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Guidelines on Biodiversity-Friendly Afforestation, Reforestation and Tree Planting

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GUIDELINES

ON BIODIVERSITY-FRIENDLY AFFORESTATION, REFORESTATION AND TREE PLANTING

These guidelines have been prepared through active dialogue with Member State experts and key stakeholders and are based on a collaborative approach. The list of Member State authorities and organisations of stakeholders and civil society who have participated in developing this document is included at the end of the document (Annex III). The Commission would like to thank them all for their efforts.

Particular thanks goes to the representatives from Portugal (ICNF - Instituto da Conservação da Natureza e das Florestas) and Spain (MITECO - Ministerio para la Transición Ecológica y el Reto Demográfico), who co-led the process of drafting these guidelines.

Unless a source (e.g. good practice) directly refers to a Member State or an organisation, the responsibility for this content, lies with the European Commission services. The text might not necessarily reflect the views of all the listed individual authorities and organisations, since it includes compromise drafting for elements on which views in the group significantly diverged.

INTRODUCTION

Under the European Green Deal, the EU's Biodiversity Strategy for 2030[1] tackles the protection and restoration of nature by making a number of specific commitments and setting several targets. Biodiversity-friendly practices for enhancing the quantity and quality of EU forests are also being promoted. The Biodiversity Strategy announced, among other objectives, guidelines on biodiversity-friendly afforestation, reforestation and tree planting. Among other things, these will contribute to the pledge to plant at least 3 billion additional trees in the EU by 2030, in full compliance with ecological principles.

A roadmap to implement this pledge is included in the new EU Forest Strategy[2] that was adopted in July 2021[3]. In addition, these guidelines support the general EU agenda on biodiversity by contributing to our global commitments under the UN Convention on Biological Diversity. They would also support other key initiatives under the European Green Deal at implementation level, in particular the Nature Restoration Law[4], the Certification Framework for Carbon Removals[5] and the Soil Mission[6].

This document has been prepared through active dialogue with Member State experts and key stakeholders to ensure it is user-friendly, fit for purpose, and based on a collaborative approach. It can complement regulatory frameworks on forestry or biodiversity conservation at national, regional or local level. The guidelines are voluntary and not prescriptive, nor do they constitute a binding condition - for example – for support by State aid or EU funding. These guidelines aim to offer a useful source of information and advice to help authorities, forest and land owners, site managers and civil society to better implement biodiversity-friendly afforestation, reforestation and tree-planting projects. They are designed to complement national guidelines (if they already exist). They have been drafted to allow for flexibility to choose the best-suited solutions depending on the local context. These guidelines should be updated as necessary in future in light of the results of their implementation, new experiences and updated best practices.

The aim of these guidelines is therefore to:

- Promote tree planting that supports biodiversity, climate mitigation and resilience at their best, without neglecting socio-economic benefits.

- Help competent authorities and key stakeholders responsible for forest, farm and urban management, nature conservation groups and Academia to develop and promote biodiversity-friendly practices in afforestation, reforestation and tree-planting initiatives, including at local level.

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[1] COM (2020) 380. The Council adopted its Conclusions on 23 October 2020.
[2] COM (2021) 572
[3] The roadmap is contained in the Commission Staff Working Document accompanying the new EU Forest Strategy [SWD (2021) 651] of 16.07.2021.
[4] COM(2022) 304 final.
[5] COM(2022) 672 final.
[6]https://research-and-innovation.ec.europa.eu/system/files/2021-09/soil_mission_implementation_plan_final_for_publication.pdf

- Promote the integration of biodiversity-friendly afforestation, reforestation and tree-planting into wider conservation and restoration objectives. These should also be included in policies and plans, e.g. in support of the Habitats Directive and the Water Framework Directive.

- Promote ecological principles and nature-based solutions[7] adapted to different ecosystems, from anthropogenic landscapes, such as urban environments and plantations, through to semi-natural areas and more natural forest ecosystems. This framework of ecological principles is built around:

  - Preserving and enhancing habitat characteristics and biodiversity, including genetic diversity.
  - Encouraging natural regeneration wherever feasible.
  - Promoting the concept of green infrastructure[8] across entire landscapes and individual sites, representing a mosaic of interacting land uses and management practices.
  - Restoring, maintaining and enhancing ecosystems and their multiple ecological, social and economic functions within landscapes, for the benefit of multiple stakeholder groups.
  - Avoiding adverse impacts on natural ecosystems while enhancing their conservation and recovery.
  - Producing positive and tangible benefits in terms of mitigation and adaptation to climate impacts.

- Promote adaptive management in afforestation, reforestation and tree planting for:

(i) long term resilience against climate change impact and natural/human-induced disasters;

(ii) biodiversity, by continually integrating design, management, monitoring and systematic test assumptions, in order to learn and adapt when necessary[9].

- Highlight the importance of mutual information, understanding, cooperation, and sharing good practices between all affected parties.

Scope:

These guidelines address:

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[7] Nature Based Solution are defined as "Solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions". https://research-and-innovation.ec.europa.eu/research-area/environment/nature-based-solutions_en

[8] Green Infrastructure (GI) can be defined (COM/2013/0249 final) as a strategically planned network of natural and semi-natural areas with other environmental features designed and managed to deliver a wide range of ecosystem services. It incorporates green spaces (or blue if aquatic ecosystems are concerned) and other physical features in terrestrial (including coastal) and marine areas. On land, GI is present in rural and urban settings.

[9] Salafsky, N., Margoluis, R., & Redford, K.H. (2001). Adaptive management: A tool for conservation practitioners.

- afforestation initiatives in agricultural land
- reforestation activities in forest land, including restoration objectives
- tree planting in urban, peri-urban environments and agricultural land.

Both active planting and natural regeneration are covered in this document.

The document is therefore organised as follows:

Part I: focuses on how to:

(i) include afforestation and reforestation initiatives in the framework for preserving biodiversity and restoring forest ecosystems.
(ii) choose tree species and make planting successful.

Part II focuses on rewilding and creating ecosystems that benefit biodiversity in urban environments. It also concerns the general challenges of planting trees in urban areas.

Part III provides a concise overview on tree planting in the context of agroecosystems.

An **additional chapter (IV)** introduces the topic of financing afforestation, reforestation and tree planting across the landscapes dealt with in the previous three parts[10].

TARGET AUDIENCE

These guidelines are addressed to all those involved in afforestation, reforestation and tree planting in different landscapes (forest, urban and agroforestry):

- forest and land owners and managers;
- public authorities;
- environmental NGOs;
- academia, interested associations, individuals.

Depending on the level of knowledge and expertise of the reader, not all the information contained in this document might be considered as equally important. The reader will find the recommendations in the main part of the document, while the annex contains further supporting information such as references to legislative and policy documents and good practices.

DEFINITIONS

Strategies

- **AFFORESTATION**

[10] This will be further developed and complemented by a guidance booklet on financial sources supporting action under the '3 billion trees' pledge, that will be produced in 2023.

Establishment of a forest through planting and/or seeding on land that, until then, was under a different land use. Implies a transformation of land use from non-forest to forest[11].

- **REFORESTATION**
  Re-establishment of a forest, through planting and/or seeding, on land classified as a forest[12].

- **TREE PLANTING**
  Planting a single or small groups of trees[13], not falling under the definition of afforestation or reforestation.

Methods

- **NATURAL REGENERATION**
  Establishment of trees or groups of trees by natural seeding (self-sown seeds), or vegetative propagation[14].

- **ARTIFICIAL REGENERATION**
  Establishment of a tree or groups of trees by direct seeding (sowing) or planting seedlings or cuttings[15,16].

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[11] Source: FAO (FRA). The term "deliberate" (before "seeding") in the FRA definition has been omitted to clarify that natural regeneration is also covered.

[12] Source: FAO (FRA). The term "deliberate" (before "seeding") in the FRA definition has been omitted to clarify that natural regeneration is also covered. Reforestation implies no change of land use and includes planting or seeding of temporarily unstocked forest areas as well as areas that were previously forested but temporarily below the optimal canopy threshold, due to harvesting or disturbances. It should be observed that this definition is instrumental to the use of the recommendations included in these guidelines, which aim at having a broad scope, and does not wish to fully align the various existing definitions at international level. For example, according to definitions used by the UNFCCC, the term *reforestation* does not include rejuvenation/regeneration within an ongoing forestry scheme, but the recommendations included in these guidelines would still apply.

[13] Under the '3 billion additional trees' pledge, not only trees but also woody vegetation can be counted.

[14] Source: EFI, adapted for the purposes of these guidelines. https://efi.int/sites/default/files/files/publication-bank/2018/ir_06.pdf

[15] Source: EFI, adapted for the purposes of these guidelines. https://efi.int/sites/default/files/files/publication-bank/2018/ir_06.pdf

[16] Where artificial regeneration is used, this should always be well justified, and it should ideally be in combination with natural regeneration. Situations where it would be the only alternative include:

- Reduced natural genetic diversity due to the historic use of uniform regeneration materials, and/or not appropriate genetic sources
- Unsuccessful natural regeneration (e.g. due to absence of seed trees). The introduction of woodland islets, with high biodiverse native species, might be a way of combining natural and artificial regeneration in areas without seed trees.
- Need for assisted migration to facilitate climate-adapted regeneration. This must in any case be a cautious approach, prioritising species from close regions of origin/provenance.
- Focus on restoring a suitable habitat for a species: e.g. planting fruits trees for creation of food habitat of a precise species such as bear.

See also section 4 of part I.

PART I —FOREST ECOSYSTEMS

Even though afforestation and reforestation activities have been promoted for a long time, they have generally focused mainly on timber production. Nowadays new afforestation and reforestation programmes are required to meet multiple objectives, such as carbon sequestration, reducing environmental and climate-related risks, and increasing biodiversity[17].

Forests are complex ecosystems providing several ecosystem services. This section addresses how biodiversity can be enhanced in forest ecosystems in relation to afforestation and reforestation, or via a combination of them. These actions and processes can take place in four main cases[18].

Reforestation:

1. After planned tree harvesting.
2. After stands get damaged (through storms, forest fires, droughts, pests, etc.)
3. Restoration/enrichment planting, with a view to the future diversification of the forest stand.

Afforestation:

4. Conversion of land (either farmland or urban areas) into a forest.

1. RECOMMENDED ACTIONS BEFORE AFFORESTATION AND REFORESTATION

1.1. Choose the correct area

To promote biodiversity and ensure the viability of the trees, we need to choose the correct area. In recent decades, forested areas, particularly in Mediterranean and mountain areas previously used for marginal crop and livestock farming, have expanded through land abandonment (and related natural regeneration) and afforestation.

While initially appearing to be positive, this can also cause a loss of non-forest biodiversity associated with open ecosystems, as light-demanding low-level vegetation is replaced by trees[19]. Moreover, if the area is not correctly chosen, in the long term the newly established forest stands might suffer due to unfavourable abiotic and biotic conditions, leading to the failure of the afforestation effort. There are several examples in scientific literature that outline the necessity to evaluate the plot and to practice adaptive management before and while acting, in order to reap all the benefits and avoid possible damage.

[17] Pérez-Silos, I., Álvarez-Martínez, J.M. & Barquín, J. Large-scale afforestation for ecosystem service provisioning: learning from the past to improve the future. Landscape Ecol 36, 3329–3343 (2021). https://doi.org/10.1007/s10980-021-01306-7

[18] Even if, conceptually, afforestation is not taking place in forests but implies that land that was under a different use becomes forest land, afforestation leads to new forest ecosystems. Therefore it is included in this section.

[19] Muys, B., Angelstam, P., Bauhus, J., Bouriaud, L., Jactel, H., Kraigher, H., Müller, J., Pettorelli, N., Pötzelsberger, E., Primmer, E., Svoboda, M., Thorsen, B.J., Van Meerbeek, K. 2022. Forest Biodiversity in Europe. From Science to Policy 13. European Forest Institute. https://doi.org/10.36333/fs13

Crucial considerations:

The policy context: to choose the right area to afforest or reforest, it is paramount to have a clear knowledge of the applicable legislation and requirements at EU/national/local level.

- **Areas to avoid** – land that already has a high climate mitigation potential and/or biodiversity value. And/or land where providing ecosystem services[20] could be negatively affected by afforestation/reforestation. To maintain existing hydrological dynamics and remarkable habitats, **the afforestation of wetlands must always be avoided[21]**. Examples of wetlands include marshes, reeds, peat soil, annual flooded areas and peatlands. In these areas, adequate ecological restoration practices and supporting natural habitats may have a greater impact on biodiversity, ensure a higher resilience and enable more ecosystem services.
- **Landscape ecology** – the creation of forest habitats for biodiversity may also need to focus on landscape distribution, configuration, and connectivity of patches, among other considerations[22]. Biodiversity conservation, restoring relevant habitats and species (including their conservation objectives) need to be considered in particular but not only for protected areas such as Natura 2000 sites.
- **Landowners** – the wishes of the private or public landowner are obviously essential. Having dialogue is important.
- **Consult other parties** – to the extent possible, take into account the concerns of civil society and neighbouring communities at local level.

1.2. Evaluate the biodiversity and soil

Before starting to plant, it is recommended to analyse what is already present on the site.

- **Identify the habitat**

This is essential in order to identify the appropriate choice of species. It is particularly important in relation to afforestation, given that this action implies a change from an open habitat to a forest habitat. It is equally important in the case of reforestation, either after cutting or more often in the event of recovery following climatic, fire or health events.

It is important to assess if the tree species that were last present were appropriate for biodiversity and the appropriate ecosystem function. In all cases, you should assess whether the change of habitat is appropriate, taking into consideration the value of the biodiversity present in the plot. The assessment should also factor in the landscape in which the relevant plot is situated. The assessment of existing habitats and ecological functions could in some cases - subject to possible requirements in national legislation - even suggest not to

[20] Pérez-Silos, I., Álvarez-Martínez, J.M. & Barquín, J. Large-scale afforestation for ecosystem service provisioning: learning from the past to improve the future. Landscape Ecol 36, 3329–3343 (2021). https://doi.org/10.1007/s10980-021-01306-7

[21] An exception could be the restoration of degraded or deforested alluvial woodlands.

[22] Part III of this document further develops this point.

afforest/reforest. Valuable biotopes, such as springs, water bodies, peatlands, rocks and rare forest types should be protected[23].

- **Soil type and health**

To choose the right species, it is essential to evaluate the soil's intrinsic characteristics. In particular, the soil's health and depth should be assessed. Soil-intrinsic characteristics are key factors in the ecological context. For instance, in riparian environments, the chosen species must be capable of living in wet soils, with little or no air available for the roots. Also, special attention should be given to arid and semi-arid ecosystems. In these ecosystems, trees not adapted to the local environment may lead to environmental degradation or a regression in some of the soil's functional properties[24]. This also applies to trees planted with particularly impacting techniques, using heavy machinery and landform changes.

The soil-intrinsic characteristics must always be assessed, to ensure you avoid inadequate afforestation projects and always promote biodiversity. Soil permeability, water-holding capacity, along with presence and availability of nutrients must be taken into account before tree planting. Possible pollutants and contaminants, including new evidence should also be examined. For example, natural gypsum soils have been afforested after being considered degraded, while they host very singular species[25].

