioners). Instead, disturbance-prevention measures should be more widely advocated and supported as they may also improve cost-efficiency in forest protection against risks. Emphasizing prevention efforts provides an opportunity to move towards effective climate change adaptation, while supporting the prevention measures may simultaneously contribute to other policy objectives such as promoting local livelihoods and local economies.

In addition to that, after large disturbances, there is an increased risk of secondary disturbances (e.g. insect outbreaks following storm damages) or ecosystem deterioration through e.g. soil erosion (after wildfires), an enhanced risk of avalanches and floods. These risks may be mitigated through appropriate preventive measures, e.g. early detection, rapid salvage fellings, extraction or debarking of windblown trees or building technical avalanche protection after the loss of protective forests.

As large disturbances of the same type rarely affect the same area more than once in the professional career of a forest manager, local expertise is often insufficient. The recent extreme disturbances, such as heat waves, droughts and others often affected regions where there was little experience in managing wildfires and pests' outbreaks of a comparable magnitude, which may result in delayed responses, increasing the damages. Appropriate forms of knowledge exchange mechanisms are necessary to facilitate sharing of expertise on topics such as enhancing forest resilience, fostering the adaptive capacity in the forest sector, disturbance prevention, early responses to disturbance events and recovery measures as well as gathering information in order to build expert capacity and inform policy makers.

Recent restructuring of forest management bodies in many countries, often including outsourcing of forestry operations, has resulted in the loss of skilled workforce in the affected subjects and there is a general need for training and capacity building. Particularly, there is an urgent need to improve skills in disturbance management and harvesting operations among managers and forest workers. Qualified staff is necessary to implement sustainable forest management practices not damaging remaining trees, soil and the environment in planting, tending and other forestry activities implemented to adapt forest stands. Therefore, targeted education programs at forestry colleges, universities and training courses for forest managers and workers should be developed and launched as soon as possible.

Silviculture and practical forest management

The following recommendations may fit to specific forest management regimes, national specifics, site conditions, species requirements, they are not meant to be generally applicable:

- Forest stability, vitality and resilience can be enhanced through silvicultural practices making the best use of natural structures and processes, more diverse tree species composition, higher genetic, age and structural diversity - horizontally and vertically, increased individual tree stability, tree species and provenances selection.
- Disturbance risks in intensive wood-production systems may be mitigated through shorter rotation cycles (younger stands are usually more resistant) and through selection of tree species (and provenances) better adapted to the projected climate.
- When salvage cutting is carried out, it should be considered that keeping some volume of lying deadwood may protect seedlings against soil erosion, avalanches, and browsing and, at a certain stage of decay, it may provide a seedbed for natural regeneration of some tree species, which is beneficial especially on heavily weeded areas.
- Traditional and/or innovative disturbance-prevention measures, e.g. managing ground cover vegetation by livestock grazing, advanced regeneration (underplanting) and conversion of monocultures into mixed forest stands, should complement emergency responses and forest recovery.
- Fire-smart landscape management e.g. through reducing fuel load (e.g. reducing flammable biomass such as shrub and grass layers, reducing thin deadwood), establishing natural firebreaks and re-introducing management of abandoned land.
- Use of natural regeneration after disturbance events should be preferred if sufficient natural regeneration is present on the site. However, this requires a sufficient amount of seeding trees suitable for the projected climate and expected future demands of the market and society. In other cases, natural regeneration should be supplemented with planting of suitable species or provenances, including assisted migration, where appropriate.
- Water availability for remaining trees in drier climates can be increased through more intensive tending (cleaning and thinning) which will reduce trees' competition for water. In some cases, restoration of natural water regimes by disabling artificial drainage systems may also improve water availability in forest landscapes.

Technical capacities and infrastructure

Technical capacities and infrastructure need to be developed to meet the needs resulting from climate change and increased disturbance risks.

Increased capacities of the whole forest reproductive material supply chain (seed collection, storage, transport, nurseries) is vital for both sustainable forest management and coping with large-scale disturbances. Particular attention should be given to the ability of the tree nursery sector to provide sufficient quantities of suitable forest reproductive materials necessary for forest adaptation and restoration.

Timber extraction after large disturbances is very complicated and its safety is compromised. Innovative remote sensing technologies can provide support in planning of restoration activities following such events, may enable the identification of dangerous overhanging and semi-uprooted trees before entering in a damaged forest to reduce the risk of injuries. Such information can also be useful to improve the planning of the restoration processes, reduce the costs and estimate the realistic value of the damaged wood.

Saturation of wood markets due to excess wood availability following large disturbances can be challenging. Additional limiting factors may be a lack of capacity in the transport and wood-processing sectors. Information exchange, improved logistical planning and key stakeholder involvement throughout the supply chain, should be enhanced. At the same time, the effects of climate change and resulting changes in tree species composition will require investments in processing capacity for hardwood as well as new wood products and further research on its better and improved uses.

Genetics and forest reproductive material

The use of appropriate forest reproductive material, selection of species, provenances and seed sources that are both suitable for the current and future site conditions and sufficiently genetically diverse to be self-sustaining in changing environmental conditions should be promoted.

Relevant national institutions should be encouraged to keep long-term records on the origin of forest reproductive material (at stand level) to make this information available for adaptive forest management. This information will allow to investigate the correlation between the performance of the stands, species and provenances and their origin, thus enabling the development of large-scale recommendations for future choice of climatically adapted forest reproductive material.

The future adaptation of forests will heavily depend on the improved availability of appropriate forest genetic resources. Countries should therefore collaborate to develop and implement a common strategy for forest genetic resources, with the aim to conserve the evolutionary potential of European tree species in a network of dynamic genetic conservation units.

Monitoring

Evidence-based climate change adaptation and pro-active disturbance risk management should be supported by intensified forest monitoring efforts (e.g. enhanced national forest inventories). Future efforts in monitoring should focus on immediate mapping of damage following large-scale disturbances or continuous monitoring of factors influencing disturbance risk, e.g. soil water deficits as early warning signal. With a broader implementation of forest adaptation practices, such as assisted migration, there will also be a need to monitor the effectiveness of the implemented adaptation measures.

Existing services based on Copernicus remote sensing data have been proven helpful in the risk and damage assessments and these services could be further improved. For the correct interpretation of remote sensing data, taking into account all national and local specifics, it will be essential to improve the collecting of national *in situ* information and the involvement of national experts and stakeholders.

To plan and target pro-active risk management, it is important to monitor preparedness, applied adaptation measures and the recovery progress after disturbance events.

Insect population dynamics and associated damages are currently being monitored (to a various degree) by regional and national institutions, but these data are not systematically compiled at international level. The scale and speed of recent outbreaks may require to improve international coordination on data collection. It would be also helpful to produce regular compilations of national reports on forest damage to provide countries with an international overview of the situation.

Public awareness

In the field of forests and forestry, the public should be properly informed about impacts of climate change, extreme natural disturbances events, how foresters have reacted to past damages as well as about the progress in preparation to and prevention of future damages. Map services can be used to improve public awareness of disturbance risks, recent disturbance impacts and associated reactions and measures, e.g. to communicate the management responses to disturbances via media. Communication should explain the steps to be taken in response to the disturbance and to facilitate recovery. More efforts should be directed towards communicating the characteristics that affect forest resilience (e.g. suitability of present tree species under the projected future climate, tree species diversity) to raise awareness of the general public, but also of private owners and forest managers. As most wildfires in Europe are humand induced, public awareness building (some countries refer to so-called wildfire-risk culture) is a crucial component in citizen involvement and prevention of natural hazards in forests.

Part II.

1 International forest policy context of adaptation of forests to climate change

1.1 International commitments at global level

The 2030 Agenda for Sustainable Development, adopted by United Nations Member States in 2015, provides a global high-level-policy framework for sustainable development until 2030. It contains 17 Sustainable Development Goals (SDGs) striving for a balance between the pillars of sustainable development. Among other things, it includes actions to mitigate climate change and its impacts, to strengthen resilience and adaptive capacity to climate-related hazards and natural disasters (SDG 13) as well as to protect, restore and promote sustainable use of terrestrial ecosystems (including sustainable forest management).

In order to align the global forest agenda with the highest sustainable-development framework, and enhance the contribution of forest ecosystems and sustainable forest management to achieving its SDGs, the United Nations Member States adopted the United Nations Strategic Plan for Forests 2017-2030 (UNSPF). The UNSPF provides a global framework for actions to manage sustainably all types of forests as well as trees outside the forest, halt deforestation and forest degradation worldwide. Particularly, its Global Forest Goal 1 is aimed to *Reverse the loss of forest cover worldwide through sustainable forest management, including protection, restoration, afforestation and reforestation, and increase efforts to prevent forest degradation and contribute to the global effort of addressing climate change.* Its Target 1.4 calls for significant strengthening of resilience and adaptive capacity of all types of forests to natural disasters and the impacts of climate change.

Besides that, the United Nations Framework Convention on Climate Change provides the primary international intergovernmental forum for negotiating the global response to climate change. In its Paris Agreement, the Article 5 commits the parties *to take action to conserve and enhance, as appropriate, sinks and reservoirs of greenhouse gases ..., including forests.* This should include alternative policy approaches, such as joint mitigation and adaptation approaches for the integrative and sustainable management of forests.

1.2 Commitments at pan-European level

Since 1990, FOREST EUROPE (Ministerial Conference on the Protection of Forests in Europe, formerly MCPFE) has provided a platform for dialogue and cooperation between governments in the pan-European region on how to protect and sustainably manage their forests (46 countries and the European Union).

Ministerial commitments, criteria and guidelines developed and endorsed by FOREST EUROPE serve to their signatories as a common, internationally agreed framework for sustainable forest management.

Here below is the summary of the main commitments made since 1990 at pan-European level connected with climate change impacts on forests and climate change adaptation in forest management.

1990 Strasbourg

In the **General Strasbourg Declaration**, signatory countries expressed their awareness that phenomena such as atmospheric pollution, forest fires, global warming, major climatic events or industrial accidents, erosion, damage caused by insects or other pests, or pathogenic organisms, as well as damage by game in certain regions, forest over-exploitation or even under-use, are threatening Europe's forests.

