ZAVOD za GOZDOVE SLOVENIJE
Slovenia Forest Service

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in obnovljive gozdne vire

FORESTS FOR FUTURE

Guidelines for mitigating and adapting to the impacts of climate change on forests

Forest management planning guidelines

Ljubljana, February 2022

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Authors: Andrej Vertelj, Živa Bončina, Kristina Sever, Andrej Breznikar, Aleš Poljanec, Matjaž Guček, Jurij Beguš, Matija Klopčič, Matevž Konjar

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Table of contents

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1. Abstract

Keywords: climate change, mitigation, adaptation, forest management planning, management guidelines

The creation of forest management planning guidelines was based on the results of forest development modelling, scenario creation and review of the existing scientific literature. Guidelines elaborate measures for the optimised, sustainable provision of a forest carbon sink (climate change mitigation) and adaptation of forest to the impacts of climate change.

The guidelines for climate change mitigation are divided into seven sections:

- **Maintaining or increasing forest cover** will play a key role at the global level.
- **Increasing forest productivity** has high potential in Slovenia. It will be based on regeneration and tending measures promoting the growth and sustainability of forest carbon sinks in existing forests.
- **Increasing the proportion of dead woody biomass** will contribute to the state of the carbon sink, carbon stocks and preservation of biodiversity.
- **Adjusting the length of production cycles** will be applicable in countries with shorter rotation periods that limit the exploitation of the full site productivity potential. In Slovenia, this measure will have limited potential due to the risk of increasing the vulnerability of stands to natural disturbances.
- **Increasing the area of forests excluded from regular management** will contribute positively to carbon sequestration. This measure is only advisable in forests that have lower susceptibility to natural disturbance and are of minor economic importance.
- **Increasing the sustainable use of wood** will contribute to a more sustainable storage of carbon in products with a longer lifespan.
- **Replacing the use of fossil fuels** with woody biomass will improve the status of carbon sinks by reducing emissions from the extraction, transport and consumption of imported, energy-intensive fossil fuels.

The guidelines for the adaptation of forests to the impacts of climate change are also divided into seven sections:

- **Forest regeneration** must ensure the species, genetic and structural diversity of stands, which constitutes the basis for adaptation of forests to the impacts of climate change. This will be achieved through planned natural and artificial regeneration with high-quality forest reproductive material.
- **Forest tending** should mainly focus on the intensification of tending measures in younger developmental stages. Silvicultural approaches will have to consider a wide range of criteria (adaptability, vigour, quality) and promote maximum work efficiency.
- **Technologies and infrastructure** must allow for low-impact interventions in forests, which will minimise susceptibility of forests to natural disturbances and avoid excessive damage to forest soils.
- **Forest protection** will need to include both preventive measures and a response to environmental change and natural disturbance.

Measures for improving adaptation of forests to the impacts of climate change will also **strengthen the protective role of forests**, **have a positive impact on the preservation of biodiversity and provide other systemic improvements to forest management in Slovenia.**

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2. Introduction

Forests are linked to climate change in two ways. Climate change has an important impact on forest development and management. On the other hand, forests play an important role in the process of climate change mitigation. Taking action to achieve mitigation and adaptation objectives is becoming one of the core tasks of the forestry sector and is a prerequisite for achieving all other management objectives (Seidl et al., 2014).

Climate change-related measures can be divided into two categories:

MITIGATION of climate change – Forests reduce the rate and extent of climate change development by absorbing atmospheric carbon (inhibiting the greenhouse effect), thus reducing its impact on the environment and society. The process of carbon sequestration is also referred to as the carbon sink. The opposite process to carbon sequestration are carbon emissions, which involve the release of carbon from the so-called carbon stock. The carbon stock is the total amount of carbon stored in above-ground, below-ground and soil biomass.

ADAPTATION to the impacts of climate change – Adaptation involves proactive and planned management that contributes to reducing the vulnerability and increasing the resilience of forests to the perceived or anticipated impacts of climate change. Adaptation reduces the negative impacts of climate change on forest development and consequently facilitates the achievement of objectives related to the ecological and social functions of forests (Smernice ..., 2021).

Forest management planning guidelines gathered in this document constitute measures for mitigating climate change and adapting forests to the impacts of climate change. The guidelines for climate change mitigation (sustainable provision of forest carbon sinks) were based from the results of forest development modelling (Forests for Future project – Output 1) and existing scientific findings. The climate change adaptation guidelines summarise the results of the LIFE Systemic project, which primarily focuses on the development of measures and approaches for adapting to the impacts of climate change in forests. The results of both projects have been combined because we assume that only the forests that are adapted to the impacts of climate change can sustainably mitigate climate change.

The guidelines have already been included in the draft of the Regional forest management plans for the period 2021–2030 (RFMP 2021–2030).

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3. Mitigation of climate change

Forests absorb carbon dioxide from the atmosphere through photosynthesis and convert it into organic compounds, thereby reducing the carbon concentration in the atmosphere (FISE, 2022). In Slovenia, forests cover approximately 58 % of the land surface and are the main carbon sink in the country. Forests contribute to the reduction of greenhouse gas emissions and more favourable national emissions balance in three ways: by sequestering carbon in the organic matter of the forest (above and below ground), by providing wood as a technical material (sequestering carbon for the lifetime of the wood product) and by providing a renewable energy resource substituting the use of fossil fuels.

The functioning of the forest as a sink for CO_2 from the atmosphere is only guaranteed if the conditions in the forest allow for the accumulation of plant and soil biomass. The wood stock in forests increases if the harvesting and mortality rates are lower than the increment. Sustainable management of forests, which sequester carbon from the atmosphere, is therefore crucial in the long term for achieving the goals of the Paris Agreement and climate neutrality.

In the new RFMP 2021–2030, carbon sequestration in forests is planned in designated protective forests, forest reserves and eco-cells without intervention. In these forests, management is limited or absent, so the accumulation of the wood stock is greater. On the other hand, accumulation in multi-purpose forests is also extremely important. When planning measures, it is necessarily to take into account and coordinate the different functions of forests. Measures to ensure different functions may conflict in certain cases. When planning and implementing measures for optimised carbon sequestration in forests (i.e., mitigating the effects of climate change) such as measures that affect the wood stock, stand structure and tree composition, care must be taken to ensure that they do not negatively impact the adaptation of forests to the impacts of climate change (e.g. stability and resilience to the impacts of natural disturbances). All planned measures also have to be considered from the perspective of other forest functions (Okoljsko poročilo, 2021).