Another point is the importance of taking adequate action before reforesting soil forests after forests fires[26]. Even if post-fire salvage logging has historically been widely practiced by forest managers, several studies show that felling and removing burnt tree trunks may hamper forest regeneration. This is because it can increase soil erosion and compaction, reduces nutrient availability, damages the seedling bank or reduces species richness and diversity.

As a result, there are increasing calls to implement less aggressive post-fire treatment policies and actions, while possible phytosanitary measures should also be taken into account. Partial cut plus lopping (i.e. felling most of the trees, cutting the main branches, and leaving all or part of the biomass in situ) has proven successful in Mediterranean forests[27], not only for the physical protection of the soil, but also for recovering soil fertility and nutrient availability.

[23] Muys, B et al, cit. footnote 19 above.

[24] Cao, Shixiong et al. (2010). Damage Caused to the Environment by Reforestation Policies in Arid and Semi-Arid Areas of China. Ambio. 39. 279-83. 10.1007/s13280-010-0038-z. Romero-Diaz, A., Belmonte-Serrato, F. and Ruiz-Sinoga, J.D. (2010), The geomorphic impact of afforestation on soil erosion in Southeast Spain. Land Degrad. Dev., 21: 188-195. https://doi.org/10.1002/ldr.946. Maestre F, Cortina J, Bautista S, Bellot J, Does Pinus halepensis facilitate the establishment of shrubs in Mediterranean semi-arid afforestations?, Forest Ecology and Management, Volume 176, Issues 1–3, 2003, Pages 147-160, ISSN 0378-1127, https://doi.org/10.1016/S0378-1127(02)00269-4

[25] Escudero, A., 2009. 1520 Vegetación gipsícola mediterránea (Gypsophiletalia) http://www.jolube.es/habitat_espana/documentos/1520.pdf.

[26] Taking also into account forest fires prevention actions.

[27] Castro J, Allen C, Molina-Morales M, Marañón-Jiménez S, Sánchez-Miranda Moreno A, Zamora, R (2011). Salvage Logging Versus the Use of Burnt Wood as a Nurse Object to Promote Post-Fire Tree Seedling Establishment. Restoration Ecology. 19. 537 - 544. 10.1111/j.1526-100X.2009.00619.x.

Anti-erosion and flood control works such as log/stem barriers[28], wooden dams and mulching has also proved to be succesful in certain situations for reducing post-fire runoff and erosion[29]. The presence of active degradation processes such as gully erosion may need additional and specific consideration before afforestation or reforestation can take place. Basic soil nurture and plantation techniques may not be sufficient to address this issue. Innovative techniques such as geomorphic restoration can therefore also be considered[30].

1.3. Choose the right species

The choice of tree species, within what may be allowed by applicable legislation, is the key to success. It must ensure, among other things, the stability, non-deterioration, structural heterogeneity and composition, resilience and genetic diversity of the future forest.

Below are listed the most important elements to be considered to ensure biodiversity-friendly and climate-adapted afforestation and reforestation, taking into account that resilient forests are also essential for climate mitigation. Please also see section 1.3.4, which specifically addresses strategies in the time of climate change.

1.3.1. Choose species adapted to the local ecological and climatic conditions and habitats

Each species has its own requirements for soil quality, climate, physiography and water supply.

When choosing a suitable tree species, you must take into account its requirements in terms of habitat and the local ecological context. The site needs to be assessed to identify the appropriate habitat type and find out whether a given species is right for that place. Please also take into account future environmental changes due to climate change and related risks.

1.3.2. Focus on native species

Compared to extensive plantation programmes, restoring native forests has proven to be a better way of promoting biodiversity and more efficiently providing critical ecosystem services such as carbon storage, soil erosion control and water provisioning[31].

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[28] The project STONEWALLS for LIFE also proved the use of drystone walls to prevent/address erosion and run-off: https://www.stonewalls4life.eu/

[29] Prats S, MacDonald L, Monteiro M, Ferreira A, Coelho C, Keizer J, Effectiveness of forest residue mulching in reducing post-fire runoff and erosion in a pine and a eucalypt plantation in north-central Portugal, Geoderma, Volume 191, 2012, Pages 115-124, ISSN 0016-7061, https://doi.org/10.1016/j.geoderma.2012.02.009.

[30] Martín Duque JF, Zapico I, Bugosh N, Tejedor M, Delgado F, Martín-Moreno C, Nicolau JM, Somolinos A, Quarry land stewardship history: From ancient and recent land degradation to sensitive geomorphic-ecological restoration and its monitoring, Ecological Engineering, Volume 170, 2021, 106359,ISSN 0925-8574,https://doi.org/10.1016/j.ecoleng.2021.106359.

[31] Hua, F., Bruijnzeel, L. A., Meli, P., Martin, P. A., Zhang, J., Nakagawa, S., ... & Balmford, A. (2022). The biodiversity and ecosystem service contributions and trade-offs of forest restoration approaches. Science, 376(6595), 839-844.

Indeed, several studies[32] comparing the diversity of species associated with native and non-native species[33] point to a quantitative and qualitative difference between them. The specific biodiversity associated with non-native species is on average lower than that associated with native species. This trend depends on the different taxonomic groups and the specific context. For example, lichens and mycorrhizal fungi appear to be particularly sensitive to the native character of tree species. When promoting biodiversity-friendly afforestation, reforestation and tree planting activities, this factor needs to be clearly considered.

However, in very specific cases and conditions, some non-native species adapted to the local soil, climatic and ecological context and habitat conditions can play a role in fostering increased resilience to climate change. They can in some cases be used as “pioneer species” to shelter native species during the early years of afforestation. The non-native species can then be removed through early thinning. These specific cases should in any case be assessed through the lens of promoting biodiversity-friendly afforestation, reforestation and tree planting activities.

Which species are native?

To find out the natural distribution of a species[34], there are many sources of information available, such as the maps of the European Atlas of Forest Tree Species[35] or those proposed by the EUFORGEN project[36]. Site-specific research can also be considered for a more tailored approach.

Examples from Member States:
Spain: information about the distribution of tree species and the area of origin[37].

In Poland, 95% of seeds used for regeneration come from stands of local origin. The possibilities for seed transfer are defined by an ordinance drawn up by the Ministry for the Environment on the basis of the country's natural and forestry regionalisation[38].
In addition, for more than 25 years, the most valuable resources of trees and stands have been collected in the Forest Gene Bank Kostrzyca, by the State Holding of Polish Forests[39].

[32]Kennedy &Southwood -1984/Newton and Haigh 1998 — Branch and Dufrêne, 2005 in Branquart and Liégeois, 2005.

[33] Non native species are species whose natural area is outside the territory in which it is located and which has been introduced into it, relatively recently.
It is generally considered that a species that has been present in a territory for several centuries and is now developing spontaneously is acclimatised. According to the time a species has been present in a given territory, there is a division into "archaeophytes" (present before the beginning of the world trade in 1500 CE) and "neophytes" (introduced after this date). "Archaeophytes" such as chestnut and walnut are often considered to be native species. This is in any case more a theoretical distinction than one with practical consequences, since many fruit species from other continents were present in Europe well before 1500 CE.

[34]The list of endemic European tree species is available as an annex to the IUCN publication https://portals.iucn.org/library/sites/library/files/documents/RL-4-026-En.pdf

[35]https://forest.jrc.ec.europa.eu/en/european-atlas/atlas-download-page/

[36]http://www.euforgen.org/distribution_maps.html

[37] https://www.miteco.gob.es/es/biodiversidad/servicios/banco-datos-naturaleza/informacion-disponible/formaciones_arboladas.aspx
https://www.miteco.gob.es/es/biodiversidad/temas/recursos-geneticos/geneticos-forestales/rgf_regiones_procedencia.aspx

[38] https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20150001425

[39] https://www.lbg.lasy.gov.pl/.

Which species

1.3.3. Avoid introducing invasive alien species

Alien species are any live specimen of a species, subspecies or lower taxon of animals, plants, fungi or micro-organisms which are introduced outside their natural range. This includes any part, gametes, seeds, eggs or propagules of such species, as well as any hybrids, varieties or breeds that might survive and subsequently reproduce.

The term 'invasive alien species' (IAS) means an alien species whose introduction or spread has been found to threaten or adversely impact biodiversity and related ecosystem services[40].

IAS represent a major and increasing threat to native European flora and fauna and cause billions of euro worth of damage to the European economy every year. The planting of species that are listed in the Invasive Alien Species Regulation as "IAS of EU concern" is forbidden. Also, national IAS regulations must be followed, since additional national restrictions may be applicable. Consideration should also be given to national guidelines on the potential invasive character of species[41], in order to prevent their accidental/involuntary introduction.

1.3.4. Take climate change into account

The current distribution of tree species in Europe is the result of geographical and ecological factors such as climate, soil fertility, the presence of predators or plant pests, and human influence. Faced with changes in these factors, species must either adapt locally (which requires several generations) or migrate to follow the shift in favourable conditions, as was the case in Europe at the end of the last ice age.

Anthropogenic climate change is rapidly affecting the condition of Europe's forests in terms of temperature regime, water availability and nutrient cycles, and will transform many of them over the course of this century. Europe's vegetation zones have already started to move upwards and northwards. By the end of this century and under a high emissions scenario, trees may grow in many of today's arctic and alpine tundra ecosystems. The transition zone between temperate broadleaved and boreal conifer forests could move several hundred kilometres northwards, and shrublands may replace the forests of Southern Europe. Scientific studies suggest that, for example, the potential distribution areas of the main forest species could move from 500 to 1 000 km northwards. This could also occur at the same latitudes but at higher altitudes where possible, even in the most proactive scenarios of limiting warming to about + 2 °C. Climate change is also likely to increase the risk of desertification in some parts of Europe. Altogether, 31 to 42% of Europe's land area could belong to a different 'potential natural vegetation' zone, depending on the emissions scenario and circulation model used[42].

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[40] Definitions from Regulation (EU) No 1143/2014 of the European Parliament and of the Council of 22 October 2014 on the prevention and management of the introduction and spread of invasive alien species.
[41]For example, in Belgium: https://ias.biodiversity.be/ and in Spain: https://www.miteco.gob.es/es/biodiversidad/temas/conservacion-de-especies/especies-exoticas-invasoras/default.aspx
[42]Hickler, T., Vohland, K., Feehan, J., Miller, P.A., Smith, B., Costa, L., Giesecke, T., Fronzek, S., Carter, T.R., Cramer, W., Kühn, I. and Sykes, M.T. (2012) Projecting the future distribution of European potential natural

A recent study indicates that projected climate change will foster a progressive decrease in beech growth[43]. As beech is a dominant tree species across large regions of Europe's forests, this indicates an important reduction in their functioning as a carbon sink to mitigate atmospheric CO_2 increases. Furthermore, as beech is of high commercial and environmental importance, a long-lasting decrease in productivity may be critical at multiple levels.

The reality will of course depend on actual climate change and its impact at the local level.

Climate change does not take the form of a continuous shift, but rather a succession of accidental phenomena. The major storms of the last 20 years and plant health crises such as the current bark beetle outbreaks in Europe show the magnitude of this, confirmed by fires outside the Mediterranean area. This is a much more unstable context, with a reasonably likely scenario of major and frequent crises affecting significant areas.

Moreover, a forest is a complex ecosystem, not just a group of trees. During spontaneous migration, a tree never moves alone, but with a host of organisms that facilitate its local integration. A tree settles and lives in a place by recruiting fungi that help its roots to feed, mites that protect its leaves, decompose its dead wood, etc. Genetic drift is caused by random phenomena. Within an isolated population with a small number of individuals, it leads to a loss of diversity, though this becomes negligible if the population is larger.

With much remaining uncertain, the following key points call for a precautionary approach:

- In many situations, environmental conditions will no longer allow given tree species or trees in general to survive.
- The nature of the forest dynamics that will be triggered can be uncertain. For example, the impact of pioneering species arising after major die-offs of beech or coniferous trees in areas where they currently dominate is largely unknown. It is therefore almost impossible to anticipate the composition, structure and, above all, the productivity of future forest ecosystems that will replace the present ones.
- The details, timeframes and geographical extensions of the changes that will take place are also largely unknown. The complexity of the processes and interactions involved remains a major research topic, and forest managers can only partially rely on forecasts and solutions validated by experience. Variability depending on local contexts is also likely to be very significant, as already demonstrated by current observations.

This makes it even more difficult to successfully implement choices for trees species to successfully grow, taking into account future natural conditions. A cautious, gradual approach to species change might be necessary, based on proper long-term monitoring of climate change impact on particular species and in particular in the context of these guidelines, which intend

vegetation zones with a generalised, tree species-based dynamic vegetation model. Global Ecology and Biogeography, 21: 50-63. https://doi.org/10.1111/j.1466-8238.2010.00613.x
[43] Martinez del Castillo, E., Zang, C.S., Buras, A. et al. Climate-change-driven growth decline of European beech forests. Commun Biol 5, 163 (2022). https://doi.org/10.1038/s42003-022-03107-3

to promote better consideration of biodiversity needs in afforestation, reforestation and tree planting.

Several factors must be considered when deciding whether to opt for suitable seed sources/tree species or rather to broaden the genetic range of native species through assisted migration. The decision must be based on the capacity to diagnose ongoing changes and the integrative and adaptive management, which is needed in a time of crisis. The reasoning must also be based as much as possible on nature.

This also calls also for closer-to-nature solutions, such as supporting the natural regeneration and creation of mixed stands to support forest stand resilience. The biodiversity of forests will undoubtedly determine their capacity for resilience and evolution.

A global, integrated and interdisciplinary approach combining foresters, ecologists, geneticists, and experts from other fields is greatly needed. It is important to obtain expert advice on the climate scenarios and therefore climatic conditions of the area in the medium/long term.

Which strategies?

A diversification of responses should be sought to adapt the new population to future climatic conditions. This should take into account the functioning of the ecosystem as a whole. The mixing of species, preferably with different hydric properties and requirements is essential.

Moreover, you are recommended to seek, as a matter of priority and where practical, natural regeneration enriched by native species adapted to climate change[44] and climate-related risks (e.g. wildfires, pests diseases). Natural genetic adaptability should also be promoted.

It is recommended to choose species which support others (e.g. endangered, rare, umbrella species, etc.) and the nearby communities.

PRACTICAL RECOMMENDATIONS

How can a forest manager take the consequences of climate change into account and seek, as a matter of priority, natural regeneration enriched by species adapted to climate change?

Examples:

GREECE

The AdaptFor project[45] demonstrated a new approach for adapting forest management to climate change by selecting four pilot forest areas distributed throughout the country. They all faced different problems that can be attributed, at least in part, to climate change (e.g. dieback of Scots pine and fir, and/or intrusion of coniferous species into broadleaves). The project disseminated the need for forest management adaptation to other stakeholders and the public.

IRELAND

[44] Species and origins limited to species that have co-evolved with our flora and fauna.
[45] http://10.226.41.95:1026/life/publicWebsite/index.cfm?fuseaction=search.dspPage

Management Guidelines for Ireland's Native Woodlands[46] provides two sets of management guidelines. The first addresses a range of specific topics (e.g. 'Area', 'Grazing', 'Products'), while the second covers specific native woodland types, such as Oak (Quercus petraea) Woodland, Hazel Woodland and Alluvial Woodland.

These guidelines have an obvious application to projects involving the restoration of existing native woodland. They are also applicable to converting non-native forests to native woodland, and afforestation with new native woodland. *Management Guidelines* is additionally relevant for enhancing biodiversity in non-native woodlands and commercial conifer forests.