Signatories declared the will to promote and reinforce cooperation between European countries in the field of forest protection and sustainable forest management, by developing exchange of information and experience, and by supporting the efforts of the international organisations concerned.

1993 Helsinki

The issue of forests and climate change was addressed in the **Helsinki Resolution 4: Strategies for a Process of Long-term Adaptation of Forests in Europe to Climate Change.** Signatory parties considered it necessary to initiate a process of long-term adaptation and adjustment of forests and the forestry sector in Europe to climate change by means of research and other actions that are compatible with the aims and objectives of the United Nations Framework Convention on Climate Change (UNFCCC) and the Convention on Biological Diversity (CBD), as well as other relevant international commitments and/or legal instruments.

1998 Lisbon

In the **General Lisbon Declaration**, the signatories shared the vision that positive contribution of Europe's forests to the global carbon cycle will continue. They, in line with UNFCCC, committed themselves to promote SFM contributing to the mitigation of the negative effects of climate change by, *inter alia*, evaluating the respective role of forest ecosystems as carbon sinks and reservoirs combined with a growing use of the wood products with long life-cycle.

2003 Vienna

In **Vienna Resolution 5: Climate Change and SFM in Europe**, the signatories expressed their commitments to, *inter alia*, support research and, as appropriate, monitoring activities to better understand the possible impacts of climate change on forests and on their goods and services, and on their ability to reduce the extent of disasters, such as extreme weather events, including floods, as well as to enhance policies and measures, and develop forestry for a better adaptability of forests to climate change.

2007 Warsaw

In the **Warsaw Declaration and Warsaw Resolution 1: Forest Wood and Energy,** the signatories recognised the role of forests, SFM and forest products as well as the ongoing need for adaptation to climate change. In the **Warsaw Resolution 2: Forest and Water**, the signatory countries declared the concern that climate change will increase the frequency, scale and intensity of natural hazards such as floods, debris flow, avalanches, storms, and droughts and will impact the forest and water resources and their management.

2011 Oslo

In the **Oslo Ministerial Decision: European Forest 2020**, signatories recognised climate change as one of the gravest threats faced by society and stated being aware of the requirement to take urgent action to minimise risks of damage from events such as storms, floods, fires, droughts, pests and diseases in order to protect European forests and their functions. They also recognised that forests and SFM contribute to adaptation to climate change and protect society and infrastructures against natural hazards.

Signatories expressed the need to seek the best way to enhance the role of European forests in contributing to solving the national and global challenges posed by climate change, desertification, loss of biodiversity, etc.

Goals for European forests the European 2020 Targets (Oslo 2011) related to climate change adaptation:

> Goal III. Forest management in Europe is being adapted to changes in climate, forests are healthy and resilient to natural hazards and protected against human-induced threats such as forest fires, and the productive and protective functions of forests are maintained.
>
> Target VI. All European countries include strategies for forests and climate change adaptation and mitigation in national forest programmes or equivalents and all other relevant national strategies.

2015 Madrid

In the **Madrid Ministerial Resolution 2** and the **Ministerial Declaration**, the signatories stated that they were aware of the changing climate and natural hazards such as erosion, forest fires, desertification, storms and damage caused by pests or pathogenic organisms, among others, that may represent transboundary threats. They also expressed awareness of a higher resilience of sustainably managed forests and, consequently, reaffirmed the need to strengthen cooperation on the protection of European forests against the trans-boundary nature of threats and to secure the protective functions of forests.

Climate change and its associated effects, which include increasing temperatures, variability of rainfall, and more extreme events, such as storms, floods, fires, heat waves and droughts, is one of the most significant factors affecting forests on a global as well as pan-European scale.

The signatories also recognised that European forests were vital in combating climate change and that adaptation of forests to climate change would be necessary to provide their mitigating effect.

2 Implementation of adaptation measures in the pan-European region

To review the implementation status of forest adaptation measures in the pan-European region, an online questionnaire survey was launched by FOREST EUROPE in 2018 and received responses from 23 signatory countries, the European Union, and 6 sub-national regions (Spain provided one response addressing the whole country and four responses from its autonomous regions).

This chapter presents the results of the survey.

2.1 *Adaptation strategies and measures by FOREST EUROPE signatories*

In the first part of the survey, respondents were asked for information on their strategic documents related to adaptation of forests to climate change in either the whole country or subnational administrative unit. The majority of respondents reported having such documents, though many had a cross-sectoral scope.

Whereas in 2007, only four of the responding signatory countries had an adaptation policy, their number increased to 12 in 2013 and 18 in 2017 (out of 23 responding). Several countries have revised their earlier documents in recent years. Later on, some signatories complemented their cross-sectoral strategies with forest-specific documents or policies (e.g. intensifying pressure from bark beetle infestations lead to continuous updates of forest policies).

Most respondents reported having the adaptation measures supported from state budgets or the European Union Rural Development Policy, but they may also include project-based funding or, as in the case of Slovenia, free planting material provided by the state forest service to private forest owners.

One of the survey's questions asked whether the signatories would prefer a close-to-nature approach to climate change adaptation (e.g. restoration of natural tree species composition, promotion of natural regeneration, diversifying forest stand spatial structure) or an intensification approach (e.g. shortening rotations of vulnerable tree species, introduction of non-native tree species suitable for future climate, replacement of declining semi-natural forests by intensively managed stands of native and/or exotic tree species, etc.). 13 respondents (of 28) indicated a preference for the close-to-nature approach, whereas 11 signatories use both approaches. Only one respondent reported a preference for the intensification approach, three did not respond to the question.

According to the questionnaire survey results, adaptation measures and strategies in signatory countries and the European Union are as follows:

Albania adopted a cross-sectoral climate change strategy in 2019, together with an action plan, however, forests are referred here just marginally.

Austria adopted its cross-sectoral (forestry, rural development and energy) strategy in 2016, subsequently complemented with the action plan. Though forest owners have the freedom to choose appropriate measures, at the same time they are, according to national legislation, responsible for the health of their forests. The adaptation is partially supported financially as well as institutionally, e.g. through cooperation between researchers and practitioners. Both approaches, close-to-nature and management intensification (shorter rotations, intensified protection against bark beetle, lowering the forest stand density in order to reduce the water demand) are employed. As the productivity of traditionally used tree species and provenances is compromised, use of new tree species (including exotic ones) and provenances is supported. Pros and cons of particular native and non-native tree species are being discussed among stakeholders.

In **Belgium**, Flanders adopted the first adaptation strategy in 2013 (to 2020). A new integrated Climate and energy plan 2021-2030 has a weaker focus on adaptation than the previous one. However, an update of the adaptation strategy is in progress. Wallonia has no formal strategy dealing with adaptation of forests to climate change; only technical advice and capacity building. Measures in Wallonia include support to mixed stands based on the natural tree species composition, assessment of windstorm risk and forest health monitoring.

Bulgaria has a Programme exclusively dedicated to the adaptation of forests to (and mitigation of) climate change since 2011. The programing period is not defined and there is no action plan to this Programme. However, forest adaptation measures are enforced by the cross-sectoral Third national action plan on climate change in Bulgaria. The implementation of measures is supported financially as well as institutionally. Reported measures, however, cover mainly the mitigation of climate change, including afforestation of non-forest land and establishment of green zones in urban areas. In October 2019, the Bulgarian Government adopted with a decision of the Council of Ministers a National strategy for adaptation to the consequences of climate change and an Action Plan to it. The document outlines the strategic framework and priorities for adaptation to climate change by 2030. The strategy identifies and confirms the need for activities in nine sectors, including the forest sector. Bulgaria declares a close-to-nature forest management approach to climate change adaptation.

Croatia was (in 2019) preparing its cross-sectoral adaptation strategy for the period up to 2040 (with a view to 2070). As Croatia is already suffering from climate change impacts, the adoption of this strategy was considered a high priority. Some adaptation measures are supported through the Rural Development programme. The applied measures, financially supported by the rural development programme, include conversion of degraded forest, e.g. coppice to high forest[1].

Cyprus adopted the cross-sectoral (agriculture, rural development, environment) Cyprus National Adaptation Strategy in 2017, the programming period is not specified. An action plan to this strategy was adopted. Adaptation to climate change is not legally enforced, however, measures related to forest protection against fires and pests are. Partial financial and institutional support

[1] Some countries reported conversion of coppices to high forests as an adaptation measure, while, in other countries, coppice stands are considered more resilient against drought due to their better-developed root system and intensive growth, which makes them relatively suitable for intensive wood production (where accepted).

are in place. Priority is given to a close-to-nature approach (natural regeneration of native tree species of local drought-resistant provenances; the same planting stock is used for restoration of burned or degraded areas). Also the removal of invasive species, such as *Acacia saligna*, *Dodonaea viscosa*, *Ailanthus altissima*, is considered an adaptation measure.

The **Czech Republic** adopted its cross-sectoral (coordinated by the Ministry of the Environment) adaptation strategy for 2015-2020, with an outlook to 2030. The strategy is complemented with an action plan. Adaptation of forests to climate change is not explicitly enforced by legislation, but it is one of the key actions of the National Forest Programme II, in which also legislation measures are proposed. Supporting financial mechanisms include incentives and tax reliefs. The measures are also covered institutionally and informationally. Both approaches, close-to-nature (e.g. promotion of continuous-cover forestry, natural regeneration, site-native tree species) and intensification (game management, forest protection) of management are applied. Special attention is paid to the water regime and improvement of water retention in forest stands.

Finland adopted its first national adaptation strategy in 2005 and the current adaptation policy framework is described in the national adaptation plan with the programming period 2014-2022. Implementation of national adaptation policy is organised sectorally and coordinated through a cross-sectoral working group steered by the Ministry of Agriculture and Forestry. The National Forest Strategy 2025 is a key instrument for implementing adaptation actions in Finland. Adaptation actions in the forest sector are based on analyses of climate change risks and vulnerabilities of forests, forestry and other natural resource sectors. Some aspects of adaptation are legally enforced as well as financially and institutionally supported. A variety of approaches, including close-to-nature forestry and intensification of management are applied.

Georgia adopted its National Forest Concept (the first national forest policy document) in 2013 that outlines the importance of the development of strategies for adaptation of Georgian forests to climate change. It defines necessary actions that are focused mainly on preparatory stages of the adaptation (e.g. analyses, preparation of guidelines, methodical support), afforestation and promotion of natural regeneration of forest stands. The measures are legally enforced, financially and institutionally supported.

