CHAPTER 3

Assessment of regeneration needs at a specific site

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Introduction

Assessing the "best" way to establish a new forest on a site requires knowledge of the aspirational, potential, operational, and contextual factors that affect the many decisions that must be made to ensure sustained long-term success. Aspirational factors are the objectives, specifically the expectations for the quantity and quality of ecosystem services the established stand will provide. Potential factors refer primarily to the past, present, and future biophysical conditions of the site as they relate to the intended tree species that will grow there. The specific methods that will be used to regenerate (afforest, reforest, or restore) the forest and the intended (silvicultural) management system that will be employed define the operational factors. All of these factors occur within a socio-ecological context of ownership, tenure, governance, regulation, and tradition.

Evaluating a site's potential requires assessing its past, present, and likely future conditions under the uncertainty caused by climate change (Millar et al., 2007; Latif, 2013; Lindner et al., 2014). The focus of this chapter is on assessing the factors that impact forestation, including afforestation, reforestation, and restoration (Chapter 2; Stanturf et al., 2024). Our objective is to raise awareness of the factors that potentially limit establishment and growth today and in the future under climate change. The focus will be on the early stage of stand initiation (Oliver and Larson, 1996), the regeneration niche (Grubb, 1977). The questions we ask include: (1) are there factors (conditions, limitations, or obstacles) potentially hindering regeneration, (2) can the identified factors be overcome or mitigated, and (3) will climate change alter the identified factors? Given the diversity of past land use, site characteristics, climate, and social context across Europe, not every factor will be relevant to all sites. The expected outcomes (i.e., ecosystem services) depend on the way the forest will be managed, specifically the intensity and frequency of interventions made to shape the composition and structure of the stand, including any biomass removals. Initially, the question is what intensity of stand establishment method will be employed—natural or artificial regeneration?

The regeneration niche (Grubb, 1977) refers to the conditions needed for a sexually mature plant to reproduce and for its seedlings to successfully germinate and establish.

Guidelines for Climate Adaptive Forest Restoration and Reforestation Projects
ISBN 978-0-443-34086-4,
https://doi.org/10.1016/B978-0-443-34086-4.00003-7

Many biotic and abiotic factors can disrupt these processes, singly or in combination. For example, late spring cold temperatures could disrupt flowering, pollination, or both, reducing seed production. Fungal diseases or weevils (e.g., *Curculio* spp.) can reduce the number of viable seeds. Animal predation can consume seeds, or dispersal agents may be lacking or ineffective. Seeds may disperse to inhospitable sites and fail to germinate. New germinants are small and fragile, thus susceptible to desiccation from the high irradiance on bare sites. Seedlings are exposed to competition from herbaceous vegetation and herbivory by ungulates and rodents. Yet interaction with shrubs (i.e., facilitation) may help seedling establishment in harsh environments (Gómez-Aparicio et al., 2004; Smit et al., 2007). All these features of the regeneration niche are critical for natural regeneration. Artificial regeneration, whether done by direct seeding or planting, seeks to reduce these risks by conducting some of these activities under more controlled conditions. Direct seeding reduces risks during reproduction and dispersal, and planting additionally provides a less risky environment for germination and early growth, shortening the path to establishment. The condition of the trees at the end of the establishment phase determines the value (i.e., the nature and level of ecosystem services) of the forest for decades.

While large-scale tree planting has recently gained international attention, foresters have long grappled with the question of which tree to plant (e.g., Minckler, 1941). The guiding principle in large-scale planting programs globally is "The right tree, in the right place, for the right purpose" (Brancalion and Holl, 2020; SCION, 2020). Artificial regeneration of protection and production forests has favored planting only one or two species. Increasingly, however, there is a shift toward establishing multispecies stands (Bauhus et al., 2017; Coll et al., 2018; Felton et al., 2024). Meeting the requirements for establishing multispecies stands requires even greater attention to site conditions, especially microsite variability. The immediate reason for assessing the site is to assist in selecting appropriate species and stock types for regenerating a forest and ensuring their successful establishment and early growth.

The long-term performance of species on a site needs to be considered as well, to ensure that the resulting forest will prosper and deliver the desired ecosystem services. Successfully establishing species that are not adapted to the site squanders not only the establishment costs but also the lost opportunity and benefits. Thus to fully assess the regeneration needs at a site requires knowing the long-term growth requirements of the target species, i.e., the species traits that must be accommodated. The primary focus in this chapter is on site potential, the capacity to support forests based on inherent factors such as landform, soil, and microclimate, which together are the integrated effects of the environment on tree survival and growth that, with management, will produce desired outputs (Ryan et al., 2002). This approach differs somewhat from the traditional forester's view that stresses the productivity of the existing tree species present on the site, or what is considered potential vegetation on the site. This potential is usually expressed as site quality, class, or index (Deal, 2018). The key features of this approach are (1) there is knowledge of which species are adapted and how well they grow on the site, and (2) climate stationarity (or stability) is assumed. Our approach, contrarily, facilitates the generalizations necessary for situations where knowledge is scarce or lacking (afforestation) and the climate is likely to change.