FRANCE The project LIFE FORECCAsT has developed a tool, now widely used in France, to help foresters decide what and where to plant. This tool is called BioclimSol[47] and it takes into account soil fertility among other factors.

ITALY

The LIFE AForClimate project aims to provide concrete options to achieve solutions in forestry and forest planning that are effective in adapting to climate change. The objective is to adapt the management of beech forests (Fagus sylvatica) to the variability of climate and its changes over time. The approach involves programming forest management and interventions on the basis of climate cycles[48].
LIFE VAIA is working on the afforestation of damaged forests through a gradual approach of mixed forests, including agro-forestry. It also refers to the possibility of agro-forestry as an economic and environmental option to adopt while the new planted trees are growing[49].

NETHERLANDS

LIFE Climate Forest shows how climate-smart forest management can increase the resilience of forests on sandy soils. This allows the forest to continue fulfilling its crucial role for plants, people, and animals now and in the future[50].

GERMANY-PORTUGAL-SPAIN

LIFE RESILIENT FORESTS[51] promotes a forest management approach at the watershed scale. It aims to improve forests' resilience to wildfires, water scarcity, environmental degradation and other effects induced by climate change.

FAO: *The protective functions of forest in a changing climate: European Experience*[52].

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[46]Cross J.R., Collins K., Management Guidelines for Ireland's Native Woodlands, https://www.npws.ie/sites/default/files/publications/pdf/Management%20Guidelines%20for%20Ireland%27s%20Native%20Woodlands%202017.pdf; https://www.gov.ie/en/publication/640f49-forestry-standards-manual/
[47] https://www.cnpf.fr/nos-actions-nos-outils/outils-et-techniques/bioclimsol
[48] https://www.aforclimate.eu/en/project
[49] https://lifevaia.eu/
[50] https://www.climateforest.eu/en/
[51] https://www.resilientforest.eu/about/
[52] https://www.fao.org/3/cb4464en/cb4464en.pdf

This paper by the UN’s Food and Agriculture Organization (FAO) and the Austrian Federal Ministry of Agriculture, Regions and Tourism collects experiences regarding protective forests. Climate change affects mountain forests and their protective functions. It also influences the occurrence of forest fires, precipitation patterns, invasive species and changes in the tree line. It is therefore paramount that the management of mountain forests evolves in response to these changing conditions.

Here are two more examples of decision-support tools for choosing tree species in light of climate change:

- Austria’s website www.klimafitterwald.at is specifically designed to help planners, forest owners and foresters to manage forests in response to climate change. It includes a collection of facts, an FAQ, a list of experts to contact for comparisons, and a tool with specific guidance on management types.
- In France, specialised sites (https://climessences.fr/en) provide data on the future climate envelopes of tree species, localised water balances and species recommendations.

Assisted migration consists of speeding up the process of migration of species and/or genetic resources within one species. It involves utilising new provenances of the same native species (assisted gene flow). Assisted migration employs the translocation at regional level of additional native tree species and mixtures of species better adapted to climate change. Climate change is of such intensity and speed that some authors claim that tree species will probably not be able to migrate quickly enough to follow the displacement of bioclimatic envelopes to maintain production. This process can be sped up by using certain species or origins from further south or from lower altitudes.

This technique should take the whole ecosystem into consideration, as well as the needs for biodiversity conservation. For example, when possible, species should be chosen that have co-evolved with flora and fauna in the place where the tree species will be migrating. It is important to note that assisted migration and especially its impact on biodiversity is still being debated. More studies or knowledge are needed to know when the technique can be appropriate. The precautionary principle must be applied, as poorly adapting the forest can accelerate its decline.

Assisted migration can also be combined with **improving forest reproductive material** through selective breeding. This accelerates the adaptation of forests to climate change risks and thus ensures that their productive capacity is maintained in the future. Again, it is essential to take into account the ecological requirements of the whole ecosystem, as well as the needs for biodiversity conservation. The decrease of genetic diversity of the species also needs to be avoided.

Of course, the assessment impact on biodiversity of introducing these adapted species is often subject to national legal requirements. Such legislation will therefore have to be integrated into any afforestation or reforestation projects.

1.3.5. Promote the mixing of species

The presence of a wide variety of species in a forest is one of the prerequisites for its proper functioning and fulfilling its multiple functions. The structural heterogeneity and composition within ecosystems makes it possible to offer many different habitats, which allows these requirements to be met in many places.

The most well-known examples of interactions between forest tree species are:

- the regeneration of trees through pollination.
- the maintenance of soil fertility through the decomposition of dead organic matter.
- the regulation of plant pests (outbreaks). The natural predators of pests help to regulate (though not always) the population dynamics of insects that proliferate cyclically, and can cause considerable damage to trees.

The mixture of species may exist at several scales:

➢ at stand level, distinguishing between:

- a fine scale, with close mixing (in which each tree is in contact with an individual of another species);
- an intermediate scale, with a mixture by small monospecific patches;

➢ at landscape level on a large scale, with juxtapositions of mono-specific stands of different species.

As most of Europe’s natural forests are characterised by a wide variety of species on a fine or intermediate scale, it can be assumed that many species are suitable for this scale of mixing.

As global warming increases, the appropriate selection of species becomes essential. To increase resilience to changing climatic conditions, it is very important to strive for the highest possible species richness (taking into account habitat requirements). Stands with a diversified species and height structure will reduce the risks and simultaneously increase biodiversity, while also providing cultural and recreational value.

Benefits for biodiversity

The effects of mixing on biodiversity are generally positive, in particular due to two main mechanisms.

In mixed settlements, overall biodiversity is more important due to the presence of:

➢ species specific to each species (additive effect);

➢ species related to the mixture, requiring the resources they provide to be complementary (synergistic effect).

In existing monospecific forests, even single-species patches within a stand but with a diverse height structure provide better conditions for the development of flora and fauna, compared to single-storey stands.

In general, broadleaved coniferous mixtures are more favourable to receiving a wide variety of species than pure coniferous stands. But this would very much depend on the natural potential and the actual site conditions. This is because in certain ecological conditions, the range of given tree species is (naturally) limited. In some sites, trees grow naturally into monospecific forests because there is a dominant species that has taken over all others.

However, it must be acknowledged that in some very degraded areas, the only viable solution for achieving an acceptable level of biodiversity may imply afforestation or reforestation. These approaches might need to be combined with a first stage involving monocultures using a pioneer conifer species. This is the case in some Mediterranean ecosystems. Conversely, it can also happen in ecosystems dominated by broadleaved species, as in Ireland with birch. However, to minimise the risk of fires, mixing species (broadleaf and conifers), if site conditions allow, remains strongly recommended.

Benefits against climate change

Mixed forests have lower climate risks (meaning notably the risk of losing entire stands). Thus, a diversity in the parameters of the mixing (nature of the mixed species, number and relative area of each of them) makes it possible to offer different habitats. These would be favourable to the presence of species with varying requirements. Overall, mixing contributes to the proper functioning of the ecosystem through aspects that can have a direct impact on timber production itself. The effects are again very dependent on the parameters of the mixing, but it can be seen to contribute to:

- improved pathogen resistance, through the dilution of food supply, physical and chemical barrier to pathogens, more natural predators and parasites of pests;
- improved resilience following disturbance. The presence of seed keepers in different groups of plant succession — pioneers, nomads, dryades — allows rapid regeneration.

As regards drought resistance, the correlation with species mixture depends essentially on the species components and on the forest characteristics[53].

Benefits for productivity

Multispecies forest plantations feature higher stability, community structure and biodiversity productivity than monocultures[54]. The productivity benefits of mixing species strongly depend on the forest types and condition. Yet in any case, higher levels of functional biodiversity increase the odds of an ecosystem coping with unexpected events, including climate extremes. This is known as the “insurance effect”, since a more biodiverse ecosystem provides greater insurance against the loss of such critical functions, or the failure of poorly adapted species or individuals[55].

[53] Grossiord et al, Les forêts tempérées face aux conséquences du changement climatique : Est-il primordial de favoriser une plus forte diversité d’arbres dans les peuplements forestiers?
[54] Feng, Y, et al. (2022), Multispecies forest plantations outyield monocultures across a broad range of conditions. Science https://www.science.org/doi/10.1126/science.abm6363

[55] Mahecha M.D. et at; Biodiversity loss and climate extremes — study the feedbacks. Nature. 612, 30-32 (2022). doi: https://doi.org/10.1038/d41586-022-04152-y

Recommendations for species mixing in afforestation and reforestation projects

- Encourage the diversity of species. The main aim is to prevent the establishment of mainly monospecific forests. This involves promoting the natural regeneration of native species, unless ecological requirements dictate a different approach. In general, the best techniques should be promoted, which are often a combination of natural regeneration and planting trees suited to the immediate growing conditions (soil, drainage and elevation). This means that inputs such as artificial drainage and fertilisers won't be needed.

- Preserve and maintain riparian areas by using an adequate mix of species. Depending on the ecosystem and where appropriate, open spaces could be introduced in areas where they would be naturally appearing.

- Prefer mixture by clusters for combined broadleaved/coniferous stands or species with different behavioural strategies.

- Prioritise mixtures of species with compatible strategies (e.g. heliophile versus ombrophilous) and growth rates.

- Consider mixtures by strata where the tolerance to shading is very different between two species.

- Avoid mixtures separated by lines or in geometric blocks with negative impacts on the landscape.

Increasing the spacing may make it possible to expand the species diversity. This especially applies to the distance between artificially introduced seedlings. It will create better opportunities for sowing many valuable auxiliary tree and shrub species as well as herbaceous vegetation

1.4. Adapt nurseries

Choosing the right species must be accompanied by the availability of that precise species in nurseries. Nurseries in turn should be kept informed about overall afforestation plans in order to plan their production. In that sense, it is important to outline the importance of nurseries with a biodiverse approach in biodiversity-friendly afforestation and reforestation projects. Their role in promoting the production of native species and local ecotypes in different biogeographical contexts should also be highlighted.

In addition to the traditional timber species, nurseries can propagate a wide variety of diverse native plants. Nurseries therefore provide unique opportunities for ecosystem management, because they offer the opportunity to not only preserve, but actually increase biodiversity levels.

2. Recommended actions during afforestation and reforestation

2.1. Protect habitats

During afforestation and reforestation operations, it is essential to take measures to preserve habitats and species. These may include the following activities, where appropriate:

- Maintain pioneering species in open forest and bare soil areas, preserving the species of the understory and other layers. This is relevant for afforestation.
- Keep live trees standing (shading, seminal potential, etc.) except in special cases which are justified by the management objectives. This applies to afforestation and reforestation.
- Refrain from regularisation and rectification cuts which destabilise stands. An exception can be made for a few localised indispensable or mandatory cuts for safety, access, landscape, sanitary reasons and prescriptions. This includes fire prevention or to shed light on regeneration or seedlings. The ownership structure needs to be taken into account while doing this. This relevant for reforestation.
- Keep trees damaged by wind (including windfalls) as much possible on site. Possible pest infestations should be controlled or excluded. This is relevant for reforestation.
- Maintain the diversity of stands, especially when they are naturally existing during afforestation and reforestation.
- Keep dead wood of as many different species and sizes as possible. Pay particular attention to dead wood of under-represented species. Fire and phytosanitary risks and relevant related mandatory prescriptions should be taken into account (relevant for reforestation).
- Promote existing regeneration and understory, which is applicable for reforestation and afforestation.
- Whole tree harvesting with stump removal by machines should be avoided, which is relevant for reforestation.

It is important to also consider the associated habitats, meaning all features present in forests and buffer zones. Examples include open areas like grasslands and openings in the canopy, along with aquatic environments such as forest ponds, peat bogs, wetlands and riparian zones.

To preserve the ecotones — regions of transition between biological communities — certain open areas, or those with certain biodiversity values should not be afforested.
On the other hand, it may be useful to diversify existing buffer strips by promoting or introducing tree species that facilitate biodiversity. For example, trees favourable to birds and insects.

2.2. Sustainably use and nurture soil, protect the water cycle

Forest soil is an ecosystem of its own, teeming with life, storing and stocking large amounts of CO_2. The health of soil is crucial for the health of the forest and its role for biodiversity and climate change mitigation. It must be protected as much as possible to prevent serious and permanent deterioration.

One relevant element of forest soil health is fungi. These are mycorrhizal symbionts, decomposers and pathogens, with significant functions. A high diversity of forest fungi is a prerequisite for a healthy forest, and a healthy forest is crucial for producing multiple and diverse forest fungi. To put it in a nutshell, “without mushrooms, no forest—without forest, no mushrooms”[56]. Mycorrhizal fungi are also known to provide their hosts with increased drought resistance in many circumstances. This can occur through improved resource acquisition, direct uptake of water, or translocating water obtained by their hosts[57].

Ploughing and other site preparation operations affect not only fungi and soil health. Depending on the scale of the operation, they may also impact forest resilience, as these operations can have negative effects on the abundance of species that help to reduce harmful forests pests[58]. Furthermore, ploughing operations can have negative climate mitigation impacts, due to the induced release of CO_2 following the disturbance of soils.

The impact of heavy machinery and building access roads can lead to superficial and deep impacts. These include:

- soil erosion, removal, displacement and compaction;
- rutting and puddling, followed by hydromorphy;
- soil asphyxiation;
- stimulating the germination of competing social herbaceous or semi-ligneous species.

Also, the use of nitrogen fertilisers negatively affects the richness and diversity of plants species and the abundance of:

- Mosses;
- lichens;
- mycorrhizal mushrooms;
- saprophytic mushrooms[59];
- ground beetles, amphibians and ungulates[60].

[56] Egli, S., Mycorrhizal mushroom diversity and productivity—an indicator of forest health?. Annals of Forest Science 68, 81–88 (2011). https://doi.org/10.1007/s13595-010-0009-3

[57] J. Pickles, S.W. Simard, Chapter 18 - Mycorrhizal Networks and Forest Resilience to Drought, Editor(s): Nancy Collins Johnson, Catherine Gehring, Jan Jansa, Mycorrhizal Mediation of Soil, Elsevier, 2017, Pages 319-339.

[58] Kosewska, A., Topa, E., Nietupski, M. et al. Assemblages of carabid beetles (Col. Carabidae) and ground-dwelling spiders (Araneae) in natural and artificial regeneration of pine forests. COMMUNITY ECOLOGY 19, 156–167 (2018). https://doi.org/10.1556/168.2018.19.2.8

59 Koskinen J. 2022, Fungus-arthropod food webs in boreal forests, http://urn.fi/URN:ISBN:978-952-61-4615-7

60 Muys, B., Angelstam, P., Bauhus, J., Bouriaud, L., Jactel, H., Kraigher, H., Müller, J., Pettorelli, N., Pötzelsberger, E., Primmer, E., Svoboda, M., Thorsen, J.B., Van Meerbeek, K. 2022. Forest Biodiversity in Europe. From Science to Policy 13. European Forest Institute.

Nitrogen fertilisers also impair root system development and limits soils' capacity to resist droughts[61].

Aquatic habitats are frequently encountered in forests, but their dynamics have often been altered by humans. These features host a rich biodiversity[62]. Trees and forest soil play an important and positive role in the water cycle by limiting run-off and regulating the water cycle. For example, filtration helps to retain and purify water.