Germany adopted a cross-sectoral (environment and agriculture) climate-change-adaptation strategy in 2008, later it was further developed within the Forest Strategy 2010 and specific strategies for the German federal states. The action plan to the strategy was adopted in 2011. Some activities, such as forest monitoring and research, improvement of forest resilience through native tree species (use of non-native species is discussed) and appropriate provenances, and deer population control, are directly enforced by legislation. The measures are supported institutionally and financially, with sufficient informational means. Germany prefers the measures based on close-to-nature forestry rather than radical changes in management systems and abandonment of native tree species. Conversion of even-aged forest stands with poor resilience to more resilient stands of native tree species is one of the measures already being applied. The measure is not legally binding, but its implementation is monitored through measurable targets. Assisted migration at the level of provenances is also considered, but there are still some legal barriers in this respect.

Hungary adopted its adaptation strategy for 2016-30 as a part of the national forest programme. Some measures, namely establishing more resilient forest stands, are financially supported. There is institutional support and informational service for climate change adaptation promotion. Hungary prefers measures based on a close-to-nature approach. Measures include the new monitoring of forest health and growth pattern changes and promotion of suitable planting stock (with measurable targets). The legal obligation to use traditional site-suitable species is still in place, considered an adaptation measure, regardless its disputability as reported.

Ireland published its Agriculture, Forest and Seafood Climate Change Sectoral Adaptation Plan in 2019 by the Department of Agriculture Food and the Marine (DAFM). Priority risks and possible consequences are identified and listed in the plan. The overarching objectives of the Plan are: to ensure a joined-up approach to adaptation planning in DAFM, to raise awareness of the impacts of climate change in the sector, to reduce vulnerability of the sector to main climate change impacts and to increase forest resilience, to embed adaptation planning in sectoral policies. A range of adaptation actions have been included in the Plan to deliver on the above objectives.

Luxembourg adopted its forest adaptation strategy in 2004 as a part of the national forest national programme; an action plan to this strategy is in force. The adaptation is also a part of the new national cross-sectoral adaption strategy 2018-2023, as well as implemented into the new forest act project. Both approaches to the adaptation, close-to-nature and diversity by actions are used; the measures consist mainly of capacity building in the forest sector.

Poland has a cross-sectoral (environment, forestry) adaptation strategy for 2013-30, combining the adaptation of forests with mitigation of climate change through carbon sequestration. The action plan covers the period up to 2020. The strategy addresses the issues of biodiversity, wood supply and non-provisional ecosystem services. The implementation is enforced by legislation, supported financially as well as institutionally. Close-to-nature approaches (improving tree species composition and structure of forest stands) are preferred in Poland, however, combined with a traditionally restrictive approach to the transfer of reproductive material.

Portugal adopted its cross-sectoral adaptation strategy for 2010-20, revised in 2015. It was further elaborated into the sectoral (forestry and agriculture) strategy in 2013, which can be considered an action plan. New strategies for the period after 2020 are in preparation; a new format of the action plan is expected. The implementation of the measures is supported financially as well as institutionally. Both approaches to the adaptation, close-to-nature and intensification are applied. Measures include the improvement of forest resilience, control of invasive pests, biodiversity conservation or soil & water protection in the desertification-prone areas. There are measurable targets set for the measures; their implementation, however, is not legally binding. All these measures have been a part of traditional forestry in Portugal, now they are, to some extent, improved to fit to changing climate.

Serbia was preparing its adaptation strategy within the framework of the Project "Climate Strategy and Action Plan Project" funded by the European Union through the Instrument for Pre-Accession Assistance (IPA funds). At the end of 2019, based on the project results, the "Draft Low Carbon Development Strategy of the Republic of Serbia with Action Plan", was prepared and publicly announced in January 2020. The Strategy provides an adaptation policy framework that addresses the priority areas in agriculture, forestry and water management. However, the documents have not been adopted until the finalisation of this publication. ”

Slovakia had a previous cross-sectoral strategy (coordinated by the enviro sector) in force from 2014, though no action plan was adopted for its implementation. In 2018, a new cross-sectoral strategy was approved, the action plan to which has been in the process of finalisation in the second half of 2019. Some adaptation measures are included also in the National Forestry Program. As no institution was directly assigned to coordinate climate change adaptation, the financial support is quite unsystematic and limited. Moreover, a coordinated monitoring of the progress in adaptation is missing. Close-to-nature approach (especially promotion of native tree species and natural regeneration) has been implemented in long term. Recently, other close-to-nature practices such as continuous cover forestry and use of natural dynamics and structures have been considered a priority and promoted by the government, which will also require appropriate support measures. Besides, traditional forest protection measures (especially salvage felling and bark beetle suppression) are being intensified as a response to large-scale disturbances. However, such measures were often opposed, especially in various protected areas, by nature conservation. Adjustments of rotation periods to changing climate are included in the strategy documents, however, the measure is seldom implemented.

Slovenia adopted the cross-sectoral (coordinated by the agriculture and forestry sector) strategy in 2008, the programming period is not specified. To enforce the implementation, there was an action plan to this strategy for the years 2010-11. The Slovenian approach is, however, traditionally influenced by the forestry legislation, promoting almost exclusively close-to-nature practises, comprising continuous canopy cover, mimicking natural dynamics, natural regeneration, tree species & genetic diversity and support to ecological functions. Financial support is in the form of free planting stock for areas affected by disturbances with changed or limited natural regeneration, and free forestry service, including intensive protection of forests against pests and the control of invasive species, promotion of forest operations, monitoring, education, research and capacity building through strengthening the cooperation with forest owners.

Spain has its nationwide cross-sectoral strategy since 2006 (National Climate Change Adaptation Plan). Now, the 3rd Action Plan, which further develops the strategy (2014-20), is in force. Forests are specifically addressed, in both the National Strategy and the Action Plans. A new cross-sectorial Strategy is going to be submitted to the European Commission for the period 2021-2030. The adaptation as a whole (not specific measures) is supported by legislation (e.g. Forestry Law, 2003) and strategic documents (Spanish Forests Plan). Some measures are supported financially (through different projects). There is a sufficient institutional framework for development of measures; however, the implementation of the measures remains challenging. There is a special cross-sectoral platform (https://www.adaptecca.es/) for exchange of relevant information. Both approaches, close-to-nature and intensification of management, are employed, depending on the forest function. The national level measures include elaboration of guidelines, selection of proper genetic resources for re- and afforestation, promotion of agroforestry and water retention, restoration of burned areas, promoted conservation of genetic resources and adaptive forest management, PIMA-Adapta Ecosystem Plans in National Parks. In Spain, the autonomous communities (regions) have their own adaptation strategies and additional measures, as they are responsible for forest management. These measures include, among others, promotion of agroforestry systems, developing fire-prevention plans, implementing fire-prevention measures (such as decreasing fire load, prescribed burning, division of forests), afforestation of vulnerable soils, planting of proper tree species, new monitoring schemes, diversifying tree species composition, intensification of forest protection, managing age and spatial structure of forests, etc.

Sweden adopted its policy on climate change in 2003 and revised it in 2009 and 2019. In 2018, this policy was complemented with the action plan of forest adaptation to climate change. The effectiveness of the institutional framework for development of measures has been disputed; however, most of the new forest policies are implemented with soft methods in Sweden. From 2019, a new regulation on climate adaptation provides an institutional framework for a range of authorities, including the Swedish Forest Agency. Adequate attention was paid to information campaigns between 2009-2015 (one-day courses, evening seminars and personal advice) reaching around 7 % of c. 300 000 forest owners and officials. Also web-based advice, films and printed material were developed. Examples of both approaches to adaptation, close-to-nature and intensification of management can be found in Sweden, such as the diversification of tree species composition and a shortening of rotation periods for Norway spruce to avoid storm-damage and spruce beetle attacks. A range of measures, however, cannot be assigned to these categories. There are measures tailored to the changing site conditions and increased pest risks, such as improved use of drought resistant pine on dry sites, use of strong, early thinning of stands to improve wind resistance, improved knowledge-based game management to promote the establishment of mixed stands for improved pest resilience, biological treatment of stumps to reduce the spread of root rots, maintenance and improvement of forest connectivity, improving road network and use of machinery less harmful to (unfrozen) soils, etc.

Switzerland adopted its adaptation strategy in 2011 as a part of Forest Policy 2020 (this strategy is coordinated with some other sectors). It also has a special climate change adaptation strategy covering all sectors. There are action plans for both these documents. Climate change adaptation is, in some respect, enforced by the federal legislation. Measures are supported financially and institutionally, there are also necessary informational means. A close-to-nature approach is applied in all Swiss forests. Measures include federal support to close-to-nature forestry, biodiversity and genetic diversity, especially in the field of improving knowledge, development of methodologies, guidelines and tools.

Turkey has its cross-sectoral adaptation strategy for the programming period of 2011-23 with an action plan adopted. The National Forest Ecosystems Monitoring and Assessment Program provides the data and information derived from systematic large-scale monitoring as well as intensive monitoring at permanent plots to assess the status and trends of forest ecosystems and their responses to environmental change due to biotic and abiotic agents. The generated respective data and information are also used in assessing the climate change effects and directed at the policy makers of Turkish Forest Service for drafting the adaptation strategy towards the measures by national financial mechanism.

Besides species and gene diversity studies and monitoring, and land-use change monitoring, the ecosystem based forest management planning with particular concern to the close-to-nature approach is preferred in Turkey.

In December 2016 **Ukraine** adopted the conception of implementation of state policy in the scope of climate change for the period of 2016-30, complemented with an action plan. Climate change adaptation is not yet enforced by legislation, but the development of a national climate change adaptation strategy and regional climate change adaptation plans were recently identified by the Government as one of the priorities for reform and effective governance. The adaptation is institutionally supported; informational means are in place. Both approaches to the adaptation, close-to-nature as well as an intensification of management, are employed.