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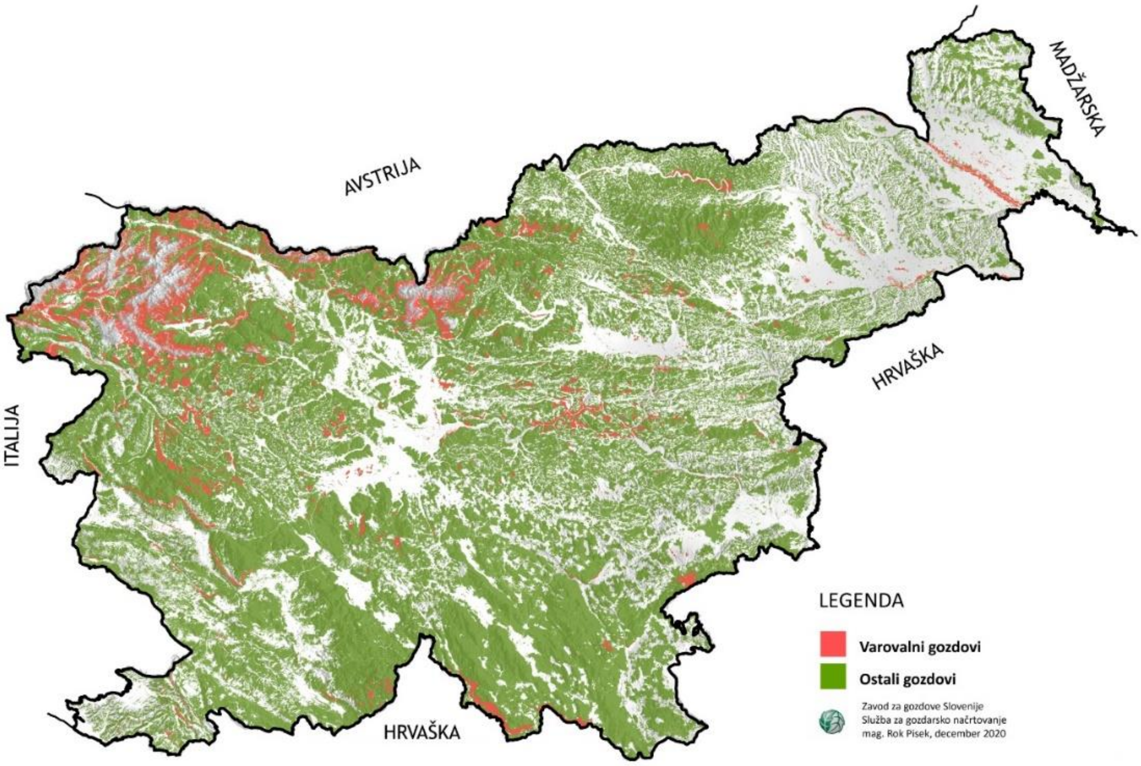

Figure 1: Protective forests in Slovenia (ZGS, 2022)

Key factors that contribute to the mitigation of climate change and the area a subject of forest management planning are following: area covered by forests, wood stock and its diameter structure, stand structure, tree species composition, increment and total allowed volume of harvesting. These factors are mainly influenced by executed harvesting and other forest management measures (regeneration and tending measures). Forest regeneration, tending and forest protection measures positively impact the stability and resilience of stands, the utilisation of the production potential of forest sites and the quality of produced timber, which can serve as a long-term carbon stock in the form of wood products.

Forestry can contribute to climate change mitigation through the following measures:

- Maintaining or increasing forest cover
- Increasing forest productivity
- Increasing the proportion of dead woody biomass
- Adjusting the length of production cycles
- Increasing the area of forests excluded from regular management
- Increasing the sustainable use of wood
- Replacing the use of fossil fuels

3.1. Maintaining or increasing forest cover

The area of forests to a certain extent correlates with the state of carbon sinks. In Slovenia, there is a parallel process of reforestation due to a reduction in the agricultural use of land, and deforestation due to land-use change, which is taking place mainly in peri-urban areas and in areas with more intensive agricultural use.

Figure 2: Development of forest cover in Slovenia, 1875–2020 (ARSO, 2022)

The area of forests has been increasing for more than 140 years, mainly due to the overgrowth of abandoned agricultural land. While overgrowth is still occurring in areas where farming is being abandoned (i.e. remote, steeper areas), the total forest area is currently not changing significantly due to simultaneous deforestation and exclusion of areas covered by *Pinus mugo* (mountain pine) from the calculation of total forest coverage. In recent years, the increase in forest coverage has been gradually slowing down. In some places, the area of forest has even slightly decreased. There are still several infrastructure interventions planned for the future that will have a negative impact on the forest area, but on the other hand, the process of overgrowth will still be present in less accessible areas. Therefore, no significant changes in the total forest area are expected in the near future (Okoljsko poročilo, 2021).

Promoting the declaration and adapted management of urban and peri-urban forests

Conservation of forests and total forest coverage in urban and peri-urban areas also contributes to the total amount of carbon sink. In contrast to the overgrowth of abandoned and less suitable land for agricultural production, in peri-urban areas and areas of intensive agriculture, there is significant pressure on forests and forest space. Among the causes of deforestation in 2020, agriculture strongly dominated with 80%, followed by infrastructure (11%) and urbanisation (4%). Other factors were, as in all previous years, proportionally less important in terms of area in 2020 (Poročilo ..., 2021).

Urban and peri-urban forests must be preserved and protected from deforestation. Forests in the vicinity of larger cities, where social functions of forests are emphasised, can be designated as special purpose forests to protect them from land-use change. The public forest service should be involved in raising public awareness about the importance of these forests for quality of life, and promote transfer of good practices from municipalities with a well-organised system of urban forest management to other municipalities. For more successful management of urban forests, it is necessary to establish participatory forest development planning with the involvement of various stakeholders, to assist forest owners in forest management, to organise forest owners for joint forest management, to coordinate the organisation of urgent and required works in municipal and national urban forests, and to carry out monitoring of urban forests (Okoljsko poročilo, 2021).

3.2. Increasing forest productivity

The productive capacity of a stand represents the utilisation of the potential of the site on which the stand is growing (Kotar, 2005). The productive capacity of a stand depends on the structure and species composition, which also depend on the site characteristics, and varies due to anthropogenic and natural influences on these two factors (Kadunc et al., 2013). The productive capacity of a stand is described by parameters such as the wood stock and increment.

The wood stock is defined as the total volume of standing trees with a breast height diameter above a measurement threshold (in Slovenia 10 cm) on a given area, usually expressed in cubic metres per hectare. Data show that in Slovenia, despite losses due to natural disturbances, the wood stock and the proportion of large-diameter trees are still increasing. Over the last 70 years, the wood stock has increased by a factor of 2.5, and is expected to increase by 3.5% over the next decade (12 million m^3 in total). The wood stock in Slovenia is currently 304 m^3/ha, which is approaching the optimal level of 320–330 m^3/ha, according to the National Forest Programme. The increase in the wood stock is mainly the result of planned forest management, with a moderate and selective accumulation of increment (ARSO, 2022).