Protecting natural landforms and geomorphic processes is the basis of healthy soils, and aquatic ecosystems. It is therefore very important to make an effort to protect them during afforestation and reforestation projects.

Practical measures concerning the preparation of sites

To prevent/minimise impacts in the event of land preparation for planting, the following actions are necessary if not already prescribed by national legislation. These requirements should also take into account the specificities of the site:

- Protect the soil as much as possible by promoting, manual planting when possible.
- Protect natural landforms and geomorphic processes and avoid soil and subsoil displacement by carefully charting/limiting constructing access roads. In some areas, afforestation projects using hard techniques for erosion control have actually resulted in increased erosion[63].
- Preference for light or low bearing machines. For instance, tracks, multiple axles, adapted wire pressure and low impact wheels/chains. Rubber track systems are particularly useful to create roughness in the surface and promote infiltration.
- Avoid using machinery in very wet periods. On sensitive surfaces such as silty or hydromorphic soils,always avoid the use of heavy machinery.
- If needed, make the machines work from the compartments and place a windrow on the exploitation compartment to protect the soil and prevent surface runoff water.
- If possible, avoid 'remediation' work such as scraping and deep ploughing.
- Avoid damage to threatened species, which could be present on the plot.
- Conserve river banks.

[61] Douglass J. Et al., Fertilization at planting impairs root system development and drought avoidance of Douglas-fir (Pseudotsuga menziesii) seedlings. Annals of Forest Science, Springer Nature (since 2011)/EDP Science (until 2010), 2004, 61 (7), pp.643-651. ff10.1051/forest:2004065ff. ffhal-00883802f

[62]Aquatic environments also play an important role in relation to biodiversity. The meeting of aquatic and terrestrial environments in forests creates an interface that concentrates rich biodiversity. Many forest species require wet or aquatic environments: hygrophilous species (willows, alders...), species for which water provides vital needs, at different stages of their life cycle; species that feed mainly on living organisms in the water (birds, mammals and reptiles adapted to aquatic environments) or which need water for reproduction (i.e. the vast majority of amphibians). Finally, for some species, water is a living environment in its own right in which they spend all or most of their lives (fish, molluscs — snails, mussels, crustaceans, insects — dragonfly larvae etc.).

[63] Romero-Diaz, A., Belmonte-Serrato, F. and Ruiz-Sinoga, J.D. (2010), The geomorphic impact of afforestation on soil erosion in Southeast Spain. Land Degrad. Dev., 21: 188-195, https://doi.org/10.1002/ldr.946

Practical measures concerning the health of the sites

In terms of preventive sanitary measures, only actions that are necessary to avoid deterioration caused by external factors or risks should be taken. For example, preventing diseases (relevant especially for reforestation).

The health of the plots will obviously depend also on how the harvesting operations (during reforestation were carried out. In general, to maximise a plot's health, it is recommended to promote extensive management of biomass residues, rather than looking for "order and cleanliness". In particular, it is important to:

- dismember tree crowns, but not in a systematic and generalised way.
- limit the treatment of windrows by placing them in large row. Avoid grinding harvested whole trees.
- avoid burning, unless burning has been prescribed to increase biodiversity.
- avoid generalised stump removal and burying stumps.
- Maintain and improve the physical, chemical and biological quality of the soil by avoiding the use of pesticides and herbicides. These substances can only be duly justified in sanitary emergencies.
- if it is necessary for well identified phytosanitary reasons, remove the affected trees.

3. RECOMMENDATIONS ACTIONS AFTER AFFORESTATION AND REFORESTATION

Irrespective of whether afforestation or reforestation was carried out, proper monitoring is essential. This is especially relevant in the early years after completing the action. Adequate infrastructure to protect new stands needs to be considered, namely against major threats like forest fires and droughts.

In particular, the following aspects should be considered:

- Competing vegetation. Controlling this during the first 3 to 5 years will be a critical factor in achieving early woodland development. Nevertheless, it is recommended to use mechanical procedures rather than herbicides, to avoid impacts on biodiversity.

- Grazing by herbivores and game is an integral part of woodland ecology. Where a site hosts herbivores at appropriate levels, this facilitates structural diversity, high biodiversity on the ground, maintains open areas and stimulates natural regeneration. However, grazing pressure must be kept within certain limits in order to be beneficial. Management plans for grazing should be integrated in the forest management plan.

  The management of populations of ungulates or other ruminants can be a strategic issue, taking the forest management and biodiversity objectives into account. While it is preferable to restore natural processes of regulation, active measures such as hunting can also be considered, as the two approaches may complement each other. It must be adapted to the state of the population, the state of biotopes and the extent of the damage they cause to trees. In turn, forest management should take into account the applicable hunting regulations.

- Protecting existing or expected seedlings is necessary in order not to jeopardise the future of the forest in areas where damage by game is such as to compromise the renewal and natural diversity of the forest.

4. BEYOND PLANTING: NATURAL REGENERATION

Both natural and artificial regeneration are commonly used practices.

Natural regeneration makes greater use of the strong potential of nature[64] and preserves the genetic diversity of the forests. This in turn is linked to their resistance and vitality[65], and should therefore be favoured. The priority will be to favour, wherever and whenever possible, the natural regeneration of species adapted to local ecological conditions.

At the same time, afforestation and reforestation by **artificial regeneration** is in some cases necessary as the only option. It can as also be a better approach on post-agricultural or post-industrial land, or after large-scale disasters or where forest replacement/improvement is needed. In the last case, artificial regeneration would be needed due to a lack of suitable seed sources, especially because of (i) impoverished genetics as a result of past exploitation or (ii) intensive grazing. In some cases, planting can also speed up the process of adapting to climate change. To preserve and support biodiversity, it is important to use proven material of known provenance.

The self-organising processes that creates naturally regenerating forests promote local genetic adaptation, encourage native species, increase spatial and temporal heterogeneity, and sustain local biodiversity and biotic interactions. These features confer greater ecosystem resilience in the face of future shocks and disturbances. The natural regeneration of desirable species has major advantages. It guarantees the good adaptation of the seedlings to local ecological conditions when the species belongs to the local habitat. Provenance in relation to the existing stand and good rooting is also ensured. In addition, natural regeneration decreases the risk of importing pests or pathogenic organisms, and promotes the vigour of the young trees. In particular, these young trees will benefit from a better sensitivity to certain insects or fungi than

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[64] Carey J., The best strategy for using trees to improve climate and ecosystems? Go natural. DOI:10.1093/forestry/cpu018.
See also https://prosilva.fr/files/brochures/brochure_risques%204%20francais%20end.pdf?PHPSESSID=188517ec705e692b5cd6f56a10ebb88c

[65] Alfaro R.L. et al., the role of forest genetic resources in responding to biotic and abiotic factors in the context of anthropogenic climate change, https://doi.org/10.1016/j.foreco.2014.04.006; brang p. et al, suitability of close-to-nature silviculture for adapting temperate european forests to climate change doi:10.1093/forestry/cpu018;
see also https://waldbau-sylviculture.ch/publica/2022_manifeste_femelschlag.pdf

seedlings from nurseries. Finally, natural regeneration is often less costly than artificial regeneration.

It is the seminal potential that is on site (soil seed stock, seed trees understory) or that which is closest (edges, neighbouring stand) that will mainly determine the composition of the future stand. Natural regeneration is facilitated by the presence of seed-bearing trees on or near the area to be regenerated. The presence of site-adapted tree species and provenances, along with reasonably frequent seed production are also factors. In addition, the site must be receptive to natural regeneration. For example, if post-harvesting, natural regeneration may be facilitated by light scarification to present pockets of bare soil for the incoming seed. In some cases, selective methods of tending cuts create suitable climatic conditions for pioneer and heliophile species.

Natural regeneration requires sufficient seed, appropriate levels of ungulate management, alternative browsing and grazing opportunities. Even a limited amount of herbivores can cause damage to young stands if there are no alternative browsing and grazing opportunities. Rainfall during the vegetation season is also needed. The limiting factors for natural regeneration - provided seeds are available in sufficient quantity - are the different climatic conditions and unmanaged forest ungulates.

The natural dynamics after cuttings or episodes of storms or disease damage result from the reproductive strategy of forest species. This depends on the surface of the area of tree cover that has disappeared, the seed stock of the soil, the proximity of seed trees and the local ecological conditions. Two main functional groups may be distinguished:
(i) Pioneer species which have a high production of easily disseminated seeds and a heliophilic behaviour.
(ii) Species that are more evolved which have few but heavy seeds, and are more tolerant to shade. However some species such as oaks have heavy seeds and are heliophilic.

Natural regeneration will be considered successful if it has the required quantity and quality determined by the management objectives. These are distribution of species over the entire surface, and seedlings that are well established and of sufficient quality (absence of deformation or destruction by pathogens) having generally survived several years' worth of growing seasons.

Enrichment planting is artificial regeneration that is done to complement natural regeneration. If natural regeneration of a desirable species does not occur, or only occurs very slowly/ very irregularly over the site after a period of time, you should consider intervening directly to achieve the desired species mix / tree density**.** Many experiments and monitoring after storms make it possible to have a clear understanding of these recovery methods.

Enrichment planting presents many advantages that allow us to:

- naturally obtain soil cover, aeration and soil restructuring,
- limit the competing social species in vertical or lateral shelter,
- recreate a forest atmosphere,
- diversify the stands in composition and structure,
- increase biodiversity and rapid landscape reconstitution.

PART II — TREE PLANTING IN URBAN ECOSYSTEMS

INTRODUCTION

Although cities occupy only 2% of the planet's surface, 55% of the world's population live in urban areas[66]. This figure is projected to reach 68% by 2050. In 2021, some 38.9 % of the EU population was living in a city, with lower shares living in towns and suburbs (35.9 %) and in rural areas (25.2 %)[67]. Trees in urban and peri-urban areas are mainly street trees and trees in parks, open spaces, on private property and in green buildings. On average, green areas such as urban green spaces, private gardens and urban forests make up 40% of the land covered by Europe's cities. Over the last decades, however, urban areas have undergone significant unsustainable land use development, which has resulted in increased soil sealing and a loss of the peri-urban agroecosystem. As a consequence, these changes have an effect on the structure of urban green spaces and their capacity to provide ecosystem services. For cities, these include erosion control-related measures, air purification and outdoor recreation[68]. In this context, European cities have a crucial role in restoring and increasing biodiversity.

The EU Biodiversity Strategy for 2030 sets the overall objective of stopping the loss of green urban ecosystems, addressing land take and soil sealing, and promoting green infrastructure and nature-based solutions in cities. It also aims for these principles to be systematically integrated into urban planning. It proposes greening urban and peri-urban areas by promoting the development of Urban Greening Plans. The proposal for a Regulation on Nature Restoration[69] sets restoration targets in urban ecosystems, including a minimum of 10% urban tree canopy cover in all cities, towns and suburbs by 2050. In this sense, it is expected that in the next few years, cities will accomplish numerous tree planting projects.

This document mainly focuses on the procedures for tree planting in urban areas within the conceptual framework of urban ecology. Trees are only one element of urban green ecosystems that can contribute to the sustainable cities and towns. The EU Urban Agenda[70] defines several points —air quality, climate adaptation, urban transport, culture and cultural heritage, urban poverty — that need to be considered together when designing urban green ecosystems. The new European Bauhaus Communication of 2021[71] also highlights the needs and advantages of reconnecting with nature.

Obviously, green urban ecosystems may have more functions than just biodiversity conservation. They provide a wide range of ecosystem services, including their fundamental role of recreation. Nature in the city also represents a strong social asset. As a source of well-being, it is also the only nature present in the daily life of millions of city dwellers. The social demand for a pleasant living environment and a greater place for nature is on the increase.

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[66] Urban areas means all settlements, and covers trees other than in forest and in agricultural land (agroforestry)
[67] https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Urban-rural_Europe_-_introduction#Area_and_population
[68] SWD (2021) 651, p. 30
[69] COM (2022) 304.
[70] Urban Agenda for the EU | European Commission (europa.eu)
[71] COM(2021) 573 final.

TREE PLANTING IN URBAN ECOLOGY

The urban environment has distinctive biophysical features compared to surrounding rural areas. These include an altered energy exchange which creates an urban heat island. There are also changes to hydrology such as an increased surface runoff of rainwater. Such changes are partly a result of the altered surface cover of the urban area. For example, less vegetated surfaces lead to a decrease in evaporative cooling, while an increase in surface sealing results in increased surface runoff. Climate change will amplify these distinctive features.

Cities can host a high richness of plants and animals, and this urban biodiversity supports multiple regulating, provisioning and cultural ecosystem services. Developing biodiversity-friendly cities is thus inextricably linked to sustainable urban development, human wellbeing and climate-neutral cities. Planting trees can contribute to this objective.

1. GREEN URBAN PLANNING AND MANAGEMENT TOOLS

There are several planning and management tools that can help to better design and manage urban trees and promote biodiversity in urban areas. They can also help mitigate the impacts of climate change, such as the urban heat island effect, thus contributing to the EU Green Deal and climate neutral cities by 2030.

In general terms, environmental spatial planning can be implemented in urban areas, considering not only the urban green, but also the effects of the cities on the environment. Strategies such as "no net land take by 2050", as stated in the EU Soil Strategy[72], propose a new horizon on spatial planning and the environment.

The development of urban green and innovation plans allows for the design of urban infrastructure that takes biodiversity and ecosystem services into account, including resilience to climate change effects, such as heat waves and droughts. This infrastructure can also factor in their contributions to carbon emission reductions. This also allows the selection of nature-based solutions and their adaptation to different urban contexts. Trees are part of green and blue infrastructure and essential to the implementation of several nature-based solutions. "Urban forestry strategies" may also be a useful technique for promoting the sustainable management of urban forests.
Such strategies are key, as they provide a set of objectives and actions agreed to by the multitude of professions and community interests that characterise the urban environment. Participation and social engagement should therefore be considered in these strategies.

[72] COM (2021) 699.

2. CONSERVATION AND ENHANCEMENT OF BIODIVERSITY IN URBAN AREAS

2.1. Biodiversity in spatial planning

The large spatial extent of urbanisation and the connections between ecosystems in landscapes mean that landscape-scale approaches are necessary for many conservation actions. One of the challenges in ecology and land use planning is to strengthen ecological continuities or corridors. These are needed to encourage the movement of species and thus ensure their preservation. Developing a coherent green and blue infrastructure allows cities to create a network of ecological continuities. Natural regeneration or tree planting can play a crucial role in creating these corridors, like in urban riparian systems. The design of the plantation is decisive for creating continuity. Some species are not able to cross major barriers. Some, like bats, rely on tree alignments to guide their movements.

When restoring connectivity in cities, it is also important to avoid creating ecological traps[73]. In other words, habitats that contribute to reducing the fitness of a species despite being selected by it. For example, some habitats may attract particular species for their presence of food, but their proximity to motorways,[74] and the lack of mitigation measures such as ecopassages may negatively affect the population of these species. Urban biodiversity monitoring and adaptive management must therefore be addressed together with tree plantation.

As part of promoting biodiversity, new tree areas should be designed to be as large as possible. For instance, one large, complex area is more beneficial than several small, simple ones. Some authors suggest that green urban areas of 10-35 ha would contain most of the bird species recorded in cities[75]. However, the role of small parks and wooded streets could be important to facilitate the dispersal of different species. In that sense, enlarging existing parks, by both adding buffer areas and creating corridors or stepping stones between parks can be a useful strategy for promoting biodiversity at urban scale.