At transnational level, **the European Union's** *EU Forest Strategy: for forests and the forest-based sector COM(2013) 659*, included 'Forests in a changing climate' as one of the priority areas, in which it highlights the importance of maintaining and enhancing the resilience and adaptive capacity of forests, for example, through fire prevention and the selection of appropriate species, plant varieties, etc.). The EU policy tools being in place ensure the contribution of forests to mitigation (LULUCF Regulation) and adaptation to climate change (EU Adaptation Strategy). The *EU Strategy on adaptation to climate change COM (2013) 216* has the overall aim to contribute to a more climate-resilient Europe. This includes enhancing the preparedness and capacity to respond to the impacts of climate change at local, regional, national and EU levels, developing a coherent approach and improving coordination.

The EU Common Agricultural Policy continues to be the main source of support for the protection and the sustainable management of EU forests, among other things, on fire and natural disasters prevention, restoration after damage, investment for climate change adaptation and provision of environmental or amenity services. In addition, the European Innovation Partnership for Agriculture's (EIP-AGRI) focus group "New forest practices and tools for adaptation and mitigation of climate change" produced a number of positive results, which can serve as the basis for establishment of new "operational groups" under the Rural Development policy.

In the field of plant-health protection, new EU legislation *"Regulation (EU) 2016/2031 on protective measures against pests of plants"* aims to ensure safe trade, as well as to mitigate the impacts of climate change on the health of crops and forests.

The *EU Civil Protection Mechanism* supports forest fire prevention through risk assessments, management plans, early warning and alert systems and awareness raising. The Emergency Response Coordination Centre (ERCC) monitors forest fire risk and incidence for coordinated and quick response, supported by the European Forest Fire Information Systems (EFFIS).

2.2 Adaptation measures by sub-regions

The range of adaptation measures in the particular countries and (sub-)regions underlines the diversity of climate-change-induced challenges and the need for developing locally adapted measures and solutions. While some adaptation measures may be applicable to (almost) the whole of Europe, others are specific to bioclimatic conditions that vary by latitude and altitude, often even within a sub-region. To analyse such differences across Europe, the reported challenges and measures were grouped into five sub-regions briefly described below.

North Europe

There is a recognition of changing weather patterns influencing forest operations, e.g. insufficient freezing of forest soils in winter and increasing storm intensity. Measures commonly proposed include earlier and more intensive thinning, shorter rotation periods, and improved forest management planning (higher flexibility and effort to increase mixed stands proportion). Increased temperatures, combined with increasing storm damages, trigger extended bark beetle infestations and more frequent fungi infections. In this respect, diversification of tree species composition at the stand level is proposed as the main adaptation measure. Increased winter temperatures, however, also lead to increased game survival, which causes increased browsing damage that undermines the regeneration of some desirable tree species.

Central-West Europe

Poor adaptation of currently grown tree species to the actual and future site conditions is a common issue. Many forests consist of spruce and pine species grown in even-aged monocultures, partially even stands of exotic conifers. Measures to tackle this problem depend on the silvicultural system. The most reported is the introduction of site-adapted species, especially broadleaves. These species should be brought into stands by either under-planting, planting and sowing after clear felling or through natural regeneration. The most frequently mentioned measures include an extensive use of tree species native to a site, their suitable provenances and genotypes. Germany reported bringing in species or provenances from the southern parts of Europe (so-called assisted migration) or introduction of non-native species suitable for the future climate and/or resistant to local pests and diseases. For example, Douglas fir is used to replace under-performing Norway spruce in lower mountains in Austria, which is, however, often opposed by nature conservationists, who are critical towards introducing non-native tree species.

Central-East Europe

Increased storm intensity, droughts, fires and pest outbreaks are particularly (though not exclusively) widespread in stands with unsuitable tree species managed with even-aged silvicultural systems. A wide range of challenges, such as a decreased forest health and productivity, may relate to the increased forest risks or, locally, lack of resilience of unnatural stands. Measures most prominently mentioned in this respect include conversion to mixed stands with a higher proportion of site- and climate-adapted broadleaves. Water retention and its improved distribution in the landscape was prominently mentioned by the Czech Republic, with the aim to support drought relief and forest fire prevention.

South-East Europe

Some countries of the region lack the institutional framework for the development of climate change adaptation measures and its implementation in sustainable forest management. In several cases, no informational means for the transfer of adaptation-related scientific knowledge and the promotion of the respective political decisions are in place. Increasing the monitoring and research of the effects of climate change are often mentioned as beneficial measures. Forest fires, increasing pest populations, and land degradation were reported as the biggest direct threats. Especially for the first two, the contributing factors include a lack of a quick and coordinated response mechanisms and insufficient access to forests, which lead to higher losses than necessary. Measures to tackle these include establishing mixed stands of native or site-adapted species and improving forest road networks.

South-West Europe

Fires, forest degradation and desertification are perceived as the biggest threats to the region. Intensified research and monitoring, forest restoration and selection of species suitable for a given fire risk, are proposed as measures to tackle these problems. Stimulating local organisations of land owners and cooperation between forest managers to better take care of unmanaged forests, (especially as regards extraction of flammable materials) and to upscaling forest products are seen as important and requiring capacity building. Many respondents mentioned promotion of traditional management, for example re-introduction of agroforestry (e.g. grazing in forests reducing fire risk), however, agroforestry products will require to be marketed. This would increase land productivity to the benefit of the local economy that can also contribute to the adaptation of forestry to the new climate. The traditional land management practices often represent both lower fire risk with reduced fuel loads and higher biodiversity.

Important considerations for climate change adaptation in forests

The received responses varied substantially in overall focus and details. However, the compilation shows some common climate change adaptation related issues:

i. the state of forests (e.g. unsuitable tree species composition[2], simplified age and spatial structures) limiting their resilience and making them more vulnerable to climate change,

ii. the importance of pro-active forest management and of the necessary forest infrastructure,

iii. the urgency of considering extreme weather events and their consequences and to address various forest disturbance risks such as outbreaks of pests and diseases,

iv. information deficits limiting the adaptation capacity of the forest sector and its response options; monitoring of extreme weather events and corresponding damages should therefore be improved to provide an evidence-base for informed decision making.

[2] Tree species composition unsuitable for the projected climate can include non-native tree species planted in the past but, sometimes, also of native species that are now suffering due to climate change.

3 Climate change adaptation know-how, needs and challenges

To complement the information from the first questionnaire and thus improve its interpretation, the FOREST EUROPE Expert Group on Adaptation to Climate Change carried out a second qualitative survey among the expert group members to subjectively evaluate the recent forest disturbance impacts and the suitability (and limits) of existing adaptation measures. The survey was open in March 2019 and 23 responses were collected from 11 countries (some of them did not answer all the questions).

The first set of questions elicited the expert's opinions on the intensity of climate change impacts over the last 10 years, whether these were in line with their expectations, and what type of adaptation knowledge has been developed during this period. The focus was on the last decade to review new knowledge since the previous assessment carried out in the COST Action ECHOES (Kolström, et al. 2011).

Two further questions explored whether the experts considered the currently adopted measures appropriate and sufficient to deal with the observed changes, and where they saw gaps in the existing portfolio of adaptation measures.

3.1 Observed climate change impacts and evolution of climate change adaptation know-how

Observed climate change impacts reported by the experts were almost entirely related to extreme events and subsequent disturbances. The impacts were associated with dieback waves following droughts, ice and wind breakages, and subsequent bark beetle outbreaks (e.g. reported from Serbia). The exceptional number and extent of forest fires was highlighted by Sweden. More extreme droughts were pointed out as a major phenomenon in several countries and the invasions of new pests and diseases were associated with climate change in several countries. Two thirds of the experts stated that the observed increased impacts exceeded their expectations (21 Experts from 9 countries responded).

The climate change pressure on forests has been known for many years and the dual role of forests acting in climate change mitigation on the one side (Canadell and Raupach 2008, Kurz, et al. 2016, Nabuurs, et al. 2017) and as climate change victims on the second, is well documented (Lindner, et al. 2010, Lindner, et al. 2014). Following the drought in 2003, climate change begun to be perceived as a threat, especially to the tree species growing outside of their ecologically defined range, and the view was expressed that foresters need to have forests adapted for an entire rotation period (i.e. several decades). However, over the last decade, the immediate threat to forests has increased and the area of damaged forest within only a few years is becoming a major reason for concern.

The main adaptive forest management options have been identified many years ago (Kolström, et al. 2011, Spittlehouse and Stewart 2003,Bernier and Schoene 2009, Bolte, et al. 2009, Brang, et al. 2014), however, their better implementation still remains a major challenge. Although it has been repeatedly recognized that the projected climate change impacts will require adaptation of existing forest management practices, the most common adaptive management response is a modified recovery after disturbances. Pro-active adaptive measures have received increased attention only recently, especially in terms of appropriate tree species selection, for example in Central European countries. The change in the perception of urgency of adapting tree species composition to the changing climate has been driven in this region by the unprecedented scale of bark beetle outbreaks. There is also improved understanding of drought risk and its possible mitigation through appropriate regeneration techniques and thinning practices.

Whereas increasing bark-beetle pressure affects forests also at higher altitudes of the Alpine region, productivity of trees in this zone is increasing as well, and the site conditions remain well within the ecological envelope of the presently dominant tree species. Therefore, no adaptation measures are immediately inevitable but may become pertinent in the future once signals of destabilization of mountain forests emerge under continuing climate warming.

3.2 Higher intensity of already known and emerging threats - lack of resilience

The intensity of forest damage in recent years has increased more than expected as the climate change induced extreme weather events were severer than previously projected. A few years of consecutive droughts were enough to severely decrease stress tolerance of trees and stands. In addition to the droughts, other extreme weather events were experienced, including windstorms and ice breakages. Similarly, the number of forest fires in boreal and temperate forests increased and severe, rapidly spreading fires, often labelled as megafires, occurred in Southern Europe. The forests, hitherto considered stable, proved to be less resilient than expected, and high rates of mortality due to biotic and abiotic damages were recorded.

In its third meeting in April 2019, the Expert group discussed whether the currently implemented measures were suited to deal with these intensified impacts. It was mentioned that the ongoing bark-beetle outbreaks are out of control, especially in the areas near the borders or outside of the ecologically defined range of Norway spruce. The most common response after disturbances is creating more diverse stands, which undoubtedly increases forest resilience, but not necessarily also productivity. The recent extreme weather with heat waves and extensive droughts resulted in widespread decline of Central European forests – the phenomenon, which was not expected so soon based on simulations of climate change (in the majority of scenarios they were projected only after 2050).