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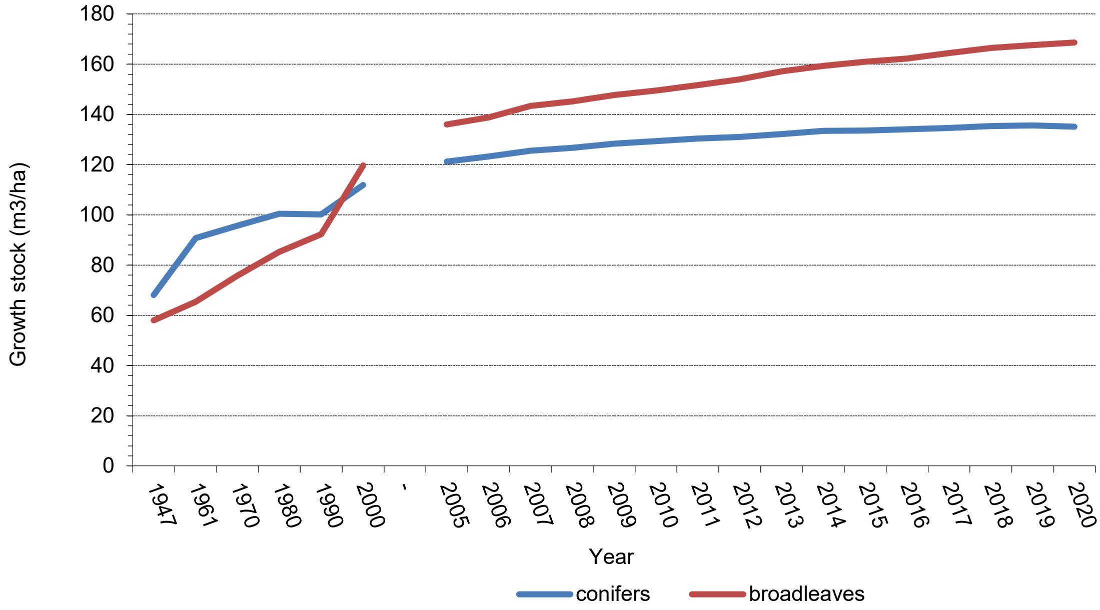

Figure 3: Growth stock of conifers and broadleaves in Slovenia (ARSO, 2022)

The increment is defined as the amount of wood in a stand that is produced in a given area over a given period of time (usually m^3/ha/year). The increment has been increasing in recent years and currently stands at 7.5 m^3/ha.

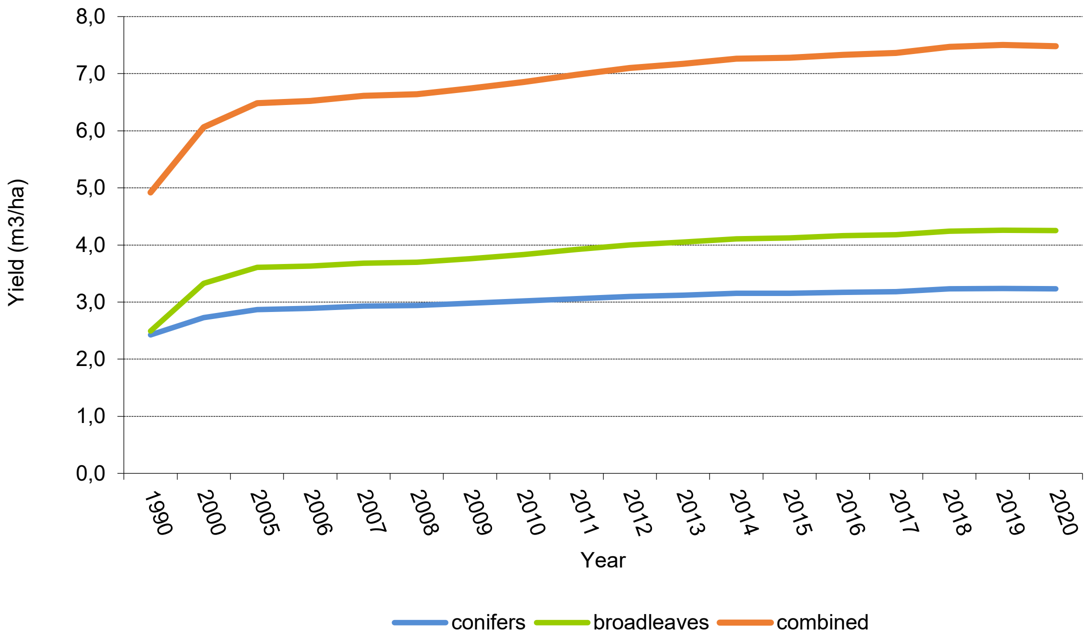

Figure 4: Yield of conifers and broadleaves in Slovenia (ARSO, 2022)

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Forest productivity can be directly influenced by the way forests are managed. Appropriate selection and implementation of measures influence tree composition, stand structure, wood stock and stand growth in a way that can contribute positively to stand productivity. Carbon sinks and stocks are closely linked to the accumulation of increment and level of growth stock, and consequently improve with increasing stand production.

Regeneration measures

Regeneration represents the phase of forest development where a new generation of trees gradually replaces the older, usually mature generation. Regeneration can vary in time and space and depends on the structure of the parent stand, the site and the influence of environmental factors (light, moisture, temperature, disturbances). Management can influence the course of regeneration and the duration of the regeneration period. From an economic point of view, regeneration is defined by silvicultural objectives, which relate primarily to the duration of regeneration and the target species composition (Kotar, 2005). Regeneration is divided into natural (primarily based on sexual reproduction of mature trees) and artificial regeneration (with the use of forest reproductive material obtained for this purpose). In Slovenia, natural regeneration prevails, while artificial regeneration is mainly used in the case of restoration after natural disturbance. As natural disturbance is becoming increasingly common, it often affects the course of regeneration in Slovenian forests. Natural restoration of damaged forests often does not take place in a way that would allow the optimal achievement of all management goals. The altered ecological conditions that arise on extensive deforested areas often lead to the vigorous growth of shrubs and other vegetation, which negatively affects the development of a new generation with the targeted species composition. Such changes often result in a delayed emergence of young trees, which is hindered by other vegetation (Schifferdecker, 2021). All of these factors underscore the importance of active management of forest regeneration.

Table 1: Implemented forest regeneration measures compared to goals set in the forest management plan (Poročilo ..., 2020)

Ownership	Plan/realisation	Natural regeneration	Regeneration with planting/sowing			Work days (n)
		Stand, ground preparation (ha)	Ground preparation (ha)	Planting (ha)	Sowing (ha)	
Private	Planned	1525,7	274,3	414,1	0,2	13214
	Executed	642,5	247,8	365,4	0,8	9735
	Realisation	42	90	88	410	74
State	Planned	563,9	275,9	324,1		7802
	Executed	924,5	284,5	315,3		9453
	Realisation	164	103	97		121
Municipal	Planned	10,6	33,0	24,4	4,8	666
	Executed	3,4	32,7	22,6	8,8	636
	Realisation	32	99	92	184	95
Total	Planned	2100,2	583,2	762,6	5,0	21682
	Executed	1570,4	565,0	703,2	9,6	19824
	Realisation	75	97	92	193	91

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In terms of ensuring carbon sequestration, it is necessary to allow forests to regenerate as quickly as possible, while also ensuring that the new generation of individuals will not only achieve other goals of forest management, but will also allow for the highest possible utilisation of the growth potential of the site. This will ensure a high level of carbon sequestration and storage. The species composition, based on species and genetic diversity, should also allow future stands to adapt to changing ecological conditions and more frequent occurrences of natural disturbances, which negatively impacts the amount of carbon sequestration in forests.

The duration of regeneration can be influenced by adapting the conditions in which regeneration takes place (stand or soil preparation) and by introducing additional reproductive material. Planting and sowing can also influence the species diversity of the stand, its adaptation to climate change and the utilisation of the site potential.