Protecting and maintaining large remnant patches of terrestrial, riparian, coastal and marine habitats should therefore be one of the main, if not the highest priority in planning for the maintenance of biodiversity in cities.

Finally, another important conservation issue is increasing the quality of the surrounding matrix. Depending on the context, different measures should be taken. Home gardens (as defined in Part III of these guidelines) and agricultural parks[76] can help create biodiverse and resilient peri-urban areas.

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[73] Hale, R. and Swearer, S.E. (2017), When good animals love bad restored habitats: how maladaptive habitat selection can constrain restoration. J Appl Ecol, 54: 1478-1486. https://doi.org/10.1111/1365-2664.12829
[74] The following is the established format for referencing this article:
Fahrig, L., and T. Rytwinski. 2009. Effects of roads on animal abundance: an empirical review and synthesis. Ecology and Society 14(1): 21. [online] URL: http://www.ecologyandsociety.org/vol14/iss1/art21/
[75] Fernández-Juricic, E, Jokimäki, J, (2001), A Habitat Island Approach to Conserving Birds in Urban Landscapes: Case Studies from Southern and Northern Europe. Biodiversity and Conservation. 10. 2023-2043. 10.1023/A:1013133308987.
[76] Tóth, A., Supuka, J., (2013). Agricultural Parks: Historic Agrarian Structures in Urban Environments (Barcelona Metropolitan Area, Spain). Acta Environmentalica Universitatis Comenianae (Bratislava). 21. 63-69.

2.2. Increase the structural complexity of vegetation

The introduction and management of woody vegetation can help increase the structural complexity of vegetation in urban areas.

The first way of improving biodiversity in cities is diversifying the tree species. In comparison with monospecific areas, diverse tree areas contribute to the creation of different niches that can be used by different fauna. Diversity of tree height within a landscape will provide the vertical structure required by many birds. For this reason, introducing small trees to allow the replacement of mature trees in future is a good strategy for creating a diversified vertical structure. In particular, it is recommended to favour natural regeneration where feasible, and complement this with artificial methods where appropriate.

Ground-storey and mid-storey density is often low in urban landscapes. The lack of complex vegetation is one cause for the reduction of particular taxa in the urban matrix. For example, a reduction of dense native shrubby vegetation correlates with a loss of small insectivorous birds. This is because they use such vegetation for shelter and food, and ground cover (grass and leaf litter) is the variable that most strongly affects non-flying insects. Incorporating a diverse mid-storey layer (i.e. shrubs and small trees) may help create more habitat niches. It can also provide a source of food and other resources for different biotic communities. Trees can additionally help create a complex ground-story layer. This reduces the removal of dead trees, logs, dead branches and leaf litter, which can aid the conservation of urban biodiversity[77].

It is also important to consider the introduction of climbing plants and vines in urban areas. These plants allow for the creation of numerous niches and require minimal intervention on urban soil. They are an opportunity in areas where unsealing sufficient portions of urban soil remains difficult.

2.3. Increase habitat resources

Larger species that mature and reach veteran status are particularly valuable for biodiversity, its conservation and enhancement. Veteran trees have the physical characteristics of ancient trees. These are:

- a large girth;
- the progressive narrowing of successive annual increments in the stem;
- ageing and associated decay of the central wood;
- the presence of hollows and cavities;
- changes in crown architecture and/or retrenchment, even if they are not ancient in years.

[77] Threlfall, C.G., Mata, L., Mackie, J.A., Hahs, A.K., Stork, N.E., Williams, N.S.G. and Livesley, S.J. (2017), Increasing biodiversity in urban green spaces through simple vegetation interventions. J Appl Ecol, 54: 1874-1883. https://doi.org/10.1111/1365-2664.12876

Veteran trees are related to fungi and rare lichens, and provide habitats for different species to nest and roost. Hollows or tree cavities are used by many species. The number of hollow-bearing trees is positively correlated with hollow-nesting fauna in urban areas, including bats.

It is therefore important to manage and conserve certain trees adequately, because they function as key elements in urban biodiversity[78]. Tree hollows are a limited resource in urban matrices. Safety is obviously a primary reason for this and it is a concern. Still, there could be defined safe areas, or peri-urban parks, where risks can be minimised and managed. Tree planting and land-use change should not necessarily always happen at the expense of old trees.

2.4. Choose the right species for biodiversity

As regards biodiversity, native and local species and subspecies should generally be used as much as possible. This is because they would be much more beneficial than ornamental or exotic species. However, since the urban environment represents an extreme alteration of natural conditions, both over and underground, the most suitable species may not be native[79] in some cases. Still, there may be some native species adapted to the local conditions, so planting non-native species should be a last resort.

Unlike forest plantation species, there is no regulation concerning provenances for the choice of species to be planted in cities. Unfortunately, despite their importance, many commercially available cultivars are not accompanied by precise information on their parental lineage. This is despite the fact that the provenance or ecotype of the tree will be critical to its performance on any given site. Nevertheless, a general recommendation is to refer where possible to the regions of origin/provenance proposed for the forest plantation schemes. This is to guarantee homogeneity in the choice of species at landscape level, as long as the range of native species is in line with the requirements of the plantation projects.

Within this objective, it is also worth considering the habitat value of the species by taking into account their propensity to provide nectar, fruits or seeds. The density and texture of the crown and its seasonal variations are also factors. Many fruits (especially the fleshier berries, drupes and pomes) are an important food source for birds and small mammals. Therefore, the planting of edible fruit trees is recommended.

Ongoing climate change is disrupting the ranges of pathogens and pests and contributing to the emergence of new diseases. It therefore increases the vulnerability to epidemics that results from lack of diversity. Strategic diversification of the urban tree population is critical for building resilience into the urban forest and associated green infrastructure. The use of a limited range of species is detrimental to the tree population as a whole. No single species should represent more than 5% to 10% of the total[80].

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[78] Lonsdale, D. (ed.) (2013). Ancient and other veteran trees: further guidance on management. The Tree Council, London 212pp.

[79] E.g. in central Dublin City, although not native to the island of Ireland, London plane is a species that is capable of growing into large mature specimens, despite air pollution and other constraints associated with the urban environment.

[80] Santamour, F.S. (1990), « Trees for urban planting: diversity, uniformity, and common sense» https://pdfs.semanticscholar.org/26a2/4c5361ce6d6e618a9fa307c4a34a3169e309.pdf

Obviously, the introduction of potentially invasive species must be avoided.

2.5. Complementary measures to improve biodiversity

Natural or artificial regeneration are not the only strategies for promoting biodiversity in urban areas. Some additional measures can be envisaged, such as implementing organic management practices at landscape scale. This includes prohibiting or reducing the use of chemical pesticides and inorganic fertilisers, and promoting biological pest control. It also entails maintaining spontaneous herbs, even in streetscapes, and avoiding the use of heavy machinery.

Other measures that can be considered may include reduced mowing, creating pollinator-friendly areas using plant enrichment, introducing beneficial-insect banks, stone walls, stone mounds and other strategic refuges for fauna. Perches, nest boxes and drinking troughs for existing wildlife habitats could also be introduced, including the ones located in buildings. Pruning should be reduced as much as possible, since trees provide habitat to fungi and lichen. If necessary, pruning should be limited to the time of the year when the impact on associated fauna is least severe.

You should also consider avoiding noise pollution from machinery and traffic and light pollution from lighting, among other sources.

In addition, weigh up the pros and cons of irrigation with recycled water, as this produces soil salinity in the medium term. It appears preferable to use species with low water needs that are resilient to future climatic scenarios.

3. PROMOTING ECOSYSTEM SERVICES IN URBAN AREAS

Artificial and natural regeneration contribute to sustainability in cities by providing ecosystem services. In this context, trees are essential tools for urban transformation.

3.1. Ecosystem services and the urban agenda

The EU Urban Agenda establishes some priority themes for cities, within which trees feature as key elements:

- **Air quality and urban mobility**

Trees can play a major role in improving air quality in cities, through their filtering capacity[81]. They also help create liveable and healthy public spaces, and promote sustainable transport modes such as walking and cycling. Sustainable urban mobility plans[82] focus on people and not traffic, and avoid the emission of pollutant particles. They therefore require the creation of accessible and resilient public spaces, in which trees play key functions. Finally, even though

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[81] Nowak, D., et al, (2006), Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening. 4(3-4): 115-123. https://doi.org/10.1016/j.ufug.2006.01.007.
[82] guidelines-developing-and-implementing-a-sustainable-urban-mobility-plan_jan2014_en.pdf (europa.eu)

trees improve air quality, avoiding pollution at source is a more effective way to address air pollution overall.

- **Culture and cultural heritage**

Some historical or traditional gardens have proved to be not only hotspots for biodiversity[83] but also can be considered to constitute cultural heritage, as they contain some local species of seeds and plants [84]. Identifying, conserving and promoting these areas and species helps create synergy for biodiversity conservation.

- **Climate adaptation and energy transition**

Trees, besides removing CO_2 from the atmosphere and storing carbon, mitigate the effects of climate change in the urban environment. In particular, they mitigate the urban heat island effect, and contribute to flood prevention from severe storms.

The urban heat island effect impacts the economy, public space vitality and electricity consumption. Modelling studies for urban temperatures over the next 70 years project that, in urban areas where the green cover is reduced by 10 %, urban temperatures could increase by 8.2 °C above current levels[85]. Urban forests cool the urban climate and microclimate by sustaining high evapotranspiration rates and preventing direct solar radiation on urban surfaces[86]. This can also reduce the need for energy[87]. Nevertheless, in colder climates, dense crowns will cool local areas in winter, potentially reducing the appeal of outdoor spaces. It is therefore convenient to design some areas that are exposed to sunlight in public and green spaces.

The urban water cycle differs greatly from the natural water cycle with regard to the main components of evapotranspiration, water run-off and infiltration. This has severe consequences for urban climate, groundwater recharge and risk management[88]. Many nature-based solutions are an integral part of concepts dealing with water-sensitive urban design, costal protection or sustainable drainage systems. Bioswales, infiltration basins, rain gardens and urban restoration are some nature-based solutions that can be introduced in cities and which require woody vegetation.

- **Social aspects (urban poverty, inclusion, jobs, skills and health)**

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[83] Kümmerling M., Müller N., The relationship between landscape design style and the conservation value of parks: A case study of a historical park in Weimar, Germany, Landscape and Urban Planning, Volume 107, Issue 2, 2012, Pages 111-117, ISSN 0169-2046,https://doi.org/10.1016/j.landurbplan.2012.05.006.

[84] Kanellopoulou, V. (2020). Seeds as Common Cultural Heritage. 10.5334/bcj.i.

[85] Key facts — European Environment Agency (europa.eu)

[86] To calculate the cooling performance of trees, LIFE Tree Check has developed an app for urban planners. This help them to identify the best investment and quantify the returns: https://www.lifetreecheck.eu/getattachment/01fa961c-ead5-4650-a943-83c059d31530/Layman-s-report

[87] Moss J.L. et al. Influence of evaporative cooling by urban forests on cooling demand in cities, Urban Forestry & Urban Greening,
Volume 37, 2019, Pages 65-73, ISSN 1618-8667, https://doi.org/10.1016/j.ufug.2018.07.023.

[88] Nature Based Solutions – Technical Handbook. (2019). UNaLab

A possible statistical relationship between low canopy cover and low-income neighbourhood areas has been shown in some cities[89]. Tree-planting programmes are therefore particularly important in these areas. Moreover, green infrastructure requires skills in both design and maintenance, and they might open up possibilities for bioeconomy products and services. Urban trees require monitoring and care, especially after planting. Sufficient skills are needed to face known and emerging challenges, such as storms and droughts. Finally, exposure to green areas increases one's physical and mental health.[90].

3.2. Minimise disservices

Trees can also cause some particular disservices, such as allergies.
Some trees, notably wind-pollinated species, can release copious amounts of pollen. This problem can be particularly severe with male cultivars of deciduous species. In some cases, such as *Cupressus* spp. or *Betula* spp., this pollen also carries an allergy-causing risk that should be considered in planting specifications. In other cases, the concentration and abundance of the same species in a specific area of a city creates pollen emission sources that carry an allergy-causing risk. This can occur even if the species by itself does not have a high allergy-causing potential.

In conclusion, it is important to consider allergy-causing potential during plant selection in relation to the distribution of trees. Promoting tree species diversity is a crucial tool to reduce allergies. On top of that, air pollution enhances the risk of atopic sensitisation and the exacerbation of symptoms in vulnerable subjects[91]. In this regard, it is important to highlight that it is not possible to avoid allergies solely by addressing species selection.

3.3. Choose the right species to provide ecosystem services

It is important to deal with species selection together with ecosystem services in their specific context.

In addition to the recommendations for biodiversity, tree selection is of strategic importance in relation to:

(i) resilience to climate change – the capacity of a species to resist climate change in a +2°C scenario

(ii) resilience to a specific context, such as flooding in water-sensitive designs.

(iii) The capacity to provide ecosystems services such as:

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89 Huang G, Zhou W, Cadenasso ML. Is everyone hot in the city? Spatial pattern of land surface temperatures, land cover and neighbourhood socioeconomic characteristics in Baltimore, MD. J Environ Manage. 2011 Jul;92(7):1753-9. doi: 10.1016/j.jenvman.2011.02.006. Epub 2011 Mar 2. PMID: 21371807.

90 https://www.nature.com/articles/s41598-020-78642-2; https://www.sciencealert.com/daycares-in-finland-built-a-forest-and-it-changed-kids-immune-systems; https://www.nature.com/articles/s41598-021-87675-0

91 D'Amato, G., Cecchi, L., Bonini, S., Nunes, C., Annesi-Maesano, I., Behrendt, H., Liccardi, G., Popov, T. and Van Cauwenberge, P. (2007), Allergenic pollen and pollen allergy in Europe. Allergy, 62: 976-990. https://doi.org/10.1111/j.1398-9995.2007.01393.x

- mitigating urban heat islands – the ability of a species to impact the summer thermal effect through shading and evapotranspiration.
- air pollution control – the capacity of a species to store or remove air pollutants.
- protecting settlements from wildfires, or sea-level rise where such a risk exists[92].
- carbon storage – the ability of a species to store carbon throughout their life.
- social, cultural and heritage aspects.

Given the long lifespans of trees, careful thought needs to be given to the species and the location of trees in relation to climate change. As part of their decisions, managers need to consider the survival of trees planted today in the face of future climatic conditions. Choosing species that are adapted to climatic conditions requires accurate diagnostics before planting. A number of diagnostic tools based on statistical models of species adaptation are already available. These include species fiches, climatic maps and maps of the current presence of species in Europe and climatic compatibility. Maps of soil diagnoses also enable us to analyse survival probabilities according to the available water reserve. In this context, reference should be made to the same procedures for selecting change-adaptable species in the chapter on "Forest ecosystems" (1.3).

3.4. Involve citizens in urban areas

People living in cities can be successfully involved in tree-planting projects. For example, in the monitoring and the maintenance of trees by "adoption" formulas. This will lower the costs for the authorities and increase the survival rate. Several examples exist, such as "custodisciMi"[93] (literally "take care of me") whereby the City of Milan asks its citizens to grow trees on private balconies during the warm season. They are then transplanted in public areas, thus reducing the nursery costs. Another example is the tree-adoption initiative in Athens[94]. In this case, an app allows people to take care of newly-planted trees that are particularly vulnerable and in need of care.