Often, there seems to be capacity to adapt forests fast enough to rapidly changing climate. In even-aged forests, stand composition conversion towards e.g. drought-tolerant tree species requires at least several decades due to the long rotation periods. In uneven-aged forests, the introduction of missing tree species through underplanting is less commonly practiced and, for some species, it may be unfeasible.

The best approach to enhance adaptive capacity of the ecosystem to climate change is gradual increasing the diversity at different levels from tree genetics to landscape structure, however, such measures also require a long time to show results, while their short-term impacts are limited.

Thus, the largest short-term challenge for adaptive forest management is to enhance forest resilience to cope with forest disturbance risks better and to increase efforts in risk prevention and preparedness.

3.3 Application and prioritization of state-of-the-art adaptation know-how

Adaptation measures can apply to different development stages of forest stands, however, as shown by Oliver and Larson (1996), the initial stage is crucial for the reconstruction of forests and thus for pro-active and passive adaptation measures, respectively (see Box 1). In this stage (in planted forests), decisions on tree species and provenance selection are taken that, in the best case, may enhance forest resistance and resilience in the long term. In the past, tree species selection often used to mean the choice of one or two site-adapted and performant species to utilise the soil productivity. Many of these biomass-centred business-as-usual models did not consider risk factors adequately. A few decades ago, tree-species-rich (complex) forest stands became a widely accepted paradigm to counteract risks associated with planted even-aged coniferous forests outside of their natural distribution range. Mixing different species, ideally with diverse and complementary ecological characteristics, leads to more resistant and resilient stands that are expected to facilitate adaptation to climate change (Brang et al. 2014). For example, tree species differ in their rooting patterns and a mixed stand with shallow- and deep-rooting species enables more effective use of soil water. Species diversification encompasses the use of many native (mostly broadleaved) tree species but also the reasonable use of non-native species. However, considering the already observed intensification of droughts in some parts of Europe and subsequent decline of several tree species due to the changing site conditions, it seems to be no longer possible to rely exclusively on locally present native tree species. There is an increasing evidence that a reasonable admixture of non-native tree species can increase forest resilience in the regions where natural forests are species-poor (see case Denmark, Box 1). Furthermore, provenances of native tree species from warmer parts of the species' distribution range could enrich genetic diversity of forests and thus increase their resilience. Especially these "rear-edge populations" (Hampe and Petit 2005) of native species often show desired adaptation traits, such as higher drought-stress tolerance compared to provenances from the core distribution area of a species.

In the past, legislation on the use of forest reproductive materials used to focus strongly on selecting local provenances and, in several countries, the use of non-local planting stock used to be prohibited. With an increased risk of decline of previously site-adapted populations, observed in the current stage of climate change (which is expected to further aggravate), it seems inevitable to abandon this rule. Assisted migration, the artificial translocation of provenances and species (Williams and Dumroese 2013) beyond their natural ranges, typically to higher latitudes and altitudes, provides a wider choice of site-adapted trees suitable for the projected climate. At the same time, forest stands must be able to withstand present climatic conditions (including still rather harsh winters), especially while young. A precondition for successful assisted migration is that the original genetic pattern in the source tree-species population was not overprinted by human intervention.

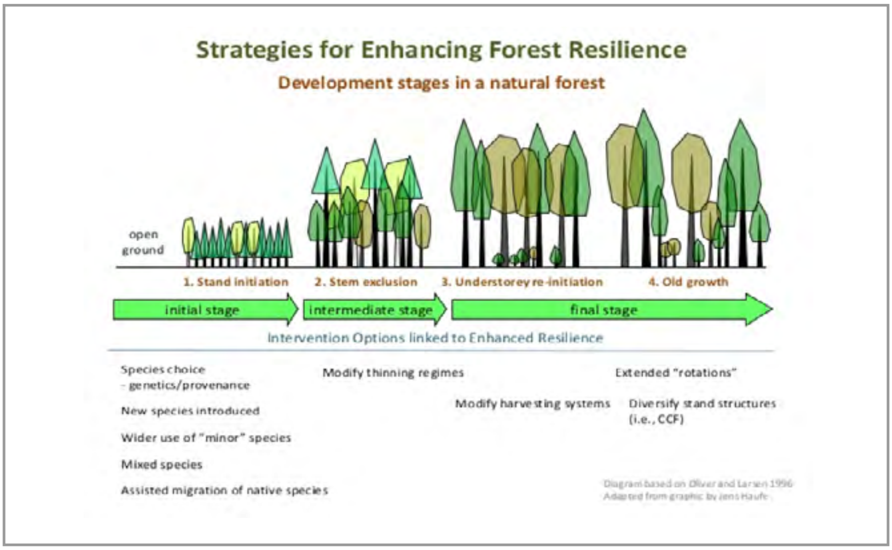


Figure 1: Model of development stages in a (semi)natural forest and possible adaptation measures (after Oliver & Larson 1996)

Box 1: Forest conversion in Denmark

Denmark has two main soil types and two dominant forest management types. Loamy soils prevail on the islands and sandy soils on Jutland. Whereas beech is more abundant on the islands, Sitka and Norway spruce dominate in Jutland. Traditional management with clear-cuts and replanting has been applied for both beech and spruce stands. Rotation age is 100-120 for beech and 60-70 for spruce.

Danish policy has changed since the late 1990s. Close-to-nature management (Larsen, 2012) is now obligatory for all Danish state forests. Forest stability and risk diversification towards climate change and weather extremes were amongst the main drivers for this change. In private forests, the application of close-to-nature management is still not as common as in public forests, but the general tendency is towards natural regeneration and continuous-cover-forestry. This is considered easier on the loamy soils and with beech as the dominant species, than on the sandy soils with the spruce species. However, with increased nitrogen availability, increased seed rain, cost saving aspirations and changing management ideas, the conversion towards continuous-cover-forestry is progressing also in areas with traditional spruce management.

Underplanting and gap filling with beech and silver fir has proven to be the easiest way to stabilisation of hitherto vulnerable spruce monocultures. In the state forests, it is now widely applied. As the implementation of these measures has started just 20 years ago, it cannot yet ensure a decreased impact of drought/bark beetles/storms. However, the conversion is starting to show its positive effects on stand stability and productivity. On the other hand, the reduced risks come with considerable costs, because spruce yields a higher profit at the mill and could be managed with shorter rotations. Best examples of this management can be seen in Himmerland Skovdistrikt.

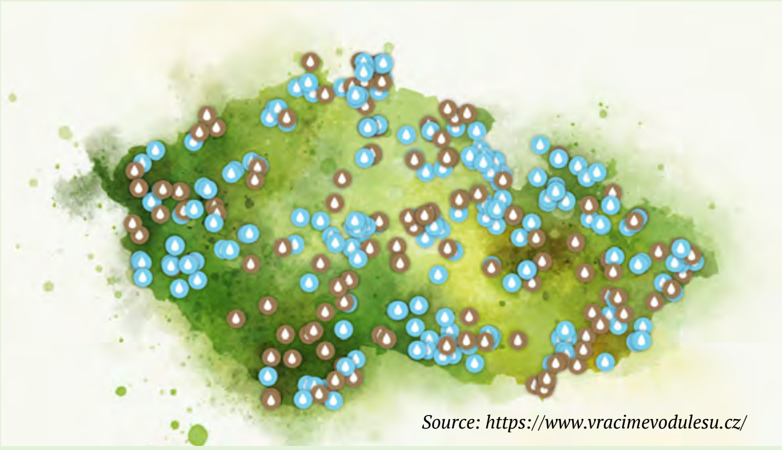
The best opportunity to enhance the adaptive capacity of forests is during a regeneration period (including advanced regeneration) and in the early stand-development stages. Later on, tree species composition can be just partially manipulated through stand tending. Thus, individual trees and tree species with a good adaptive capability can be favoured at the expense of vulnerable individuals and species. In mature stands, the most vigorous and healthiest trees, well adapted to the site, should be identified and selected as the future seed trees (standards) to deliver genes to the future generation.

Box 2: "We are returning water to forests" – a nationwide program of the state enterprise Lesy ČR, which manages 45 % of the forests in the Czech Republic

"We are returning water to forests" is a nationwide program aimed at implementing measures for enhanced water retention in the Czech forests. Achievements of this program include building and restoring small water reservoirs, wetlands and restoration of meanders. A total budget of 1 billion CZK (ca. 38.5 mill. EUR) has been allocated for the realisation of the measures.

The dissemination part of the programme highlights the important contribution of forests for:

- Supporting the formation of precipitation[3]
- Serving as a natural cooling system
- Provisioning of groundwater
- Creating air and moisture flows
- Reducing and slowing down surface water run off



Source: https://www.vracimevodulesu.cz/

Another focus in adaptive sustainable forest management is improving soil water (moisture) management at landscape level. Climate change scenarios project a negative water balance during the vegetation season over large parts of Central Europe by 2070. Thus, improving the water retention in forest landscapes (Box 2) and enhancing the water storage in soils deserves

[3] Forest undoubtedly have an influence on precipitation formation (e.g. Ellison et al, 2017), however, the issue is too complex (with many uncertainties in distribution of precipitation gains and losses) to be recommended generally as a measure to change precipitation pattern in a particular area.

more attention[4]. Appropriate adaptation measures include the admixture of broadleaves to coniferous stands to increase the content of organic carbon in the mineral soil. Some research results also suggest that rising the share of deciduous species enhances water infiltration into the soil in winter and early spring through reduced water interception in the leafless period and larger stemflow of water into the soil (Müller 2009).

The proper management of forests can optimise the water availability for individual trees through changes in forest microclimate (especially of those with dense canopy). This can contribute to mitigation of water deficits. Specific measures include:

- suppression of water-consuming consuming herb layer;
- intensive thinnings to redistribute the limited amount of water in favour of fewer trees;
- appropriate combining of tree species (e.g. oaks with their deep roots can use soil water from deeper and, to some extent, redistribute it to higher soil horizons where used by shallow-rooting species, thus increasing their resistance to drought through hydraulic water lift (Anderegg et al. 2018).