Tending measures for younger developmental stages

Forest tending directs the development of forests, promotes regeneration, improves stability and resilience to the impacts of climate change, increases the increment, improves the quality of the wood and positively contributes to achieving goals related to other functions of forest management (Nega gozda, 2015). Tending measures are divided into indirect and direct tending. Indirect tending is provided by creating favourable conditions for the development of younger forest under the coverage of a mature stand through the appropriate execution of felling. Direct tending is implemented in practice through measures in forests, among which the tending of younger developmental stages plays a central role. By setting the right target values of parameters (e.g. wood stock, diameter distribution, stand structure, tree composition) and implementing tending measures appropriately, we can achieve synergistic effects, both in terms of production functions and management goals such as biodiversity conservation and the provision of carbon sinks.

The insufficient implementation of planned tending measures has a negative impact on achievement of set goals related diameter structure, stand structure, tree composition, etc. Inadequate tending of young stands is reflected in slowed or disrupted development, which can be further hindered by the presence of competing species such as climbers and shrubs. Lack of tending can also affect the stability and resilience of younger stands in the event of natural disturbance. All mentioned qualities also affect the degree of carbon sequestration in the forest.

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Table 2: Volume of tending measures carried out in 2020 compared to planned volume that was set in the Forest Management Programme for 2020 (Poročilo ..., 2020)

Ownership	Plan/realisation	Preparation for regeneration (ha)	Thinning per developmental stage (ha)			Total (ha)	Work days (n)
			New growth (ha)	Sub-10cm DBH (ha)	10-30cm DBH (ha)		
Private	Planned	1547,4	3274,8	1396,9	1214,65	*3274,8*	*36011*
	Executed	1050,2	835,0	286,4	159,24	*835,0*	*11719*
	Realisation	68	51,0	21	13	*25*	*33*
State	Planned	997,3	1560,4	649,2	380,69	*1560,4*	*15754*
	Executed	910,9	1439,5	554,2	271,92	*1439,5*	*13827*
	Realisation	91	188,0	85	71	*92*	*88*
Municipal	Planned	46,0	63,8	8,8	11,25	*63,8*	*712*
	Executed	38,2	38,1	4,2	2,05	*38,1*	*451*
	Realisation	83	124,0	48	18	*60*	*63*
Total	Planned	2590,7	4899,0	2054,9	1606,59	*4899,0*	*52477*
	Executed	1999,3	2312,5	844,8	433,21	*2312,5*	*25997*
	Realisation	77	92,2	41	27	*47*	*50*

The proportion of properly tended stands, especially in the younger developmental stages and in private forests, needs to increase. Measures should have higher priority in stands susceptible to natural disturbance. Care should be taken to ensure that tending measures are timely and of the appropriate intensity. Tending should be intensified (primarily thinning) in young and older pole stands. This improves the stability of the stands.

To ensure the implementation of forest tending activities in private forests, it is necessary to train forest owners, provide 100% funding, strengthen promotion for the implementation of works and ensure monitoring of the implementation (Okoljsko poročilo, 2021). It is important to clearly inform the public and forest owners about the importance of regular tending as a tool for sustainable provision of all forest functions. Forest owners should be encouraged to connect with the purpose of joint management and sale of forest wood products (Diaci et al., 2021)

<u>Increasing the intensity of management on productive sites</u>

The effectiveness of tending measures depends on the characteristics of the existing stand and site. Increasing the intensity and frequency of thinning on productive sites has a positive long-term effect on growth (compared to unthinned stands) (Bončina et al., 2006), which subsequently affects the level of carbon sequestration. Tending measures should also be adapted to the species composition of the stand and the needs of the different tree species. Some species, such as fir, require more intervention to ensure the preservation of species throughout the development of the stand, but subsequently grow well even in old age (Klopčič and Bončina, 2011). This characteristic should be exploited for provision of lasting carbon sequestration in forests.

<u>Conversion and supplementary planting in low-productivity forests</u>

Forest area has increased significantly due to the abandonment of agricultural use. These areas are often covered by pioneer species, which often do not achieve the yields that the site potential allows for. If we are to increase the carbon sink in these forests, it is necessary to increase the utilisation of the production potential of the site. This is also the orientation of the National Forest Programme.

The total area of forests with inadequate structure on productive sites is approximately 31,400 ha (Veselič et al., 2014). Overgrown land that is suitable for development into a forest should be rapidly developed into a productive forest using various silvicultural practices (Uredba …, 2020).

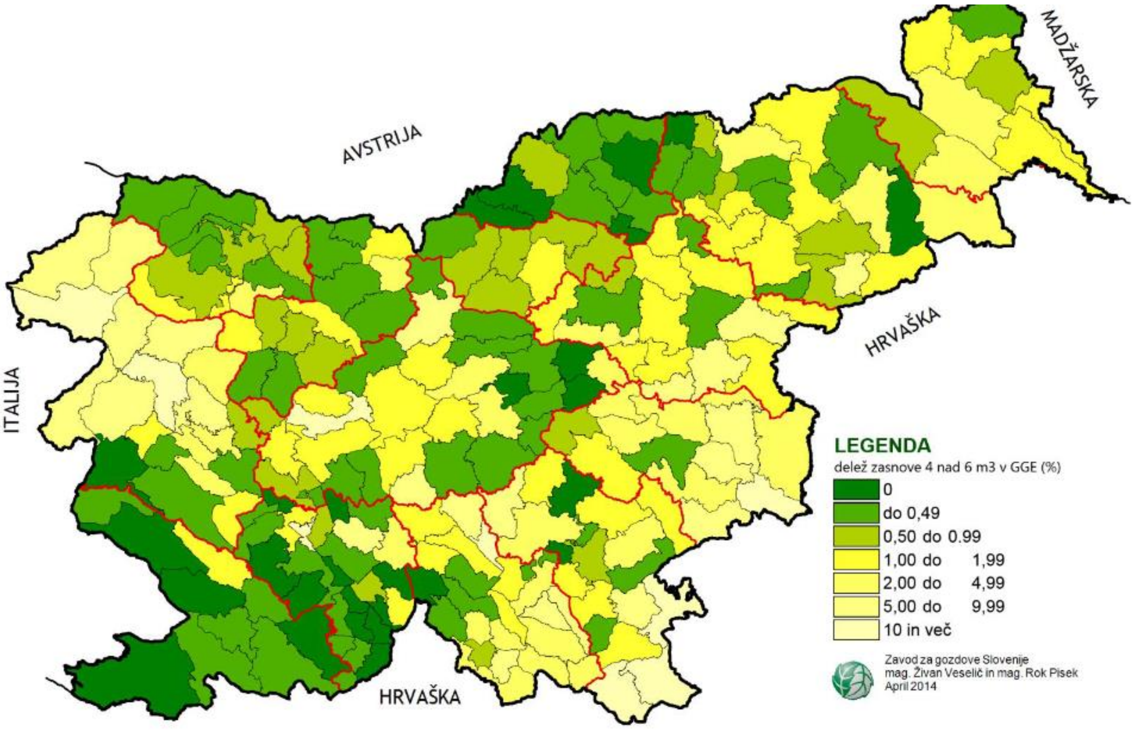

Figure 5: Proportion of forests that largely under-utilise site potential on productive sites (Veselič et al., 2014)

In the case of severely altered and less suitable species composition in productive stands, forest conversion can potentially be applied. Forest conversion is a silvicultural measure that alters tree species composition and stand structure in a forests that largely under-utilised site potential. Conversion is especially applicable in stands that have been in the past exposed to over-exploitation of forest timber and other forest resources (Slovarček, 2022).