4. TARGET DIFFERENT TYPES OF URBAN GREEN SPACES

Different types of green spaces can be managed to improve the habitat suitability of the urban matrix. Examples include:

- public parks:
- golf courses,
- sports pitches;
- the curtilage surrounding these areas - private gardens, residential back gardens and informal green spaces.

[92] E.g. Portugal has legislation regarding "fuel management" around settlements
[93] https://forestami.org/custodiscimi/
[94] Example: Adopt-a-Tree City of Athens - Novoville;

Differences in the spatial scale and ownership of green spaces mean that each type of area should be considered separately.
The public use of the space should also be considered, meaning not all green areas should be equally open for public use. Cities may dedicate areas with high ecological value to research, conservation, observation and educational activities. At the same time, spaces not easily accessible for public use, or dedicated areas in large parks offer opportunities for enhancing biodiversity via tree planting.

Before planting trees in each of these areas, it is necessary to evaluate biodiversity to avoid the risk of damaging valuable ecosystems that may already exist.

4.1. Parks

Urban parks may promote biodiversity conservation by maintaining remnant vegetation, hollow-bearing trees and other wildlife habitats. Urban areas are optimal for increasing structural complexity, increasing habitat resources and implementing complementary measures for improving biodiversity.

4.2. Residential and private gardens

Backyards and private gardens constitute a significant proportion of green spaces in cities, especially in areas of low-density housing. Consequently, gardens can contribute to residents having connection with nature and urban biodiversity. For instance, floral diversity is often much higher in backyards than surrounding natural areas. The spatial scale of individual residential gardens is much smaller than that of public pockets of land set aside for conservation. However, combining multiple gardens, if appropriate gardening practices are applied collectively, can improve conservation and biodiversity outcomes in the urban matrix.

Given the generally small scale of residential gardens, biodiversity conservation can be aided by encouraging the planting of native plants that include complex ground-storey, mid-storey and canopy cover. The planting of dense native mid-storey vegetation, flowering plants and providing habitat resources (e.g. water features, nesting boxes, rock piles and logs) can also help.

4.3. Informal green spaces

Informal green spaces include:

- vacant lots;
- brownfields;
- railway tracks and associated verges;
- street verges (such as road verges, roundabouts, footpaths and other traffic infrastructure);
- spaces under power lines between walls and buildings;
- spontaneous vegetation growing on built structures or in cracks and holes in built infrastructure.

Informal green spaces are generally ‘unmanaged’ and have the potential to provide stepping-stone or corridor functions. These areas are optimal for natural regeneration, but measures against invasive species should be considered.

4.4. Streets and squares

Street trees are a significant part of the urban canopy in urban areas. Woody streets can be considered an “intermediate” landscape between streets without trees and parks[95]. In particular, there is great potential for promoting biodiversity by planting trees in streets that connect different urban parks, which can potentially function as corridors.
It is important to consider the dimensions of tree pits in streets. As reduced planting space results in reduced maximum size[96], one way of improving biodiversity and tree health is making tree pits larger. One possible way of doing this is creating trenches. When possible, it is important that trees are not planted in isolation but are part of a more complex habitat that has a higher ecological value. Other options for enlarging the unsealed soil volume in paved areas should be considered[97].

Tree pits can be designed both close to façades (for climbing plants) and separated from them. Tree selection should consider the distance between the tree pit and the façade, to avoid disservices caused by the growing trees.

Litter from trees (e.g. leaves and fruit) can be a nuisance, particularly on paved sites. One possible solution is to design larger tree pits, which can at least temporarily collect leaves and fruits, minimising this problem.

In streets, protection from damage should be carefully considered. Trees are subject to many stress factors that can hinder their development and alter their health. To avoid injuries and infections, good management practice is vital, such as protecting the trunk and collar against scalds, vandalism and construction accidents.

4.5. Other areas

Almost every surface in a city can sustain trees. Rooftops, yards, parking lots, balconies and facades are all areas where trees can be introduced. For this reason, public and private bodies as well as individuals can make their contribution to enhancing biodiversity in cities. Different nature-based solutions can be conceived for each specific area[98].

Special attention should be given to public buildings and their yards. In particular, buildings in the educational, social and healthcare sectors can benefit from multiple ecosystem services provided by tree planting and natural regeneration.

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[95] Fernández-Juricic, E., (2000). Avifaunal Use of Wooded Streets in an Urban Landscape. Conservation Biology. 14. 513 - 521. 10.1046/j.1523-1739.2000.98600.x.
[96] Sanders, J., Grabosky, J., Cowie, P. (2013). Establishing Maximum Size Expectations for Urban Trees with Regard to Designed Space. Arboriculture and Urban Forestry. 39. 68-73. 10.48044/jauf.2013.010.
[97] Johnston, M., Percival, G. (2012). Trees, People and the Built Environment - Proceedings of the Urban Trees Research Conference, 13-14 April 2011. 10.13140/2.1.2755.4888.
[98] https://unalab.eu/system/files/2020-02/unalab-technical-handbook-nature-based-solutions2020-02-17.pdf

5. MONITORING AND ADAPTIVE MANAGEMENT.

Monitoring and evaluation are crucial for demonstrating the success or failure of urban ecosystem projects. Biodiversity (measured using pre-defined metrics based on the original aim of the intervention) and ecosystem services must be monitored over the long term. This is because changes in response to urbanisation can have a significant lag time. Monitoring can be conducted through an adaptive management process that iteratively monitors and reviews project outcomes and adjusts actions accordingly. It should provide a framework for continuous evaluation, flexible implementation and engagement across sectors. Management must also consider other applicable regulations, such as dire prevention mandatory prescriptions and safety rules, which are particularly relevant in urban areas.

PART III –TREE PLANTING IN AGRICULTURAL LAND

INTRODUCTION

Agriculture is an important European land use, occupying more than 162 million ha, slightly more than 38% of the EU's total land area. Unsustainable agriculture is the most important driver of loss of biodiversity and ecosystem services worldwide[99]. Biodiversity losses may also reduce yield significantly. This highlights the importance of promoting management alternatives that have synergistic benefits for agricultural production, biodiversity and ecosystem services in agricultural landscapes.

The EU Biodiversity Strategy for 2030[100] sets the objective of covering at least 10% of the EU's agricultural area with high diversity landscape features by 2030[101], which include hedges and trees. There are different approaches about how to integrate biodiversity and agriculture[102]. The proposed regulation on Nature Restoration also includes specific targets and objectives for agricultural ecosystems.

Land sharing, often called wildlife-friendly farming, advocates conserving and improving the levels of biodiversity and ecosystem services of agricultural land[103].

In the EU, agroforestry has a simple and flexible definition: "*a land use system in which trees are grown in combination with agriculture on the same land*"[104]. EURAF[105] defines it as: "*the integration of woody vegetation, crops and/or livestock on the same area of land*."

Agroforestry, compared to simple crops, is considered a useful strategy for the following objectives related to ecosystem services and biodiversity:

- Improving overall biodiversity.
- Creating buffer zones (e.g. riparian buffers).

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[99]https://ec.europa.eu/eurostat/databrowser/view/tag00025/default/table?lang=en[99] Paula Barral, José María Rey Benayas, Paula Meli, Nestor Oscar Maceira, Quantifying the impacts of ecological restoration on biodiversity and ecosystem services in agroecosystems: A global meta-analysis, Agriculture, Ecosystems & Environment, Volume 202, 2015, Pages 223-231, ISSN 0167-8809, https://doi.org/10.1016/j.agee.2015.01.009.

[100] EUR-Lex - 52020DC0380 - EN - EUR-Lex (europa.eu)

[101] Actions Tracker | Knowledge for policy (europa.eu)

[102] Phalan, Ben & Green, Rhys & Dicks, Lynn & Dotta, Graziela & Feniuk, Claire & Lamb, Anthony & Strassburg, Bernardo & Williams, David & zu Ermgassen, Erasmus & Balmford, Andrew. (2016). How can higher-yield farming help to spare nature?. Science. 351. 450-451. 10.1126/science.aad0055. Fischer, Joern & Batary, Peter & Bawa, Kamaljit & Brussaard, Lijbert & Chappell, M. Jahi & Clough, Yann & Daily, Gretchen & Dorrough, Josh & Hartel, Tibor & Jackson, Louise & Klein, Alexandra & Kremen, Claire & Kuemmerle, Tobias & Lindenmayer, David & Mooney, Harold & Perfecto, Ivette & Philpott, Stacy & Tscharntke, Teja & Vandermeer, John & von Wehrden, Henrik. (2011). Conservation: Limits of Land Sparing. Science (New York, N.Y.). 334. 593; author reply 594-5. 10.1126/science.334.6056.593-a. Rey Benayas, J.M., Bullock, J.M. Restoration of Biodiversity and Ecosystem Services on Agricultural Land. *Ecosystems* **15,** 883–899 (2012). https://doi.org/10.1007/s10021-012-9552-0

[103] Rey Benayas, J.M., Bullock, J.M. Restoration of Biodiversity and Ecosystem Services on Agricultural Land. Ecosystems 15, 883–899 (2012). https://doi.org/10.1007/s10021-012-9552-0

[104]Reg 1305/2013 Article 23. The European Federation of Agroforestry EURAF complements this definition as follows: "*Agroforestry practices include all forms of association of trees and crops (silvoarable systems) and/or animals (silvopastoral systems) on a parcel of agricultural land, whether in the interior of the parcel or on its edges (hedges)*".

[105] European Agroforestry Federation (EURAF) https://euraf.isa.utl.pt/welcome

- Establishing biological corridors to enhance landscape connectivity and landscape-level biodiversity. Promoting natural regeneration along riparian ecosystems, and hedgerows between plots is particularly worthwhile for this objective.
- Transformation from conventional to organic agriculture, leading to a decreased need for pesticides and fertilisers[106]. This is especially useful if woodland favourable to pollinators and including sources of natural enemies of pests are used.
- Reclamation and rehabilitation of degraded or abandoned agricultural land.
- Improving support for ecosystem services and regulating aspects such as nutrient cycling, soil formation, water regulation, flood control and, erosion control, etc., and prevention of damage from agriculture to adjacent environments.
- Mitigating climate change through increased carbon sequestration.
- Adapting to climate change, in particular by creating micro-climates which regulate extreme temperatures for both animals and crops.
- Increasing the use of short supply chains by forest farming and home gardens.
- Improving overall yield.

1. BENEFITS AND EXAMPLES OF AGROFORESTRY

Field research has shown that integrating trees within agricultural land provides the synergistic benefits of increased land use efficiency and income diversification. It also enables improved animal welfare, enhanced biodiversity, soil conservation and carbon sequestration.

Some examples[107]:

✓ *Food and animal health*: Given their deep roots and recycling of the mineral elements from the soil, trees offer much more nitrogen and nutrient feed (e.g. calcium and magnesium) than meadow grass. Because of its high lignin content and astringence, this fodder is often less digestible than grass. Yet it is a good supplement for livestock[108], particularly in times of fodder shortage.

✓ *Trees and poultry*: The presence of trees in poultry farms improves the comfort and reduces stress for the animals, resulting in an increase in the average weight of chickens for the same feed intake and the same development time. This results in healthier, higher quality and homogeneous poultry throughout the year.

[106] Rosati A, Borek R, Canali S. Agroforestry and organic agriculture. Agrofor Syst. 2021;95: 805–821. https://multifunctionalagroforestry.net/wp-content/uploads/2021/05/Rosati2020_Article_AgroforestryAndOrganicAgricult.pdf
[107] https://ap32.fr/wp-content/uploads/2019/10/livretAP32_agrof_armagnac.pdf.
[108] Ash, elm, mulberry and poplar are the trees most used for their leaves. The most appreciated are ash and poplar, whose energy values are comparable to those of dry hay (0.4 to 0.6 Fourrager Unit) for much higher protein contents (90-120 g/kg dry matter compared to 30-40 g for hay). The leaves of trees also have therapeutic properties.

- ✓ *Crops*: when planted at the heart of cultivated plots, trees grow faster than in forests and are more resistant to wind. With regular lower-branch pruning, they can produce knotless wood which can be used for timber. Agroforestry cereals can have a higher protein content than monoculture cereals. They are more protected from climatic hazards and benefit from soils with enhanced fertility.

- ✓ *Soil*: due to falling leaves and the continuous renewal of fine roots, trees inject organic matter into the soil, feeding the flora and fauna there and increasing biological activity to make it a living and fertile soil. In addition, their root system improves the soil structure. Porosity increases, allowing better infiltration, the storage of water and further promotion of biological activity. Finally, trees create a temperate microclimate favourable to the development of microbial populations, microfungi and microfauna (e.g. lumbrics, etc.). In addition, grazing in orchards compared to intensive orchards/fruit trees is beneficial, since livestock can reduce or even remove the need to use pesticides.

- ✓ *Carbon*: Studies have suggested that agroforestry on 10% of the EU land under "high environmental pressure" could absorb up to the equivalent of 235 million tonnes CO_2 equivalent in year 1[109].

- ✓ *Fauna*: Hedges and woody strips, made up of trees, shrubs and grasses, are all elements of the environment necessary for the presence, development and renewal of wild fauna and game. They are particularly rich environments that can generate complete food chains. Natural pressure on crop pests often results in reduced pesticide use.

- ✓ *Yield:* In comparison with monoculture, agroforestry allows for an overall increase in the yield of a parcel. With 50 trees per hectare, agronomists have measured that the productivity of one hectare in agroforestry can be equivalent to the productivity of one and a half hectares of cereals and wood on separate parcels[110]. These calculations do not take the contributions made by trees to agricultural production into account (reduction of inputs and protection of crops against climatic hazards). Nor do they include the recovery of wood from tree maintenance.

2. KEY ELEMENTS OF AGROFORESTRY

2.1. Create heterogeneous agricultural landscapes

Agricultural intensification has resulted in simple agricultural landscapes characterised by monocultures, large areas of agricultural land, large field size and the absence of non-crop habitats. This leads to a loss of biodiversity. A strategy for improving biodiversity and ecosystem services, and in particular pest control, consists of transforming simplified

[109] Kay S, Rega C, Moreno G, den Herder M, Palma JHN, Borek R, et al. Agroforestry creates carbon sinks whilst enhancing the environment in agricultural landscapes in Europe. Land use policy. 2019;83: 581–593.
[110] Dupraz C, Lawson GJ, Lamersdorf N, Papanastasis VP, Rosati A, Riuz-Mirazo J. Temperate agroforestry: the European way. In: Gordon AM, Newman SM, Coleman BRW, editors. Temperate Agroforestry Systems. Wallingford: CAB International; 2018. pp. 98–162.

agricultural landscapes into more diverse landscapes. Mosaics of well-connected and diversified habitats in different ecological conditions (crop, herbaceous, forests, shrub patches, etc.) sustain biodiversity. They also contribute providing crucial ecosystem services for agriculture[111]. Tree planting and afforestation, through natural and artificial regeneration of tree and woody vegetation, can be useful for implementing these strategies.