3.4 Societal demands affecting acceptance of adaptation strategies

Conflicting preferences, particularly between forestry and nature-conservation stakeholders (and similar opinion differences between people living in rural and urban areas), have important implications for the acceptance of management strategies responding to climate change and increased disturbance risks. Forestry is increasingly criticised by society asking to stop or limit felling trees in protected areas[5] (and many times also outside them), even if caused by forest disturbances. Frequently, disputes arise if salvage and sanitary cuttings are acceptable (or necessary) in the case of windthrows and pest outbreaks in protected areas (e.g. Natura 2000 sites or sites of national networks of protected areas). While these measures aim to mitigate secondary disturbances, the spread of bark beetles in spruce forests surrounding damaged areas, some nature conservation stakeholders see the decline of spruce as an opportunity to naturally improve tree species composition. However, spruce is native in many protected areas[6] and, in such cases, its decline may contribute to ecosystem degradation.

When planning the post-disaster responses, especially in protected areas and protective forests of various categories, numerous factors should be therefore taken into consideration. On the one hand, any damaged forest can recover from the disturbances without human interventions through natural succession. Salvage cuts undoubtedly have some negative impacts on nature conservation values or, in certain cases, also on protective functions. On the other hand, the main purpose of salvage cutting is to prevent the large-scale secondary forest damage also

[4] Forests can improve water infiltration to soil, however, they are also important consumers of water, which might be evident especially in dry areas. Water interception by forests can also significantly reduce the amount of water reaching soil surface, though this depends very much on the tree species and the structure of the forest. Dense and multi-strata canopy, in general, intercept more precipitation, and there are important differences between deciduous and evergreen tree species. For further reading see, for example, SFM Toolbox of UN FAO at http://www.fao.org/sustainable-forest-management/toolbox/modules/forest-and-water/further-learning/en/ or IUFRO publication at https://www.iufro.org/fileadmin/material/publications/iufro-series/ws38/ws38.pdf

[5] The public does not necessarily distinguish between strictly protected and actively managed protected areas. The case of Bialowieza forest even shows that the public considered all the forests in Bialowieza protected, including those outside protected areas of any category.

[6] See, for example, the Interpretation manual of European Union habitats (European Commission 2013)

having impacts on biodiversity, and resulting in loss of some other societally appreciated forest ecosystem services such as improvement of air quality and microclimate, reducing water runoff, protection of infrastructures etc. Salvaging may also be necessary around hiking trails, even in protected areas, to ensure visitor's safety. In large areas damaged by windstorms, extraction of slashed timber reduces fuel loads and enables artificial regeneration.

Whereas salvaging the damaged trees immediately reduces the carbon storage in the forest ecosystem, in the long term most of the deadwood carbon would be released to the atmosphere anyway. On top of that, wood utilisation has the potential to enhance the amount of stored carbon in harvested wood products, especially in long-lived products (e.g. in wood construction), and offer substitution effects (Jasinevičius, et al. 2017, Leskinen, et al. 2018).

Stakeholder views may differ also in the acceptance of the use of prescribed burning in order to reduce wildfire risk, intensity of game management, pesticide use in forest protection, or the species selection for reforestation (particularly the use of non-native species). Participatory multi-stakeholder engagement and better communication of the issues at stake could help identifying compromises with broader public acceptance. In some cases, especially in protected areas, debarking of timber slashed by windstorms may provide a win-win situation - keeping deadwood in the area, but reducing bark-beetle outbreaks in surrounding forests. This, however, brings other implications regarding the high costs, availability of workforce as well as occupational health and safety, which have to be considered as well.

3.5 Adaptation challenges for the timber industry

The challenges and consequences of climate change on the timber industry are only starting to be recognised. Presently, huge volumes of salvaged wood are swamping the market and the sawmill industry is working at maximum capacity. However, when forest decline affects entire regions, the industry may be flooded by timber initially and start lacking timber a few years later. Trees which are now being pre-maturely harvested will cause a deficit in the future. Though, in the short term, timber industries (sawmills, bioenergy, pulp and paper) can acquire the raw materials at low prices, the situation is not sustainable. Forest owners are increasingly seeking new markets for the salvaged timber abroad, with roundwood exports to China as a prominent option, thus moving a large share of the potential added value outside of the regional economy. Exporting the regional timber production is jeopardising the effectiveness of the policies aimed at strengthening the economies in rural regions, where timber production together with its related wood processing are essential pillars.

To mitigate these mid-term trends in the forest-based industry and their adverse impacts on rural economies, it is necessary to search for technological solutions making the industry resilient and at the same time prepared for replacement of declining tree species by the species being better adapted to the changed climate. To mitigate climate change, this should be accompanied by sound consumption patterns that favour and promote long-lasting wood products. While the current large-scale disturbances pose considerable threats to the forest sector, this crisis may also provide opportunities to steer the sector into a more resilient future through the adaptation of the whole wood-production chain from the production of planting stock, adaptive sustainable forest management concepts and innovative wood processing technologies. These efforts call for a concerted action by politicians, timber producers, timber industry and the whole society.

3.6 Knowledge gaps and challenges

Legislation on the use of reproductive material still needs a further improvement. While in some countries the respective legislations are insufficient, in others the existing rules are too restrictive, virtually preventing use of assisted migration of tree species and their provenances from warmer and/or drier regions. Moreover, the mere (un)availability of proper planting stock makes adaptive forest management difficult as many planting stock producers still remain focused on a few tree species required in the past. The supply of diverse reproductive material from various tree species and provenances is often insufficient. Moreover, knowledge on tree species selection is lacking experimental evidence of the success of particular tree species and their provenances in the future climate.

Balancing between adaptation and mitigation is another challenge. Drought-tolerant broadleaved species are often less productive and, despite the higher wood density and often enhanced soil organic carbon storage, the overall carbon sequestration after conversion to drought-tolerant broadleaved stands may be reduced. However, the more resilient tree species composition should reduce forest dieback and sustain carbon sequestration over longer periods of time.

Also, game browsing and bark stripping remain a big problem as they hinder successful implementation of adaptation measures (e.g. the introduction of missing tree species). Measures such as fencing off the areas or individual protection of saplings are costly and can be applied only to ecologically and economically feasible areas. Populations of ungulates can also be controlled through both hunting and predators, but hunters often disagree with forest managers on the extent of necessary reductions.

Knowledge gaps also exist in relation to forest economics and future market prospects when softwood will get scarce and larger volumes of hardwood will need to be marketed. In the regions with massive spruce decline, the industry will face two subsequent contrasting challenges: after the processing of extraordinarily large volumes of salvaged wood, the regional forest resources will remain depleted and local mills may face wood shortages. The substitution of conifers by broadleaves, for example in wooden constructions, would require new processing technologies, which may be costly and requiring targeted investments. Other industry-related concerns include the possible impacts of extreme weather events and changes on the wood quality (e.g. irregular year rings and declining wood density resulting from stronger thinnings combating drought risks). While the proposed adaptive measures are based, to some extent, on ecological rationales, they are not yet supported by a viable economic concept. The economic margins of timber production in Europe are modest. Replacing commercially attractive, yet vulnerable, tree species with less attractive, yet stress-tolerant, tree species is challenging. Depending on the region and the extent of future climate change (considering also emission reductions in line with the Paris agreement), current species including spruce may remain economically viable if managed with shorter rotations, of course with consequences to forestry economy and provision of some ecosystem services. Replacing faster growing conifers with broadleaves tends to result in longer rotation periods and, subsequently, in wood shortages in the future. However, continuous cover forestry has a certain potential to partially mitigate this through distribution of fellings of remaining coniferous stands over a longer period.

3.7 The way forward: comprehensive planning for adaptive forest management

There are several possible approaches to increase the adaptive capacity of forests through the implementation of sustainable forest management practices. Continuous-cover forest management represents one of these practices as it promotes species-rich and structurally diverse stands, which enhance the adaptive capacity of forests under climate change (Brang et al. 2015). However, it should be recognised that the present tree species might be unsuitable for the changing climate with more extreme weather events. In that case, pro-active adaptation measures, such as assisted migration, will be required. In the intensively managed forests with shorter rotations, tree species composition can be adapted and the provenances more suitable to the future climate can be introduced much faster than to near-natural forests. On the other hand, such forests may be less resilient to other types of disturbances or their provision of some ecosystem services may be compromised. There might be no one-fits-all-strategy – adaptive sustainable forest management should consider the past and present circumstances when planning for enhanced forest resilience and efficient climate change adaptation, while also finding the right balance between the three pillars of sustainability.

Comprehensive planning for adaptive forest management should therefore include a participatory stakeholder engagement and consider:

- The site-suitability of the existing tree species (and/or their provenances) at present and in the future relevant for the measure being planned (e.g. the entire rotation for tree species composition planning, several decades for tending, etc.) and, in this respect, to assess whether natural regeneration is a viable silvicultural option or not.
- The possible long-term changes that will influence the forest, including changes in weather patterns, possible extreme events and forest disturbance risks, as well as the associated inherent uncertainties of projecting future climate and its impacts on forests.
- Identification, selection and testing of potentially suitable tree species and provenances that can complement natural regeneration and, if necessary, replace the current species through artificial planting or seeding.
- Diversification of tree species composition, stand structures and management approaches (including improved water retention[7] or promotion of continuity and appropriate spatial distribution of forest cover at landscape level) as a fundamental way of enhancing the resilience of forests and forest landscapes.
- Understanding natural processes, adaptive traits of species and complementary functional strategies of species that can help to increase the forests' resilience to climatic stress.
- Pro-active disturbance risk mitigation with focus on the prevention of and preparedness to diverse forest disturbances (for example by developing more resilient forest stands and landscapes that minimize disturbance risks or investing into monitoring and capacity building to shorten response times and enhance knowledge transfer on disturbance risk management).
- Continuous monitoring of abiotic and biotic impacts of climate change and of tree responses, including investigation of the effectiveness of adaptive measures.
- Improving the flexibility of wood-processing industry via its transformation to processing of diverse types of wood, producing innovative products and searching for new markets.