In the context of conversion, it is only appropriate to classify low-yield forests as those forests that poorly exploit growth potential of productive sites. Possible reasons for this include an insufficient number of trees at a given average tree diameter, inadequate stand composition or inadequate tree quality (poor tending of stands) (Veselič et al., 2014).

On karst sites with low productivity, it is sensible to introduce deciduous trees suitable for the site through gradual succession. Deciduous trees are suitable in terms of sustainable management because they contribute to biodiversity in the forest environment and are better adapted to impacts of climate change such as forest fires. The introduction of the desired species can be achieved by direct large-area planting or by establishing migratory corridors through which the species can later spread spontaneously via natural regeneration (Gajšek and Brus, 2016).

3.3. Increasing the proportion of dead woody biomass

According to the Forest Protection Regulation (Pravilnik ..., 2016), dead woody biomass in forests is represented by standing dead trees, fallen trees, standing parts of broken trees, lying parts of broken trees with roots, lying pieces of broken trees and logging residues. Dead woody biomass is an important functional and structural component of forest ecosystems, as it significantly impacts mineral and nutrient cycling, medium-term carbon storage, regeneration and preservation of the environment and biodiversity. Due to the important functions of dead woody biomass in the forest ecosystem, the amount of dead woody biomass is used as an indicator of sustainable and environmentally-friendly forest management.

In accordance with the goal of preserving biodiversity in forests, the proportion of dead wood according to data from the Forest Service is increasing and was in 2021 estimated at 21 m^3/ha (6.9% of the wood stock). The Forest Protection Regulation requires the average proportion of dead woody biomass to be 3% of the average wood stock. This proportion is currently achieved mainly due to thin standing dead trees (diameter at breast height less than 30 cm), while the proportion of medium and large standing dead trees (diameter at breast height over 30 cm) is too low. Reasons for the increased proportion of dead trees include a better understanding of the role of dead woody biomass in maintaining a favourable biodiversity status, the increased influence of natural disturbances in the recent past, low prices for lower quality wood after storms, and the high costs of harvesting and extraction (Okoljsko poročilo, 2021).

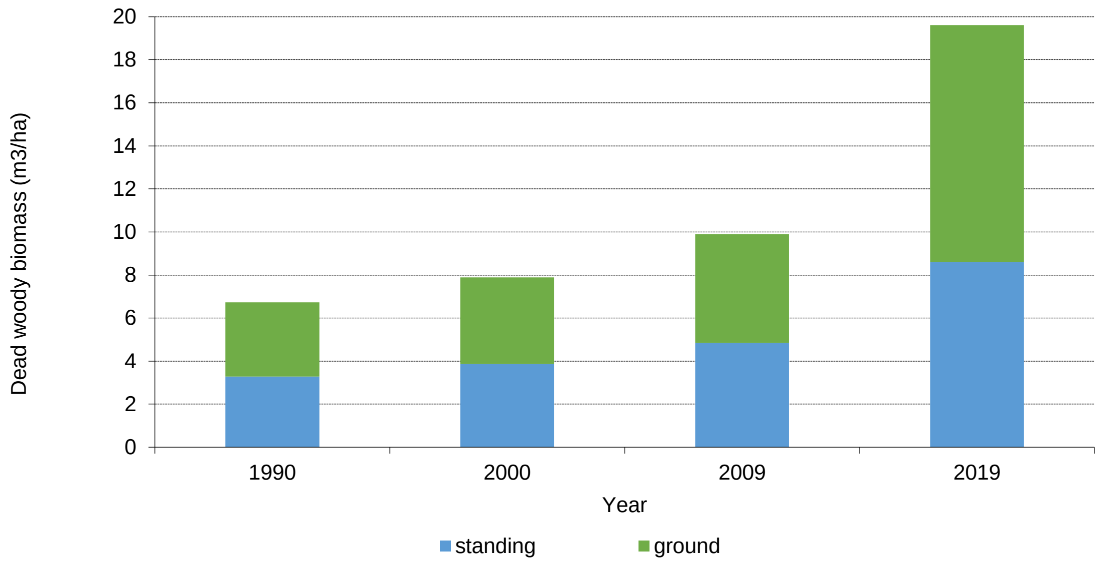

Figure 6: Amount of dead woody biomass per type (standing/ground) (ARSO, 2022)

For the purpose of optimising carbon sink management, it is sensible to leave additional dead woody biomass in stands where the economic benefit of logging is due to various factors (topography, wood quality, importance of other functions) marginal. Examples of such biomass include trees attacked by bark beetles that were not harvested in a timely manner, trees growing in very difficult conditions for felling and harvesting, individual low-quality trees in stands, and individual specimens within otherwise regenerated areas. When implementing such measures in stands with a higher proportion of conifers and other threatened stands, forest protection considerations should still be prioritised.

Habitat trees are excluded from management in order to maintain biodiversity and carbon accumulation in forests. These are dead and living trees, trees colonised by fungi and fauna, hollow trees, and trees with large dimensions and special growth form (Pravilnik …, 2016). They are left to develop naturally and are delineated outside of eco-cells and with the consent of the forest owner. Financial compensation for the retention/conservation of habitat trees is provided to private owners from the Forest Fund and the budget of the Republic of Slovenia.

3.4. Adjusting the length of production cycles

The amount of carbon sequestration depends on the growth of stands, which in turn depends on the rotation period and the intensity of intervention. In countries where the rotation period is based on technical and financial considerations, the rotation periods are usually shorter and do not allow for full utilisation of the site potential (Kotar, 2005). On the other hand, excessively long rotation periods do not allow for optimal utilisation of the site potential as the growth of stands begins to decline at a certain age. Additionally, the age of stands, which is linked to the volume of the growth stock, significantly impacts the likelihood of natural disturbances (Bentz et al., 2009, Klopčič et al., 2009).

In Slovenia, the length of rotation periods has varied in the past. In the last management period in particular, a reduction in rotation periods was observed across several forest management regions, the purpose of which was to increase the utilisation of the productive capacity of the stands and the resilience of the stands to natural disturbances. Rotation periods were particularly reduced in the case of forests converted to spruce and spruce plantations.

In the future, the length of rotation periods will need to be continuously assessed to ensure optimal carbon sequestration as well as better adaptation of forests to the impacts of climate change. Without reducing the productive capacity of stands, rotation periods can be further shortened by increasing the intensity of tending, in particular by carrying out first thinning and second thinning operations that lead to increased growth.

3.5. Increasing the area of forests excluded from regular management

By excluding certain areas from regular management, stands are temporarily or permanently left to develop naturally with the aim of accumulating live and dead woody biomass. This type of management is particularly suitable for areas of forests that are not sufficiently accessible and less economically interesting, thus further contributing to the conservation of biodiversity. Forests without intervention are divided into forest reserves and unmanaged eco-cells.