The creation of heterogeneous landscapes can be used as a tool for building a coherent network of green infrastructure. Before tree planting or afforestation, it is necessary to consider the landscape matrix with a view to designing corridors that permit the movement of wildlife (e.g. key species) along different habitats. This will enhance the provision of ecosystem services (e.g. the re-establishment of flood alluvial forests along riparian systems).

2.2. Agroforestry systems and practices

There are several agroforestry systems and practices:

Tree location	**Agroforestry system**	**Agroforestry practice**	
		Agricultural land	Forest land
Trees inside parcels	Silvopastoral agroforestry	1. Wood pasture	9. Forest grazing
	Silvoarable agroforestry	2. Tree alley cropping 3. Coppice alley cropping 4. Multi-layer tree-gardens	10. Multi-layer tree gardens
	Permanent crop agroforestry	5. Orchard intercropping 6. Orchard grazing	
	Agro-silvo-pasture	7. Alternating cropping and grazing	
Trees between parcels	Tree landscape features (addressed by CAP conditionality rules)	8. Tree landscape features: protected hedges, scattered individual trees, trees in line, small groups of trees	
Trees in settlements	Urban agroforestry	Home gardens, allotments, etc.	

[111] Bianchi F.J.J.A, Booij C.J.H and Tscharntke T., 2006 Sustainable pest regulation in agricultural landscapes: a review on landscape composition, biodiversity and natural pest controlProc. R. Soc. B.2731715–1727 http://doi.org/10.1098/rspb.2006.3530

Table 1: Agroforestry typologies[112].

Agroforestry must be implemented in a way that does not lead to ecological degradation, but instead to ecological restoration. This applies to both biodiversity and ecosystem services. There are many sources of information and advice available to assist farmers with agroforestry planning and development[113]. In particular:

- Trees inside parcels

Trees and woody vegetation inside parcels should be planted for promoting community assemblages that influence synergistic benefits and enhance ecosystem services. These include:

- pest control;
- increased yield production;
- nutrient cycling and retention;
- carbon sequestration;
- animal welfare.

It is important that tree planting inside parcels is designed to restore the ecology of the areas where they are settled. For example, reforested areas can turn into multi-layered tree gardens and simple crops in simplified land can turn into intercropped tree alley systems.

- Trees between parcels

Linear and scattered trees along with woody vegetation features can be mostly found between fields or at the borders of streams and rivers. For developing new landscape features, a similar approach to the one for trees inside parcels should be considered.

For promoting biodiversity, special attention should be given to scattered trees. They are considered keystone structures, because their effect on ecosystem functioning is relatively disproportionate for the small area occupied by any individual tree. Introducing just 3-5 trees per hectare in treeless sites can double species richness, triple the richness of bat species and increase bat activity one hundred times[114].

It is also important to conserve and adequately promote the presence and development of veteran trees (see section 2.3 of Part II).

Hedgerows can be multi-strata and incorporate herbaceous, woody vegetation and trees. They also create an opportunity to provide ecosystem services[115] . Compared to arable land without hedgerows, these linear landscape features contribute to soil carbon stock (both in the hedgerow and adjacent field), intercept nitrogen and phosphorus from the surface and subsurface flow, and function as soil sediment traps. It has also been shown that, if wisely

[112] Dupraz, C & Lawson, G & Lamersdorf, N. & Papanastasis, V. & Rosati, A. & Ruiz-Mirazo, J. (2018). Temperate agroforestry: the European way.. 10.1079/9781780644851.0098.
[113] For example the EU research programmes funded under FP4 (SAFE); FP7 (AGFORWARD and AFINET (REF)); Horizon Europe (Agromix ref and Mixed - ref) and EIP-AGRI (Agroforestry Focus Group)
[114] Fischer J, Stott J, Law BS. 2010. The disproportionate value of scattered trees. Biol Conserv 143:1564–7.
[115] Van Vooren, Laura, et al. “Ecosystem Service Delivery of Agri-Environment Measures : A Synthesis for Hedgerows and Grass Strips on Arable Land.” AGRICULTURE ECOSYSTEMS & ENVIRONMENT, vol. 244, 2017, pp. 32–51, doi:10.1016/j.agee.2017.04.015.

designed and managed, providing ecosystem services such as pollination can lead to an increase in overall crop production. Additionally, hedgerows can generate important quantities of timber if managed correctly.

A specific type of linear landscape feature is riparian vegetation. This should be restored to avoid surface water pollution and so support compliance with the EU Water Framework Directive[116]. Riparian vegetation refers to vegetation directly adjacent to rivers and streams. Riparian forest extends laterally from the active channel to the uplands, thereby including active floodplains and the immediately adjacent terraces. These help control sediment, reduce the damaging effects of flooding and help stabilise stream banks[117].

Riparian forests can deliver a number of benefits, including:

- filtering capacities;
- providing shade, shelter and food for fish and other aquatic organisms;
- providing wildlife habitats and corridors for terrestrial organisms;
- protecting cropland and downstream communities from flood damage[118].

Even though it is not a widely-used or popular management tool, periodic riparian vegetation removal – traditionally called 'clean up' – should be avoided. It does not have any function in flood mitigation, and can have a negative ecological, hydrological and hydrogeological impact in the river or stream.

- Trees in settlements

Home gardens[119] are combinations of trees/shrubs with vegetable production that is associated with peri-urban or urban areas[120]. Home gardens are currently considered within the circular economy and bioeconomy to be a key tool for mitigating climate change. Activities linked to the increase in fruit trees and horticultural crop production in the surrounding areas of cities reduces transport fuel expenditure, thereby improving the balance of greenhouse gas emissions. These phenomena are mainly associated with urban or peri-urban areas, but also with rural areas. Home gardens provide an excellent way of promoting local food and create a link between cities and the countryside.

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[116] EUR-Lex - 32000L0060 - EN - EUR-Lex (europa.eu)

[117] Scholz et al. 2012, Ökosystemfunktionen von Flussauen - Analyse und Bewertung von Hochwasserretention, Nährstoffrückhalt, Kohlenstoffvorrat, Treibhausgasemissionen und Habitatfunktion. (Ecosystem services in floodplains - analysis of flood water retention, nutrient retention, carbon storage and habitat provision)

[118] Barth and Döll, Assessing the ecosystem service flood protection of a riparian forest by applying a cascade approach, Ecosystem services, 2015

[119] 'Home gardens' is a term which is most often used for multi-strata tropical forests. It is not the same as "kitchen gardens", which are defined by EUROSTAT as '*areas of an agricultural holding devoted to the cultivation of agricultural products (vegetables, root crops and permanent crops, among others) – not intended for selling but for self-consumption by the farm holder and his household*'.

[120] Mosquera-Losada, María Rosa & Santiago-Freijanes, José & Rois, Mercedes & Moreno, Gerardo & Herder, Michael & Vazquez, Jose Antonio & Ferreiro-Domínguez, Nuria & Pantera, Anastasia & Pisanelli, Andrea & Rigueiro-Rodríguez, Antonio. (2018). Agroforestry in Europe: a land management policy tool to combat climate change.

Related activities linked to permaculture, agroecology and agroforestry (when the woody component is present), should be enhanced to deliver more healthy food and provide benefits to biodiversity.

Notwithstanding the above, some particular open agricultural ecosystems, including crop and grasslands, may be valuable for biodiversity conservation and carbon storage[121] . Tree planting or afforestation may actually damage their value. For example, the management guidelines for some areas of Natura 2000 recommend limiting afforestation to promote the conservation of given species[122].

When restoring connectivity in agricultural landscapes, it is also important to avoid creating ecological traps. In other words, habitats that although selected by a species, help to reduce its fitness[123]. For example, hedgerows along roads[124] may attract particular species for their presence of food, but may negatively affect its population.

In conclusion, it is always advisable to complement agroforestry with monitoring and adaptive management, to minimise the loss of biodiversity and ecosystem services.

Recommendations for designing and managing agroforestry systems

- Assess the interdependency and relationship between trees/forest and agriculture/pasture, namely to meet their specific requirements.
- As of the planning phase, consider future management interventions, with the objective of guaranteeing long-term system sustainability and the provision of goods and ecosystem services.
- Take into account the scale of the plot for choosing the type of agroforestry. For example, when dealing with small farms/plots, it is recommended to consider the agroforestry approach that mixes trees, crops and pastures on the same piece of land in a spatial or temporal sequence.
- Take into account temporal variability. When trees grow, shade will impact the understory crops by reducing the energy available for photosynthesis. It will also lengthen the life of leaves and reduce their surface temperature and local evaporation. Also, plan the replacement of trees in windbreaks and shelterbelts or hedgerows in advance when this becomes necessary.

[121] Bond, William. (2016). Ancient grasslands at risk. Science. 351. 120-122. 10.1126/science.aad5132. O'Connor, Timothy. (2019). Open Ecosystems: Ecology and Evolution Beyond the Forest Edge: By William J Bond 2019, Oxford University Press, Great Clarendon Street, Oxford, OX2 6DP, UK192 pages, hardcover and Ebook DOI 10.1093/oso/9780198812456.001.0001ISBN 9780198812456 (hardcover), ISBN: 9780191850318 (Ebook). Price £55.00. African Journal of Range & Forage Science. 36. 203-204. 10.2989/10220119.2019.1695663.

[122] This is the case, for example, with ZEPA Tierra de campiñas (Spain), a cereal-crop steppe, for which it is recommended to promote sustainable management of unirrigated arable crops and limit the creation of new forested patches.

[123] Hale, R. and Swearer, S.E. (2017), When good animals love bad restored habitats: how maladaptive habitat selection can constrain restoration. J Appl Ecol, 54: 1478-1486. https://doi.org/10.1111/1365-2664.12829

[124] Fahrig, L., & Rytwinski, T. (2009). Effects of roads on animal abundance: An empirical review and synthesis. Ecology and Society, 14(1), 21

- It is important to select vegetation that creates synergistic benefits between trees and crops and improves yield. When planted in rows, the tree understorey could be planned to be part of the production system itself. This can be achieved by cultivating short-rotation coppice, berries or hazelnut shrubs. Alternative crops include herbs or flowers, or perennial crops like artichoke, rhubarb and mushrooms. Appropriate legume and grass species, varieties and cultivars should be selected for sowing in shade under given conditions. It is highly recommended to maintain herbaceous strips under linear trees.

- Young trees may require their seedlings to be protected from animals. This requires the use of temporary fences or individual protectors, or limiting/controlling livestock. In areas with a combination of trees and crops, using low-tillage systems and avoiding ploughing near trees would also prevent damage to their root systems.

PART IV - FINANCING AFFORESTATION, REFORESTATION AND TREE PLANTING[125]

As stated in the introduction, this section represents an initial analysis and will be further developed and complemented by a guidance booklet on financial sources (including private funding) supporting action under the '3 billion trees' pledge, to be produced in 2023.

1. COMMON AGRICULTURAL POLICY

Within the framework of the Common Agricultural Policy (CAP), Member States have the possibility to financially support afforestation measures through the European Agricultural Fund for Rural Development (EAFRD). CAP funds are implemented via shared management between the Commission and the Member States. The CAP Strategic Plans Regulation[126] provides for a certain degree of flexibility in designing such measures under the instrument of investments, which Member States have to define in their CAP Strategic Plans coming into force as of 2023, if they chose to make use of this possibility.

When designing afforestation measures under the CAP, Member States must ensure that the measure contributes to at least one of the nine specific objectives (Article 6 of the CAP Strategic Plans Regulation), plus the cross-cutting objective, and is consistent with environmental and climate-related objectives that align with sustainable forest management principles, as developed in the Pan-European Guidelines for Afforestation and Reforestation.

Up to 100 % of eligible costs of the investment can be reimbursed if the afforestation measure(s) contributes to at least one of the specific objectives for:

- mitigating and adapting to climate change;
- promoting sustainable development and the efficient management of natural resources,
- mitigating and reversing biodiversity loss.

In addition, the CAP framework also offers the possibility of financial support for maintaining already afforested land under Art. 70 of the CAP Strategic Plans Regulation ("Environment, climate-related and other management commitments").

At least five Member States[127] fund their forestry programmes, including agroforestry, outside the CAP through State aid.

[125] This is only an introductory text, a detailed text will be integrated in these guidelines at a later stage.
[126] Consolidated text: Regulation (EU) 2021/2115 of the European Parliament and of the Council of 2 December 2021 establishing rules on support for strategic plans to be drawn up by Member States under the common agricultural policy (CAP Strategic Plans) and financed by the European Agricultural Guarantee Fund (EAGF) and by the European Agricultural Fund for Rural Development (EAFRD) and repealing Regulations (EU) No 1305/2013 and (EU) No 1307/2013.
[127] Ireland, Finland, Netherlands, Sweden, Luxembourg and three German Länder.

2. COHESION POLICY

Cohesion policy targets all regions in the European Union to support job creation, business competitiveness, economic growth, sustainable development, and improve citizens' quality of life. To reach these goals and address the diverse development needs in all EU regions, EUR 392 billion – almost a third of the total EU budget – has been set aside for cohesion policy for 2021-27.

The bulk of cohesion policy funding is concentrated in less developed European countries and regions, to help them to catch up with their peers and so reduce the economic, social and territorial disparities that still exist in the EU. The European Regional Development Fund (ERDF), ESF+ and Cohesion Fund will support five policy objectives in the 2021-27 programming period. These will focus on creating a more competitive, smarter, greener, more connected, more social and inclusive Europe that is closer to its citizens.

Investments under policy objective 2; "A greener, low-carbon transitioning towards a net zero carbon economy and resilient Europe", will directly contribute to achieving the objectives of the European Green Deal. EUR 92 billion has been allotted for the 2021-2027 period. A minimum 30% of the national ERDF allocations has to be invested under this policy objective. Investments to protect and preserve nature and biodiversity, and to tackle all sorts of pollution will be supported by EUR 7.4 billion from the ERDF and the Cohesion Fund over the period.

Cohesion policy funds are also implemented via shared management between the Commission and the Member States. Each Member State is required to prepare a Partnership Agreement, which is then implemented through programmes at national or regional level. This includes sub-regional territories such as cities, as well as programmes for cross-border, transnational and interregional cooperation. These programmes determine the strategy and investment priorities to be supported by each fund to address the specific development needs and challenges of the territory covered. They are also designed to be complementary and to not overlap with other EU instruments. These funds are available for all territories, including rural areas.

Afforestation and reforestation measures are important investments that feature prominently under cohesion policy, such as:

- protecting and preserving nature and biodiversity;
- managing and restoring Natura 2000 sites and other biodiversity hotspots;
- developing green spaces (e.g. parks, public gardens, green roofs, coastlines, urban forests and meadows, trees and hedges).
- interconnections between green spaces (e.g. green corridors).
- ecosystem restoration projects.
- nature-based solutions for climate change adaptation and disaster-risk reduction.
- green infrastructure with multiple benefits (climate, water, air and risk management).

3. LIFE

The LIFE programme is the only EU programme dedicated exclusively to the environment, nature and climate action. It fully contributes to the objectives and targets of the European Green Deal. With more than 5,000 projects financed in the 30 years of its existence, LIFE has delivered important results such as protection and the conservation of habitats and species of European importance. It has implemented EU air quality, waste, chemicals, water and climate policies.

LIFE has co-funded several projects to protect forest biodiversity, improving the conservation status of forest habitat types and species of EU importance (according to the Habitats and Birds Directives). These projects aim to support the ecosystem services they provide in climate and water regulation, carbon sequestration and storage, soil stabilisation and air and water purification.