[7] However, water retained by an ecosystem is to a large extent used by the vegetation itself, which , especially in dry areas, may mean less water in streams and dams. See, for example, a thematic study "Forests and water" (FAO 2008) prepared in the framework of the Global Forest Resources Assessment or the outcomes of the long-term Hubbard Brook experiment (Campbell et al 2007).

4 Contributions from the FOREST EUROPE Workshops

4.1 Agroforestry – potentials for enhancing resilience

Agroforestry represents a promising climate change adaptation concept of sustainable land use as it can contribute to fire prevention, soil erosion control and microclimate management while providing livelihood and supporting food security. The main agroforestry practices include silvo-arable agroforestry, establishing the riparian buffer strips, silvo-pasture, forest farming and home gardens (Mosquera-Losada et al. 2018), with three main systems applied in Europe: arable agroforestry, livestock agroforestry and high value tree agroforestry (den Herder et al. 2017).

Sharing the state-of-the-art knowledge and building mutual understanding between the agricultural and forest sectors in the field of agroforestry was the main purpose of the workshop ***Understanding the contribution of Agroforestry to landscape resilience in Europe*** organised by FOREST EUROPE on 9-10 October 2018 in Budapest, Hungary.

The workshop focused on identification of possible options for further joint work between the agricultural and forest sectors and formulating recommendations on further steps in the pan-European region, to promote agroforestry as a tool (if implemented properly) for adaptation of a landscape to climate change, combating land degradation and desertification, forest fragmentation and forest fires, while improving biodiversity protection, water regime and soil fertility, etc.

Workshop conclusions

In Europe, applicability of the particular agroforestry practices varies across the continent significantly, depending on natural conditions, legislative framework regulating land use, cultural aspects, etc. For example, in the Mediterranean, agro-silvo-pastoral systems may represent an important management option for reducing fire risk in fire-prone forests.

In other conditions, agroforestry systems may include establishing and maintenance of shelterbelts (windbreaks) in agricultural fields, riparian galleries, short-rotation forestry and coppices on abandoned agricultural land, or the maintenance of traditional landscape mosaics. Such agroforestry components may positively influence the landscape resilience, e.g. through increased biodiversity at landscape level, reduced wind speed and overland flow (reduced soil erosion and improved water quality), reduced fire load (and consequently lower fire risk) and increased carbon sequestration.

At the farm level, agroforestry can diversify production (e.g. food, forage, timber and fuelwood). Although profits provided by agroforestry may vary at the plot and farm levels, global profits are considerable, especially if ecosystem services are taken into account.

In the pan-European region with its significant variability in natural conditions, a huge diversity of traditional land-use practices exists. Currently, agroforestry is applied on less than 10 % of agricultural land in Europe. However, a potential for establishment of modern agroforestry systems with high environmental and cultural value is increasingly identified.

Barriers and drivers of the further development of agroforestry

The contribution of agroforestry to a number of high-level environmental and societal goals (e.g. increased biodiversity and carbon storage, improved water quality, and high quality agricultural products), is still not sufficiently acknowledged and promoted by policies. The value of some of these benefits is not fully perceived by markets and, in some countries, current policies and legislations constrain agroforestry implementation.

Insufficient landowners' awareness of agroforestry and interest in its potential benefits are also considered limiting factors that need to be improved through various types of education and extension services. The existing good examples can be used for sharing experiences and learning agroforestry practices in particular conditions.

Traditional agroforestry systems should be promoted as the traditions in the farmers' families are one of the main drivers of the implementation of agroforestry practices. An increasing number of consumers demand local products from family farms. Similarly, improving cooperation between farmers, landowners, foresters and other partners might increase the use of agroforestry practices in future.

The full workshop report is available at the FOREST EUROPE website under the section *"Publications"*.

4.2 Managing forest disturbance risks and adaptation of forests to climate change

Noticeable forest disturbances (windstorms, extended, heat waves combined with drought, bark beetle outbreaks or forest fires) driven by climate change were observed during the previous years in most of the European countries. The countries reacted to these phenomena by development of various strategies, policies and by the implementation of various measures at operational level.

However, the frequency and intensity of recent events underlined the importance of going beyond traditional emergency response approaches in disturbance management by strengthening disturbance prevention measures and enhancing forest resilience to mitigate future disturbance impacts. This was a central idea of the workshop ***Pro-active Management of Forests to Combat Climate Change Driven Risks: Policies and measures for increasing forest resilience and climate change adaptation*** organised by FOREST EUROPE on 3-4 September 2019, Istanbul, Turkey.

The workshop discussed the following issues:

- climate change impacts and potential adaptation options for increasing the resistance and resilience of forests
- existing and possible future development of adaptation policies and tools in the forest sector and beyond
- feasibility and effectiveness of adaptation measures based on practical experiences under different climatic conditions across Europe

Workshop conclusions

European forests are diverse and serve various societal needs. Climate change impacts and disturbance risks depend on both these aspects and, therefore, specific adaptation strategies are needed to fit to local circumstances and there is no one-size-fits-all strategy.

However, there are several legal and policy barriers at different levels across Europe, which hamper adaptation of European forests to climate change. Therefore, the workshop participants mentioned the need to revise legislative frameworks and policies to remove these barriers and allow the implementation of necessary adaptation measures and proactive disturbance risk management.

Such revisions may be aimed at enabling transfer of adapted forest reproductive material as a part of assisted migration, adjusting game management policies or promoting pro-active forest and nature-conservation management to increase the resilience of the forests, which may vary from close-to-nature approaches to intensification measures, depending on local conditions and objectives in particular areas.

Nevertheless, cross-sectoral cooperation and consensus building will be crucial for such a policy revision as well as for successful implementation of the appropriate measures. Bringing different stakeholders into a joint planning process can help setting priorities of the future management and sharing resources.

Appropriate solutions, which may motivate landowners and forest managers to adopt the adaptation measures and pro-active disturbance risk management, can include economic tools such as payments for ecosystem services or market-based instruments. Another important principle is that support measures targeting prevention should prevail over reactive responses e.g. in restoration.

Expertise in managing large disturbances is often missing at local level as these events are not reoccurring at the same place (e.g. forest management unit) in the lifetime of a forester. However, some countries have developed specific capacities and partial expertise that could be used to assist other countries. Therefore, appropriate forms of international cooperation and experience sharing of good practices are needed, ideally through a stable international framework to enable rapid responses in the case of disturbance events on one hand, as well as continuity in capacity building and expertise sharing on the other.

Evidence-based climate-change-adaptation measures and timely disturbance risk management should be supported by improved forest monitoring. To plan and target pro-active risk management, it is important to expand the scope of monitoring also to include the preparedness to and prevention of large disturbances, as well as tracking the progress of the recovery after the disturbances.

Successful management of climate change impacts would also require appropriate technical capacities and infrastructure such as storage capacities for timber, improving access to forests and infrastructure for the whole chain of forest reproductive material supply, from seed production (e.g. seed orchards, seed stands), collection, seed and transplants storage capacities (e.g. refrigerators), transport, nurseries, planting, etc.

According to the workshop conclusions, it is crucial to raise public awareness of the need for climate change adaptation. The public should be informed about extreme events and how foresters have reacted to the resulting damages, why particular management actions were important, as well as about the ways of preventing future damages. Appropriate tools for raising the awareness, such as publicly accessible maps of wildfire risk or of current forest decline and projected future climate conditions, should be developed, together with improved communication.

The full workshop report is available at the FOREST EUROPE website under the section *"Publications"*.

5 Country examples in climate change adaptation and disturbance risk prevention

5.1 Changing tree species composition (Czech Republic)

The decline of spruce and pine stands of all age categories caused mainly by droughts and subsequent bark beetle and honey fungus infestations is a major climate-change-related problem in the Czech Republic. To enhance ecological stability and resistance of forest stands to biotic and abiotic agents, it is a good practice to restore site-suitable tree species composition and to improve the spatial structure of forest stands.

The improvement of the tree species composition has been supported by the government since 1996. A minimum share of soil-improving and stabilising tree species after the stand is established used to be one of the legally binding provisions for forest estates larger than 3 ha. Increased costs of planting were partially reimbursed. Since 2018, state subsidies for natural and artificial regeneration of the respective tree species have increased by 50 %, in order to promote their use. In 2019, a new legislation for forest management planning came into force. The main changes were as follows:

1. The minimum share of the soil-improving and stabilizing species has been increased significantly.The list of the financially supported soil-improving and stabilising tree species for particular site types was significantly widened.
2. Seeding of the (newly redefined) preparatory and pioneer tree species was added as an additional measure that qualifies for financial support.
3. Planned rotation age of threatened spruce stands was lowered.

Since 1996, according to the stand inventory[8], the share of conifers has decreased from 76.9% to 71.5%. According to the National Forest Inventory[9] (2011-2015), the share of conifers was even just 57.7 % (± 1.0%).

In the same period, the average annual state subsidy for planting soil-improving and stabilising tree species has reached 11 mill. CZK/year, and for reforestation, establishment of stands and their tending 200 mill. CZK/year.

State subsidy for planting a minimum share of soil-improving and stabilising tree species in the form reimbursement of increased costs is enacted by the Forest act. State subsidies for reforestation, establishment of stands and their tending is also based on legislation. The sum allocated for this purpose has varied over the years.

Recently, the measure has been adjusted to allow reactive management after disturbances resulting from climate change.

[8] A stand inventory is based on the summarising of stand data in valid forest management plans (FMPs). These data are available for (almost) all forest stands but they are 1 – 10-year-old depending on the cycle of FMPs updating.

[9] National forest inventories are statistical, based on the grids of small inventory plots. They are more up-to-date than stand inventories, however, still not considered „fully official “.

5.2 Future forest stands (France)

The climate-related problem addressed by this newly introduced adaptation measure is the decline of autochthonous tree species due to droughts and increasing temperatures. In the coming years, increasing temperatures and severer droughts are expected to drastically modify the existing site conditions, causing the decline of several tree species. According to current climate change scenarios, the change will be too fast for current species and provenances to adapt to the new conditions, which will result in their decline.

Based on the climate change scenarios and financial resources available for the adaptation and critical regions were identified. For these regions, a list of species and provenances resistant to the projected future climate (2070 and 2100) was proposed based on their growth potential in the new conditions (tree heights min. 30 metres in the maturity age). The selection was based on scientific estimates and experiments in southern locations where the current climate is similar to the expected future climate of the critical areas. The proposal is to introduce these new species to the critical areas via planting (at least 0.5ha) to test their resistance. These future stands will be backed by RENEssences, an experimental R&D network.