Forests reserves are forests with a special purpose (legislative status of specially protected forests) that include specific protected habitats and/or have a highly pronounced research function. Because of their structure, species composition, stage of development and evolution to date, these forests are extremely important for biodiversity conservation, provision of a carbon sink, and sustainable provision of certain other functions. Research shows that they absorb more carbon than they emit

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(Luyssaert et al., 2008). Depending on the management regime, they are divided into forest reserves with a strict protection regime and forest reserves with a reduced protection regime (Uredba…, 2020).

Areas with difficult conditions for forest production are particularly suitable for the establishment of eco-cells. With the consent of the owner, they can also be established in other forests. The establishment of permanent eco-cells, which are permanently excluded from management, is preferable. Otherwise, the forest is left to develop naturally for at least 20 years. It is preferable to establish larger areas of at least 5 ha. They are established with the consent of the forest owner. The extent of the exclusion of eco-cells from management is determined on the basis of the objectives set out in the programme of management of areas protected under Natura 2000 and forest management planning guidelines for nature conservation that are integrated in the forest management plans of the forest management units (Okoljsko poročilo, 2021).

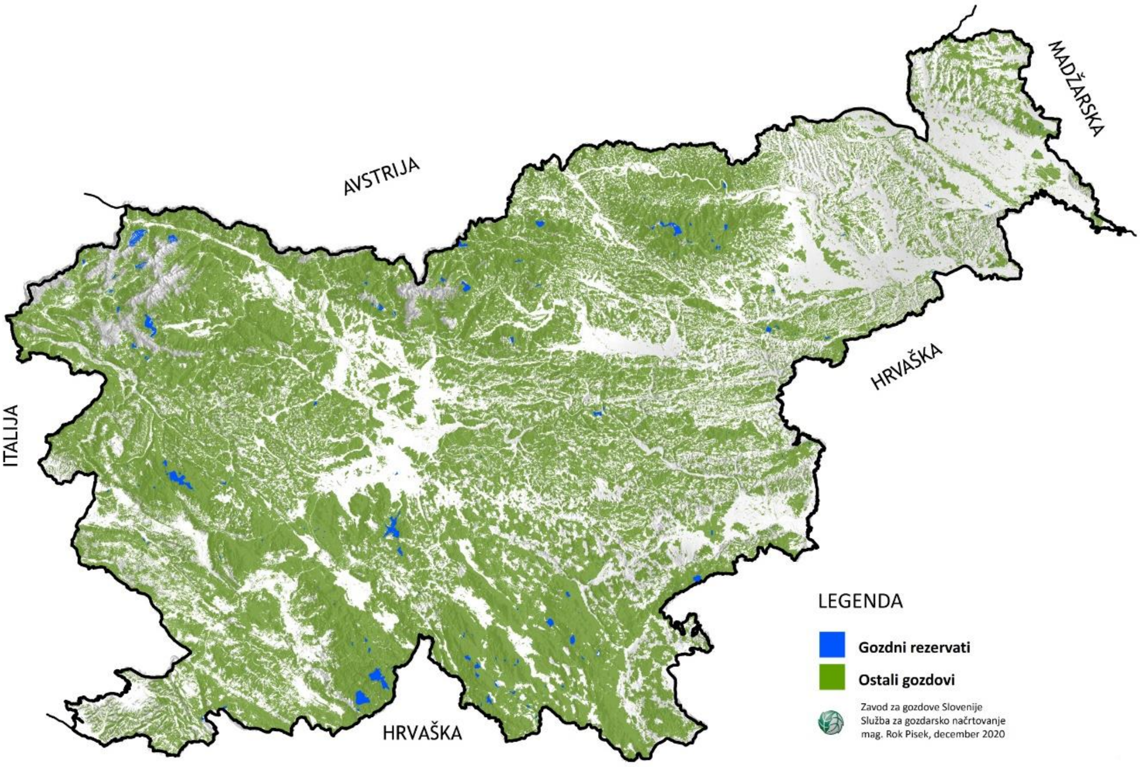

Figure 7: Forest reserves in Slovenia (ZGS, 2022)

Forests vary in their suitability for being excluded from a regular management regime. It is sensible to reduce management in forests where intervention is unprofitable due to the exceedingly demanding harvesting conditions and poor general quality of timber, or even undesirable due to the sensitivity of the growth sites, stands and habitats. On the other hand, exclusion from regular management should not be performed in forests that are exceedingly susceptible to disturbance and protective forests where intervention is necessary for maintenance of their function. Forests that are important from the perspective of the sustainable provision of timber and other forest resources should also maintain this role as wood represents an important technical raw material and energy resource that plays a key role in the process of the green transition.

The network of forest reserves must be reviewed and upsized. The network of eco-cells should be established in a planned manner in national forests, covering at least 5% of the forest area (Okoljsko poročilo, 2021). In order to ensure the accumulation of woody biomass and increase the carbon sink, all areas where intervention is not necessary due to the nature of forest stand development (e.g. younger stands with lower stand densities, stable mid-aged stands) can be temporarily excluded from management.

3.6. Increasing the sustainable use of wood

Wood, as an important renewable natural resource, has always contributed to the development of industry and the economy in the Republic of Slovenia, especially in rural areas. Therefore, for the further development of the economy, it is important to support forestry and the wood industry in order to ensure sustainable wood processing, wood use and provision of added value in the domestic environment. As wood is an energy-saving technical material and a potential long-term carbon sink, the sustainable use of forests and forest products makes an important contribution to the efficient use of energy and a cleaner environment (Resolucija …, 2007)).

A large amount of wood is still exported in the form of timber, while at the same time sawn wood products are being imported. If we want to improve the competitiveness of the forestry and wood processing sector and increase the amount of domestic wood processing, it is essential to promote the use of wood and invest in wood-processing capabilities.

Producing quality forest timber

The main measures in terms of ensuring an increase in the sustainable use of wood are the promotion of commercially interesting tree species and the production of quality timber. The main instruments for steering stand growth in this direction are forest regeneration and tending measures. The intensity of intervention can be planned on different levels. The minimum level is necessary to ensure the stability of forest stands, while the optimum level also ensures an improvement in the quality of forest timber assortments (Environmental Report, 2021).

Silvicultural measures can be used to direct stands towards the production of quality timber that can serve as material for housing construction, production of furniture or other wood products. This ensures higher levels of sequestered carbon compared to the use of wood as an energy resource. It makes sense to promote valuable broadleaves (i.e. maple, elm, cherry, oak), as they contribute positively to species diversity and economic output. The volumetric yields of broadleaves are similar to ones gained from the dominant species (i.e. beach, spruce), particularly in lowland or hilly areas. Monitoring the market situation and adjusting the timing of harvesting to this situation is essential for a favourable economic outcome (Kadunc et al., 2014). The promotion of broadleaves is important and supplements the demand for timber, which is otherwise heavily oriented towards species such as spruce, fir and beech.