The current Programme for the Environment and Climate Action for 2021-27 pursues these goals, with a budget of €5.43 billion for 2021-27. The EU co-financing rate is between 60% and 75%.

Through area-based conservation or restoration measures, the sub-programme‘ Nature and Biodiversity’, aims to:

- restore natural or semi-natural forest habitats and species in their structure, composition and functioning;
- improve forest resilience to fires, droughts, diseases and climate change, and prevent/reduce the impact of natural disasters;
- protect the EU’s primary and old-growth forests;
- create ecological corridors and other green infrastructure;
- test/demonstrate new management approaches, including “closer to nature” forestry practices.

Under restoration projects within and outside the Natura 2000 network and existing protected areas, reforestation measures are essential measures to ensure the protection of forest biodiversity and ecosystem services. They are also vital for improving forest health and resilience, and mitigating existing pressures and threats.

The LIFE programme has supported and continues to support the creation of dedicated plant nurseries to produce suitable native species and local ecotypes. These are to be used in the management and restoration of Natura 2000 sites and other biodiversity hotspots.

The sub-programme Climate Change Mitigation and Adaptation encourages, among other practices:

- Projects that address practices which enhance carbon removal in soils and biomass (e.g. improved forest management, afforestation and forest restoration).
- Adaptation solutions for forest managers, Natura 2000 managers and other land managers to ensure resilience and reduce climate risks. These include afforestation, reforestation and forest restoration.
- The better use of genetic diversity and non-harmful plant genetic resources, including by broadening the supply of suitable, high-quality plant reproductive material. Another method is encouraging collaborative, transnational production and the transfer of seeds and planting material though active policies and actions.

This sub-programme also provides support for operating the European Climate Pact[128]. Examples include tree planting, and improving the climate resilience of existing plantations and green spaces.

4. HORIZON EUROPE

Horizon Europe funds research and innovation projects (R&I) and facilitates their collaboration. It also strengthens the impact of R&I in developing, supporting and implementing EU policies while tackling global challenges. The programme aims to ensure the creation and better diffusion of excellent knowledge and technologies.

Cluster 6 of Horizon Europe (Food, Bio-economy, Natural Resources, Agriculture and Environment) will support the afforestation, restoration and planting activities. This will be through improving the scientific and practical knowledge base on suitable species selection, site requirements and forest management practices. This knowledge base will support the objectives on climate change mitigation, adaptation, biodiversity and the bioeconomy of newly established or restored forests.

Examples of relevant projects are:

- SUPERB - Systemic solutions for upscaling urgent ecosystem restoration for forest-related biodiversity and ecosystem services[129].
- MAIL - Identifying Marginal Lands in Europe and strengthening their contribution potentialities in a CO_2 sequestration strategy[130].

5. TECHNICAL SUPPORT INSTRUMENT (TSI)

The Technical Support Instrument (TSI)[131] provides technical support upon request to design and implement reforms in the Member States. The support is provided upon request across a wide range of policy areas, such as implementing the EU Forest Strategy at Member State level. This includes the EU Biodiversity Strategy, forest restoration and reinforced sustainable forest management in the context of other EU priorities like the green and the digital transition.

A guide on all funding options for the environment was published by DG Environment in 2022[132]. This guide aims to provide practical information about possible EU funding options and technical assistance for interested project promoters.

[128] https://climate-pact.europa.eu/index_en
[129] https://cordis.europa.eu/project/id/101036849
[130] https://cordis.europa.eu/project/id/823805
[131] Regulation (EU) 2021/240 of the European Parliament and of the Council of 10 February 2021 establishing a Technical Support Instrument.
[132]https://op.europa.eu/en/publication-detail/-/publication/33b54f0d-0251-11ed-acce-01aa75ed71a1/language-en/format-PDF

ANNEX

1. RELEVANT EU LEGISLATION AND INTERNATIONAL GUIDELINES

The **Environmental Impact Assessment (EIA) Directive** 2011/92/EC[133] as amended lists "*Initial afforestation and deforestation for the purposes of conversion to another type of land use*" in its Annex II, meaning that any such project must undergo screening in accordance with the Directive, to establish whether a full EIA must be carried out.

The protection and management of Natura 2000 sites designated in forests under both the **Habitats Directive** and **Birds Directive[134]** is governed by Article 6 of the Habitats Directive. Article 6 contains three key provisions that requires Member States to:

- establish the necessary conservation measures on each site, which correspond to the ecological requirements of the protected habitat types and species of EU importance present (Article 6.1);
- take measures to avoid deterioration of the habitats, or any significant disturbance of the species for which the sites have been designated (Article 6.2);
- introduce an appropriate assessment procedure for plans or projects that are likely to have a significant negative impact on a Natura 2000 site (Article 6.3 and 6.4).

Afforestation projects, enrichment planting and natural regeneration likely to have a significant impact on protected species and habitats in Natura 2000 sites should therefore comply with Art 6(2-4) of the Habitats Directive.

While the use of Forest Reproductive Materials (FRM)[135] falls under the competence of Member States, it is mandatory to ensure that all material used (seeds, plants and cuttings) has been produced from approved basic material, and meets the requirements of one of the four categories of forest reproductive material (source-identified, selected, qualified and tested categories) of the **Forest Reproductive Material Directive[136].**

Guidelines supporting reforestation and restoration actions also exist at international level, such as the European Guidelines for Afforestation and Reforestation[137] and the PEOLG (Pan-European Criteria, Indicators and Operational Level Guidelines for Sustainable Forest Management[138]), published by Forest Europe, the FAO'S Forest and Landscape Restoration Mechanism[139], the Forest landscape restoration promoted by the IUCN[140], and the guidance on forests and Natura 2000 by the European Commission[141].

[133] https://ec.europa.eu/environment/eia/eia-legalcontext.htm
[134] https://ec.europa.eu/environment/nature/legislation/index_en.htm
[135] https://ec.europa.eu/food/plants/plant-reproductive-material_en
[136] http://data.europa.eu/eli/dir/1999/105/oj
[137] https://foresteurope.org/publications_type/guidelines-for-afforestation-and-reforestation-2009/
[138]https://foresteurope.org/publications_type/resolution-l2-pan-european-criteria-indicators-and-operational-level-guidelines-for-sustainable-forest-management/
https://foresteurope.org/publications_type/resolution-l2-pan-european-crite
ria-indicators-and-operational-level-guidelines-for-sustainable-forest-mana
gement/
//ec.europa.eu/environment/nature/natura2000/management/guidance_en.htm

2. GOOD PRACTICE

Examples of national/regional guidelines/good practice

Good practice example	**Technical manuals on (1) project preparation, (2 & 3) choice of species (Atlantic and Mediterranean areas), (4) silvicultural operations and (5) planning and execution of forest logging / Portugal**
Category	X Forest ○ Urban ○ Agroforestry
Subjects covered	○ X Choice of species ○ Climate change ○ Protection of habitats ○ X Protection of soil and water ○ X Natural regeneration ○ X Other: further dimensions of successful afforestation/reforestation, including several silvicultural operations, and planning and implementation of forest logging and forest infrastructures.
Lessons learned	The overall outcome of these manuals was considered quite positive since they came out as important contributions to popularise – in straightforward language and with the help of appropriate illustrations – relevant aspects of successful afforestation/reforestation practices. They were instrumental in alerting silvicultural practitioners in Portugal to the need to value the environmental importance of their choices, which included the need for a balanced choice of species, integrating valuable hardwoods in appropriate mixtures with conifers, avoiding harmful site preparation techniques, using judicious methods to conserve soil and water and control competing vegetation, adopting sound methods of building forest roads and awareness of the risks of using hazardous and unsafe working methods. Despite the time that has already elapsed since their publication, the recommendations in this set of manuals are still mostly valid.
Weblinks:	Set of technical manuals on (1) project preparation, (2 & 3) choice of species (Atlantic and Mediterranean areas), (4) silvicultural operations and (5) planning and execution of forest logging: 1. https://www.icnf.pt/api/file/doc/17f892058c7285c5 2. https://www.icnf.pt/api/file/doc/54f608c229f6286b 3. https://www.icnf.pt/api/file/doc/e63263774895d9cf 4. https://www.icnf.pt/api/file/doc/e550b62b6b44f397 5. https://www.icnf.pt/api/file/doc/acf7f6df5f0f5ec2 Main contact information:

	Cristina Santos Head of Forest Management and Competitiveness Division Institute for Nature Conservation and Forests Cristina.santos@icnf.pt

Good practice example	**Technical and ecological bases of the forest restoration project / Spain**
Category	○ Forest ○ Urban ○ Agroforestry
Subjects covered	○ ○ X Choice of species ○ Climate change ○ Protection of habitats ○ Protection of soil and water ○ X Natural regeneration ○ X Reforestation and afforestation
Lessons learned	
Links	Volume 1: basestecnicasyecologicasdelproyectoderepoblacionforestal-tomo1_tcm30-534170.pdf (miteco.gob.es) Volume 2: basestecnicasyecologicasdelproyectoderepoblacionforestal-tomo2_tcm30-534171.pdf (miteco.gob.es)

Good practice example	**Adaptation of Stocking Targets – "Forest of the Future"/Austrian Federal Forests (Bundesforste) / Austria**
Category	x Forest ○ Urban ○ Agroforestry
Subjects covered	x Choice of species x Climate change

	○ Protection of habitats ○ Protection of soil and water ○ Natural regeneration X Stocking targets
Lessons learned	Bundesforste has launched a strategic forest management project until the year 2100. It aims to adapt stocking targets to the future conditions of under the campaign slogan “Forest of the Future” (see the website below). To establish close-to-nature forestry practices perfectly adapted to their site, only mixed forests are allowed. The range of tree species will be expanded and the share of each per area will change. Some of these changes will be significant. For example, the main species spruce will come down from 58 to 41%. These targets are implemented by the annual plan which covers 10% of the Bundesforste area. The operational measures concern reforestation activities in clear-cut areas, as well as tending operations in areas with natural regeneration. What seems important to us is that the achievement of the targets is regularly monitored within the existing forest control system.
Links	https://www.wald-der-zukunft.at/ Dr.Norbert Putzgruber, Austrian Federal Forests plc. (Österreichische Bundesforste AG): norbert.putzgruber@bundesforste.at

Good practice example	**Polish Silvicultural Guidelines (PSG)/ POLAND** This details the objectives and principles of sustainable forest management defined in the National Forest Policy and the Polish Forest Law. The guidelines continue the direction of semi-natural silviculture based on natural patterns created in the past and contemporary processes of developing natural phenomena. The practices take socio-economic requirements and principles of sustainable development into account.
Category	**x Forest** ○ Urban ○ Agroforestry
Subjects covered	x Choice of species x Climate change x Protection of habitats x Protection of soil and water x Natural regeneration x Other (please specify) x Forest management x Forest nursery x Artificial regeneration with seedlings or seeds x Principles of water management x Principles of forest afforestation
Lessons learned	The PSG has a directional and framework character and is based on documented results of scientific research. It has also been informed by the experience of successive generations of foresters. The guidelines may be applied to forests of all forms of forest ownership. It is updated approximately every 10 years and may be supplemented, specified and made more precise in the form of guidelines or other provisions. These will be implemented in state-owned forests by appropriate regulations. Due to local conditions, experience and climate change, the guidelines can be modified to a certain extent during the preparation stage of the forest management plan.

Links	https://www.lasy.gov.pl/pl/pro/publikacje/copy_of_gospodarka-lesna/hodowla/zasady-hodowli-lasu-dokument-w-opracowaniu Michał Magnuszewski, Ph.D Eng. Specialist Silviculture Unit Directorate General of the State Forests michal.magnuszewski@lasy.gov.pl

3. MEMBER STATE EXPERTS AND KEY STAKEHOLDERS

Member State Experts	
Austria	Federal Ministry for Agriculture, Forestry, Regions and Water Management
	Federal Ministry for Climate Action, Environment, Energy, Mobility, Innovation and Technology
Belgium	Service Public de Wallonie (SPW)
	Forêt.Nature
	Research Institute for Nature and Forest (INBO)
	Sonian Forest Foundation
Bulgaria	Executive Forest Agency
	Ministry for Agriculture
	Ministry for Environment and Water
Croatia	Ministry for Agriculture
	Ministry for Economy and Sustainable Development
Cyprus	Ministry for Agriculture, Rural Development and Environment – Department of Forests
Czechia	Ministry for Agriculture
	Ministry for Economy and Sustainable Development
Denmark	Ministry for Environment
	Danish Environmental Protection Agency - Landscape and Forest
Estonia	Ministry for Environment, Forest & Nature Conservation Departments
Finland	Ministry for Agriculture and Forestry
	Finnish Environment Institute
	Ministry for Environment
	Natural Resources Institute of Finland
France	Ministry for Agriculture
	Ministry for Environment
	Ministry for European Affairs
Germany	Federal Ministry for Environment, Nature Conservation, Nuclear Safety and Consumer Protection
	Federal Ministry for Food and Agriculture
	Federal Agency for Nature Conservation
Greece	Ministry for Environment and Energy, Directorate General for Forests and Forest Environment
Hungary	Ministry for Agriculture - Department for Forest Management
Ireland	The National Parks and Wildlife Service - Department for Housing, Local Government and Heritage
	The Forest Service - Department of Agriculture, Food and the Marine
Italy	Institute for Environment Protection and Research
	Ministry for Agriculture, Food Sovereignty and Forests
	Ministry for Environment and Energy Security
	UNIFI - Università degli Studi di Firenze
Latvia	Ministry for Agriculture

	Ministry for Environmental Protection and Regional Development
Lithuania	Ministry for Environment
Luxembourg	Ministry for Environment, Climate and Sustainable Development
	Ministry for Agriculture, Fisheries and Animal Rights
	Ministry for Environment, Energy and Enterprise
	Ambjent Malta
Malta	Parks Malta
Netherlands	Ministry for Agriculture, Nature and Food Quality
Poland	Ministry for Climate and Environment
	Directorate General for the State Forests
	Institute for Conservation of Nature and Forests
Portugal	Ministry for Environment and Climate Action
Romania	Ministry for Environment, Waters and Forests – General Directorate of Forests and Strategies in Forestry
Slovakia	National Forest Centre
	Ministry for Environment
Slovenia	Ministry for Natural Resources and Spatial Planning
Spain	Ministry for Ecological Transition and Demographic Challenge - Directorate General of Biodiversity, Forests and Desertification
Sweden	Swedish Forest Agency
	Swedish Environmental Protection Agency

Forest Stakeholders, Civil Society Organisations and others
CEPF- Confederation of European Forest Owners
CEPI - Confederation of European Paper Industries
COPA/COGECA - Farmers and Forest-Cooperatives Organisations
EFNA- European Forestry Nursery Association
ELO- European Landowners' Organization
EOS- European Organisation of the Sawmill Industry
EUSTAFOR - European State Forest Association
FSC- Forest Stewardship Council International
PEFC- Programme for the Endorsement of Forest Certification

USSE - Unión de Selvicultores del Sur de Europa
BirdLife Europe and Central Asia
EEB - European Environmental Bureau
EuroNatur
Fern
Protect the Forest
Wild Europe Foundation
WWF European Policy Office
EFI- European Forest Institute
EURAF - European Agroforestry Federation
FACE - European Federation for Hunting and Conservation
Pro Silva
Saami Council