The forest climate change adaptation project has just started. These future stands are planted by ONF (Office national des forêts). More than 200 stands will be established by 2022. On half a hectare, 750 trees will be planted which is, in total, more than 150 000 trees on more than 100 hectares. Forest managers are highly interested and involved in this project, as well as researchers.

5.3 Assisted migration of tree species (France)

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5.4 Tree Species Composition Planning (Slovak Republic)

Though the tree species composition of Slovak forests was not altered by forestry so significantly than e.g. in Western Europe, there are some spruce monocultures and other unnatural forest stands in Slovakia. These forests have always been vulnerable to natural disasters and pests, and now they need to be adapted to a new climate.

Since the 1970s, Slovakia has developed a very complex system of planning the tree species composition at the stand level. It is based on detailed site mapping (180 site units) and the knowledge base on the natural tree species composition for particular sites. There are two planning steps. In the first step, specialists prepare management models that consider not only natural species composition but also actual tree-species-composition types, forest health and risks, economic factors, nature conservation and other forest functions. In the second step, these models are connected with a particular forest stand through 18 parameters that are included in both management models and forest management plans. This approach promotes improvement of tree species composition of each forest stand towards a more natural composition. "Models" are updated and delivered to the respective forest management planning subjects by the National Forest Centre.

Tree species composition of newly established forest stands is randomly inspected by the state administration, however, forest managers are given some flexibility in this respect. The actual tree species composition of each stand is also included in forest management plans and is routinely compared to the models. Trends in particular tree species are assessed through annual stand inventories.

In some regions, practical implementation of these models is challenging. Re-introduction of some tree species may be unsuccessful due to game browsing. Despite investing significant efforts into the introduction of missing native species, spruce still dominates the newly regenerated stands. Nevertheless, the proportion of spruce is noticeably decreasing in Slovakia, from 26% in 2000 to less than 20% in 2019. On the other hand, proportions of some promoted tree species, such as Silver fir and "noble oak species", are also decreasing.

The measure is loosely included in the Forest Act and specified in the Regulation on forest management. The guidelines for tree species composition planning are in place. The compliance of actual tree species composition with the prescription (the "management model" for respective conditions) is still not adequately promoted.

The measure was introduced long before climate change became an issue. However, its purpose, improvement of forest resilience, is now more desirable than ever. In 2019, a study of the new tree species composition planning was conducted. The system proposed is simpler and directly based on future climate projections. It is planned to use this new system as a basis for adaptation support from the Rural Development Fund, however, it has not been implemented into practice yet.

5.5 A large -scale forest restoration experiment (Austria)

In Austrian mountain forests, some Norway spruce stands are underperforming. The trees need to cope with nutrient poor soils and harsh climate conditions. The available information of alternatives to the presently used tree species in the future climate is scarce and based more on personal views than experimental evidence.

To improve the situation, a large-scale forest restoration experiment was set up to test various tree species in various mixtures. The experiment includes different adaptation-related testing:

- The performance of different provenances of Norway spruce is compared. Attention is given to provenances that are presently recommended for low-elevation sites.
- Assisted migration by planting tree species, that are productive at lower elevations but are not yet stand-dominating at higher elevations, is considered.
- Alternative tree species, that are currently thriving at high elevation, are tested as possible substitutes for Norway spruce.
- Non-native trees that are successful in other mountain ranges with similar site conditions are included.
- The tree species are combined in different types of mixed forest stands.
- Some tree species, presently of no commercial relevance, are also included to reflect potential long-term changes in the timber market.
- Performance of naturally regenerated Norway spruce (in situ or from locally excavated seedlings) is used as a benchmark.

The experiment is meant to be long-lasting. The measured parameters include the annual height increment, the survival of seedlings, and the phenological development in spring (that is related to the risk of frost damages and the resilience). Moreover, the local micro-climate is monitored, soil chemistry is investigated and genetic analyses of trees are made. The area restored within the experiment framework can be considered a contribution to adaptation itself.

The costs of the experiment are not disclosed. Yet funding is derived from the contribution of a private owner, a research funding agency, and an in-kind contribution of the Austrian Research Center for Forests (BFW).

The experiment fully adheres to the existing Forest Act. The permission to clear a sufficient area for the experiment was granted by the Forest Authority. The combined measures are declared as targets in the Forest Strategy 2020+[10]. The Austrian Research Center for Forests (BFW) and the private forest owner are jointly implementing the experiment.

The adaptation to climate change was the main objective of the experiment. Therefore, it includes tree species that are currently not commercially important. The results of the experiment will allow owners of forests in similar site conditions to make informed decisions on their future timber production and sustainable provision of ecosystem services for society.

[10] https://www.bmlrt.gv.at/forst/oesterreich-wald/waldstrategie-2020.html

5.6 Forest fire prevention measures (Spain)

The climate-related problem addressed by the adaptation measure is the increasing flammability of forests and subsequent frequency and intensity of forests fires.

In Spain, wildfires burn more than 100.000 ha/year on average (2006-2016)[11].

During the last few decades a decreasing trend in wildfire affected areas has been observed. However, due to climate change, an increase in the virulence and severity of fires is very probable. This is because risk factors are expected to increase (reduction of the relative humidity due to higher temperatures, more frequent heat waves, etc.). Especially "megafires" (more than 500 ha affected) are expected to rise. All the Spanish forests are threatened by this climate-related problem.

The measure is aimed at increasing or maintenance of the fire resistance of the vegetation cover; improvement of fire prevention infrastructures; support of preventive infrastructures in particular Spanish regions with the highest risk of forest fires; and development of prevention measures with local communities in order to reduce the occurrence of anthropogenic fires and to improve landscape resistance to wildfires.

Moreover, specific preventive silviculture measures (management and control of biomass) are promoted such as: construction of firebreaks and areas more resistant to fires (release operations, removal cuttings, pruning, prescribed burning, forest waste removal, planting, replanting, etc.) and implementation of coordination protocols among stakeholders in order to improve the capacity of organisations to deal with extreme fires working together.

Measures developed by the Integral Prevention teams (EPRIF):

During 2018, the EPRIFs worked in collaboration with ranchers, farmers, hunters and local administrations to reconcile interests and raise awareness of forest fire prevention.

It is worth mentioning the treatment of 526 hectares with a hundred of prescribed and controlled fires. This helps to reduce the fire risk by reducing fire load and creating discontinuities in the vegetation cover, with additional benefits such as improving pastures, favouring the habitat of various species or improving forest accessibility. 655 plots were prepared for burning, though the weather conditions did not allow all burnings to be completed.

Measures developed by Preventive Work Brigades (BLP):

The Ministry of Agriculture Preventive Work Brigades, in collaboration with the autonomous administrations, carried out fire prevention works on more than 1.381 hectares of forest land, which included thinning, pruning and underbrush removal. In total, within 11 months of 2018 (with the break in summer) more than 400 workers of 10 Preventive Work Brigades carried out preventive forestry measures in forests. Occasionally, the BLPs also support the EPRIFs in the execution of prescribed burning.

In the current CAP programming period (2014-2020) these measures are co-funded by the European Agricultural Fund of Rural Development (EAFRD) and the Spanish Government.

[11] https://www.mapa.gob.es/es/desarrollo-rural/estadisticas/incendios-decenio-2006-2015_tcm30-511095.pdf

Spain has been implementing wildfire prevention for many years, by "Preventive Work Brigades" (BLP) since 2006 and "Integral prevention Teams" (EPRIF) since 1998. Though always being a part of traditional forest management in Spain, currently it is considered a part of the adaptation to climate change.

Key challenges for the future:

- Improvement of coordination between administrations and institutions.
- More emphasis on training and awareness of rural population.
- Spread of this kind of actions to other territories where they are not yet applied.
- Reinforce collaboration between public administration and the population as a way to achieve sustainable results.

5.7 Forest fire risk assessment and prevention, and support to silvicultural decisions (Switzerland)

Longer and severer dry periods in summer months have increased the risk of forest fires threatening forests and their services, as well as human settlements and infrastructure.

The measure consists of research followed by the development of an automated warning system and the mapping of forest fire risk based on dryness indicators to estimate fire danger at local and canton levels[12]. Dryness indicators were developed and adapted for local, regional, canton and federal level. Practical implementation includes removal of flammable material (branches) from the forest floor in dry areas and in the vicinity of human settlements.

The measures are a part of the 2020-2025 Action Plan for Adaptation to Climate Change in Switzerland (not limited to forests, but with many specific measures for forests). The primary objective of the measure was adaptation to climate change (namely to dry periods) resulting in increased mortality of trees and fire danger. However, historically, fire monitoring, prevention, and control have always been a part of forest management. Thanks to this, in spite of fire risk being increased due to climate change, fire damages have not increased dramatically in Switzerland.

The multi-year national program "Forests and Climate Change" projects the future development of forests throughout Switzerland under the influence of climate change. A free smartphone application called Tree-App will be available in autumn 2020. It will enable forest managers and forest owners to obtain information on the tree species that will be ideal for their forests in the future. They will thus be able to take proper decisions about which species to promote from now on. The goal is to ensure that all forest ecosystem services will be maintained as much as possible.

[12] https://www.waldbrandgefahr.ch/en/web/waldbrandgefahr/current-situation

5.8 Creation and investigation of the provenance tests of forest tree species and selection of individuals and populations resistant to climate change (Ukraine)

The climate-related problem addressed by the adaptation measure is creation of forests from plant material of species, populations and individuals that are more resistant to climate change.

For provenance tests, samples of plant reproductive material are collected from populations in different parts of the natural range and planted on experimental plots. The growth, quality and resistance characters of variants are observed every 5-10 years. Analysing the results allows selecting the individuals and populations that are more adaptable to climate change.

During the 20th century, provenance tests of 14 species were created on 38 sites on the territory of Ukraine. The total number of tested populations is 327. While climate change adaptation was not the main objective for introducing this measure, it is a part of forest tree improvement, seed growing and forest gene pool conservation activities which will be crucial to cope with climate change.

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