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Advising forest owners on timber harvesting

The implementation of planned measures has a significant impact on the provision all forest functions. Regular harvesting has a positive impact on the stability of stands, sustainability of yields and the cultivation of quality timber. The predominantly private ownership of forest estates in Slovenia, their fragmented structure, and inadequate equipment and skillset of owners affects the realisation of potential harvesting in private forests. In addition, many owners are not economically dependent on forest work and have no interest in forest management (Marenče et al., 2012). Planned harvesting is almost fully realised in state forests, while in private forests the realisation rate is significantly lower. Private forests make up 77% of the forest area in Slovenia, so it is important for the public forestry service to intensify communication with forest owners, educational activities, informing and raising awareness among owners. The target audience are forest owners (private owners, municipalities, agrarian communities, etc.). Forest owners should be assisted in networking, obtaining funding, cooperating with other institutions and participating in the forest management planning process. They should also be provided with sufficient opportunities for education about the role and correct implementation of forest protection measures (Okoljsko poročilo, 2021).

3.7. Replacing the use of fossil fuels

The use of wood as a natural material and a renewable source of energy represents one of the key elements of sustainable development and the successful transition to a low-carbon economy. Slovenia is a country rich in wood. We must consider and utilise this competitive advantage in order to make the transition to a low-carbon society more efficient. The pillars of this transition are the processing of wood into various products with high added value and the efficient use of wood for energy purposes. Both types of usage lead to a common goal: reducing greenhouse gas emissions, improving air quality, achieving energy independence and ensuring a successful bio-economy (Strategija ..., 2019).

The use of wood and wood products contributes to the replacement of other energy sources and materials (fossil fuels, plastics and metals) and thus to a reduction in greenhouse gas emissions. The highest quality wood should be used for the production of products and materials with a longer lifespan. For the production of products with short lifespan and energy, lower quality wood, sawmill by-products, wood waste and recycled materials should be used. It is important to respect the principles of the circular economy, which involve reuse and recycling of all wood products. Systems with a local supply of woody biomass should be encouraged, as this not only prevents the release of carbon from fossil fuels, but also reduces emissions resulting from the import of energy products that do not originate locally (Resolucija …, 2022).

To improve the situation in this area, we must:

1. Improve the conditions for the more active role of forestry professionals in promoting the efficient use of woody biomass for energy purposes.
2. Increase the interest of forest owners in forest management, even in areas with a higher proportion of lower-quality forest wood.
3. Improve counselling and coordination between decision-makers and experts in the field of renewable energy (Akcijski načrt …, 2018).

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4. Adaptation of forests to the impacts of climate change

The consequences of climate change, manifested in rising average temperatures, increasing temperature extremes and more frequent natural disturbances (e.g. ice storms, windstorms, droughts, pest outbreaks, rapid spread of non-native invasive species), are also having a major impact on Slovenian forests. The main future challenge for forest management in Slovenia will be to adapt the tree composition and structure of forests to changes in the environment (Okoljsko poročilo, 2021).

Adaptive forest management measures are required for systematic reduction of vulnerability and increased resilience of forests to the expected negative impacts of climate change. This can sustainably ensure the production of timber and provision of all ecological and social functions of forests (Smernice ..., 2021).

The forest plays an important role in adapting to the impacts of climate change in a broader sense, as its protective function contributes to reduction of negative impacts of climate change on the environment and society. Therefore, it is important to maintain appropriate species and stand structure in forests that protect settlements, objects and infrastructure against various natural hazards (Okoljsko poročilo, 2021).

Measures and recommendations to improve the adaptation of forests and forestry to the impacts of climate change have been divided into the following sections:

- Forest regeneration
- Forest tending
- Technologies and infrastructure
- Forest protection
- Strengthening the protective role of forests
- Preserving biodiversity
- Systemic adjustments to forest management in Slovenia

This chapter presents a summary of guidelines for adapting forests to the impacts of climate change, which have been prepared as one of the results of project LIFE Systemic (Smernice ..., 2021).

4.1. Forest regeneration

Due to climate change, it is crucial to steer the species composition of forests towards a diverse and adapted structure that allows stands to thrive in changing environmental conditions. This can be achieved through management of the regeneration phase, as the regeneration sets the foundations for the species and genetic structure of the new stand.

The regeneration system needs to be adapted to the increasing frequency of natural disturbances and to prioritise post-disturbance measures and methods for restoring damaged forests. The aim should be to carry out regeneration measures on smaller areas, while also providing conditions for the regeneration of species with higher light requirements. In order to prevent disturbance, regeneration must be initiated in a timely manner, especially in the most threatened stands. Natural regeneration should be carried out under the cover of a mature stand wherever possible. When determining the regeneration periods, we should aim towards the shortest regeneration periods that still ensure the achievement of the targeted diversity of the future stand. Species diversity, adaptability and permanent ground cover can also be ensured by artificial regeneration, which should include the use of suitable provenances and adapted genotypes.

The species and genetic diversity of the regeneration should be as high as possible. Minority species should be supported, especially in stands where a single species is highly dominant (e.g. beech). The proportion of species with higher temperature and light requirements as well as those with pioneer characteristics, should be maintained. Support should be given to species that have been displaced by other species on certain sites (e.g. fir sites that were planted by spruce). On sites where conifer monocultures have grown in the past, sufficient stand diversity should be ensured, and spruce monocultures should be converted to a more stable stand structure through regeneration.

It is also necessary to provide support for non-native genotypes of indigenous species and for non-native species originating from neighbouring countries which may potentially thrive in the future under the changed conditions of our growing sites. It is also necessary to identify areas where non-native, non-invasive species already thriving in Slovenia (i.e. *Pseudotsuga menziesii, Juglans nigra, Quercus rubra, Pinus sp.*) can be managed without major risks. Management strategies should be also reconsidered and defined for the semi-invasive (i.e. *Robinia pseudoacacia*) and invasive non-native tree species (i.e. *Ailanthus altissima*) already present in the country.

A prerequisite for the successful implementation of all measures is to ensure sufficient genetic diversity in both natural and artificial regeneration. In order to ensure the quality of artificial regeneration, it is necessary to ensure the suitability of seed stands (sufficient genetic diversity, suitability in terms of adaptation of individuals to change, sufficient size, etc.), the sufficient quantity of harvested seeds, the appropriate cultivation of seedlings and genetic diversity of the material, which can also be achieved by combining suitable seed from different stands. Additional contributions to genetic and species diversity can be made through complementary planting and sowing. The basis for ensuring sufficient diversity is also the introduction of mechanisms for continuous monitoring of the state of genetic diversity.

4.2. Forest tending

Forest tending includes all silvicultural measures that improve the growth, quality and resilience of forests, as well as regulating the mix of tree species in young and mature forest stands. Most adaptation measures focus on changing existing practices (i.e. changing the intensity and frequency of measures) (Smernice ..., 2021).

The resilience of trees and forest stands refers to their ability to remain essentially unchanged after a natural disturbance (Roženbergar et al., 2017). The first condition for ensuring the resilience of stands is the application of tending measures of sufficient frequency and intensity. Tending of younger stands influences stand density (reducing density and decreasing the height/DBH ratio) and vertical structure, which should be as diverse as possible throughout the development of the stand. The tending approach should be adapted to the specifics of the stand and site. Traditional silvicultural approaches (i.e. selective thinning) can be combined and complimented with new approaches that have recently been developed (i.e. situational tending).

The intensity of measures should be adapted to the stand condition and existing risks (e.g. the question of delayed thinning). Selection of individual trees that stay in the stand after tending should be subjected to broader range of criteria (vigour, adaptability to conditions, quality, etc.). The increase in risk from disturbance following stand intervention can be reduced by shortening the return interval of the management interventions.

In the context of the irregular shelterwood system, we should aim to manage smaller areas and maintain the stepped structure of the forest edge. It is necessary to promote structures with permanent uneven aged structure and preserve viable survivors in areas of past disturbance. Protective forests should also be actively managed.

4.3. Technologies and infrastructure

The guidelines that we have already mentioned in the previous two chapters should be followed when planning the technologies for the implementation of measures. It is crucial to strive for small-scale harvesting, which should be spatially oriented based on the position of rejuvenated areas and vulnerability of the stands. Production must be planned so that new internal forest edges are, if possible not directly exposed to strong winds and direct sunlight. When selecting technology, we should encourage the use of technologies that preserve forest soils (maintaining the production capacity of growth sites and carbon stocks in soils, protecting water sources, etc.) and allow for selective logging or less intensive interventions.

4.4. Forest protection

The impacts of climate change are expected to intensify as temperatures continue to rise and the likelihood of extreme weather events increases. Protection against natural disasters should be based on prevention, i.e. diverse stand structure, natural species composition, appropriate methods and timing of forest works as well as application of preventive measures when managing logging debris. Protection measures should place a special focus on vulnerable forests.

Pest and disease management – biotic factors

In order to prevent the negative impacts of bark beetles, it will be essential to modify the tree composition of the most threatened stands, which in pure spruce monocultures can also be carried out by means of controlled gradual conversion. Such measures will be particularly useful on sites where spruce plantations that are prone to bark beetle infestations threaten natural stands with a higher share of spruce. In addition to changing the tree composition, it will also be necessary to ensure that the planned forest management regime is implemented and that we have technologies and infrastructure allowing for rapid and effective sanitary logging. Damaged areas will need to be restored with seedlings adapted to the changed and more difficult conditions for development.

In order to mitigate the threat posed by invasive alien species, it will be necessary to ensure regular inspections for the early detection of harmful organisms on our territory and to provide a rapid response to any findings.

Natural disturbance management and fire prevention – abiotic factors

As in the case of the bark beetle, it will also be necessary in relation to abiotic factors to first identify the most endangered stands and plan specific adaptation measures for them.

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For fire-prone forests, it will be important to consistently remove combustible biomass, which can be done in various ways (e.g. by removal, grazing, tending and potentially also controlled burning). In certain stands, it will be necessary to adjust the tree composition to include a higher proportion of species with lower flammability (e.g. broadleaves compared to conifers). In terms of systemic and organisational solutions, it will be necessary to first update fire protection plans and use them to establish or update the necessary fire protection infrastructure. It will also be necessary to establish systems for coordinated response and regular communication among all fire protection services, and to ensure adequate public awareness and education.

For the purpose of preventing windstorms, it will be necessary to implement measures that encourage more favourable dimension ratios and stand structure diversity. These measures should be planned in such a way as to best ensure consistent forest canopy coverage. It will also be necessary to spatially plan harvesting in a way that minimises the formation of new sharp forest edges over large areas and on exposed sites that are susceptible to windthrow. It would also be sensible to investigate shortening rotation periods in order to increase stand stability.

It will be important to implement timely tending measures in relation to both windthrow and snow damage. In particular, excessive thinning can increase the susceptibility of trees to snow damage.

4.5. Strengthening the protective role of forests

As the impacts of natural disturbances on the environment increase, the protective role of forests for forests and society will also increase. The optimal achievement of the objectives related to these functions will be significantly influenced by active and site-adapted measures to ensure appropriate species diversity and stand structure. It will be particularly important to assess and implement adapted measures in stands where the wood stock is greater (fallen dead trees and increased likelihood of disturbance impacts) and in sites where there is a high risk of erosion (importance of maintaining constant coverage and diverse structure; ensuring the presence of deep-rooted species).

4.6. Preserving biodiversity

To maintain biodiversity and gene flow, protecting large forest areas at the landscape level will be key, as they are crucial for maintaining the resilience and diversity of populations and connecting corridors between larger forest complexes. Connectivity will also need to be strengthened by planning and designing new ecological corridors in the landscape. It will be necessary to prevent further fragmentation of forests and increase the proportion of eco-cells, especially those intended for endangered species that are confirmed to be present in a given area. It will be necessary to redefine and implement forest management in terms of recreation and tourism in the forest area. Creating diverse and robust forest edges will also have a positive impacts on biodiversity conservation.

4.7. Systemic adjustments to forest management in Slovenia

Adaptation of forest management planning

As climate change brings a high degree of uncertainty to forestry, forest management planning will have to adapt accordingly. Planning will need to become more dynamic, take into account multiple scenarios (especially for vulnerable forests) and provide separate goals and measures for them. Additionally, in the future, changing needs of society, particularly in terms of social functions, will need to be taken into consideration. Further investments in the development of forest development models, which are important supporting tools in decision-making, will be required, as will investments in methods for monitoring the state of conditions in the forest.

Adaptation of forest infrastructure and technology

Adequate and technologically appropriate forest infrastructure and technology for implementing measures in forests will be crucial for an appropriate response to the impacts of climate change on forests. Forest road access (including protective forests requiring regular management interventions) will be a prerequisite for the implementation of sanitary logging and measures that promote the stability and resilience of stands. In addition to forest roads, it will be necessary to provide round wood storage facilities that allow timber to be stored in accordance with the principles of forest protection (e.g. in the event of a bark beetle attack) and to provide relief to the market in the event of increased timber volumes that arise as a result of natural disturbances. Because droughts will also play an important role in the future, it will be important to manage water resources in the forest in a planned, preventive manner. Such strategic measures include preventing a drop in the groundwater supply by restoring water regimes in floodplain forests and deactivating drainage systems.

Forest seedling and seed production

Access to quality and genetically diverse reproductive material is a prerequisite for the successful restoration of large areas of damaged forest. In order to ensure that nurseries will be able to provide an adequate amount of quality seedlings in the future, it will be necessary to ensure adequate production capacity of forest nurseries that can quickly be activated in the event of natural disturbances and increased demand for seedlings/seed. At the same time, it will be necessary to ensure a constant supply of seed from different tree species, store seed that maintains its viability over time and can be used for rapid seedling growth in the event of increased disturbance. When introducing seedlings to the field, planting mixed batches of seedlings grown from seed from different seed stands of appropriate provenance is recommended.

Adaptation of national forest policy

To ensure that adaptation measures are fully put into practice, certain systemic, organisational and financial changes to the existing system and policies will need to be made to ensure that the measures are fully implemented in practice and that the process is financially viable. Before this, the mitigation and adaptation strategy will need to be coordinated with all stakeholders involved in process of forest management. In addition to the legislative and financial prerequisites, it will be necessary to ensure that all stakeholders are sufficiently informed and connected. This will ensure that existing potential (funding, measures) is fully exploited and that new management adaptations are developed as a result of cooperation and communication between both researchers and experts working in the field.

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