Forestation encompasses a range of conditions, including afforestation on sites previously used for other land uses, reforestation on formerly forested sites that have been completely cleared of trees due to harvest or disturbance, and restoration on degraded sites, which may or may not retain remnants of overstory vegetation. A successful forestation system proceeds in 10 steps covered in this book (Table 3.1). Additional consideration is given to the effects of planted forests on biodiversity (Chapter 9) and climate change mitigation (Chapter 10).

Objectives

To address site limitations and strategies for overcoming them under changing environmental conditions, it is essential to define clear objectives and targets for forestation (Gregor et al., 2024). These objectives may vary depending on tenure, site conditions, who decides between natural or artificial regeneration, who covers the planting costs, and who ultimately benefits from the resulting ecosystem services (Bateman et al., 2023). The process of setting objectives requires engaging with all stakeholders, those who influence or are affected by forestation decisions (Bryson, 2004; Reed et al., 2018; Elias et al., 2022). The context of public versus private land ownership sets different expectations on how implementation decisions are made (Martin et al., 2021; Staddon et al., 2021; Mansourian and Vallauri, 2023). Since Europe is the context for this book, many of the complex governance and tenure issues typically found in tropical countries that consume the restoration literature do not apply here (Mansourian and Sgard, 2019; D'Amato et al., 2022). Nevertheless, social acceptance and compliance with both land use planning rules and forestry practice regulations apply to all ownerships (Kangas, 1994; Buchy and Hoverman, 2000; Fischer, 2018). In some countries, limitations on the species that may be planted constrain what is possible, limiting the use of species or provenances that could be better adapted to future conditions (see Chapter 1).

Multiple objectives in forestation may be pursued for different reasons (Di Sacco et al., 2021; Bateman et al., 2023). A common primary or secondary objective is to improve productivity (Martin et al., 2021), which can be achieved by planting site-adapted, genetically improved material (Millar et al., 2007; Dumroese et al., 2015a; Chakraborty et al., 2024). The immediate objective may be to rapidly reoccupy the

Table 3.1 The 10-step process to follow for successful forestation, showing the relevant chapters describing each step in detail.

Step	Procedure	Description	Chapter
1	Identify objectives	With stakeholders, define clear objectives of the forestation project. Many objectives are possible, and some may be compatible and pursued together, but other combinations may require compromise and trade-offs	3
2	Characterize the site	Knowledge of site characteristics facilitates species selection, site preparation, and other necessary practices	3
3	Identify special considerations	Special considerations needing to be considered early in planning to avoid later problems or complications include biological, social, and regulatory factors	3
4	Define major limiting factors	Site factors that limit forestation success need to be identified so that steps to mitigate or avoid them can be taken in a timely manner. Infertile soil, pests (insects and diseases), and pollution are some examples	3
5	Select the best species and seed source	Considering the above factors, select the best species and seed sources that meet objectives and establish and grow given site limitations	4
6	Identify the best forestation method	The choices are natural regeneration, direct seeding, or planting	5
7	Select the best stock type or seed source and seeding/ planting procedure	The best stock type or seed source includes ensuring that the best nursery procedures and seed treatments are followed, along with the most appropriate and cost-effective seeding/ planting procedure	5
8	Determine site needs	Site preparation seeks to overcome any limitations and create the most hospitable environment possible for the newly germinating or planted seedling	6
9	Determine seedling protection and establishment needs	Protection and abiotic stress amelioration during establishment may be needed from insects, diseases, animals, competing vegetation, and drought	6, 7
10	Monitor and evaluate	The forestation process proceeds for 5 years and must be monitored and evaluated to assess success and the need for further interventions such as supplemental planting to compensate for early mortality	7, 8

Adapted from Dougherty, P.M., Duryea, M.L., 1991. Regeneration: an overview of past trends and basic steps needed to ensure future success. In: Duryea, M.L., Dougherty, P.M. (Eds.), Forest Regeneration Manual. Kluwer, Dordrecht, pp. 3–7.; Stanturf, J., Mansourian, S., Kleine, M., 2017. Implementing Forest Landscape Restoration: A Practitioner's Guide. International Union of Forest Research Organizations, Vienna, Austria.

site and quickly regenerate a stand after harvesting or disturbance to avoid soil erosion or sediment delivery to water courses (Borrelli et al., 2018; Prescott et al., 2021). Planting multiple species of locally- and climate-adaptive provenances may serve a range of objectives, including reducing soil movement and producing timber, but also supporting biodiversity or sequestering carbon (Duveneck and Scheller, 2015; Huuskonen et al., 2021; Mina et al., 2022). Similarly, planting riparian buffer strips with locally- and climate-adaptive provenances could improve water quality and quantity while benefiting climate resilience and biodiversity (Hughes et al., 2005; Sonesson et al., 2020; Hasselquist et al., 2021). Despite the fact that native species are often preferred or even required by regulation (Pötzelsberger et al., 2020), increasingly the value of retaining or planting translocated climate-adapted provenances or species is recognized (Chakraborty et al., 2024; Konic et al., 2024; Nyssen et al., 2024). Alternatively, forests currently comprised of nonnative or climatically maladapted species could be converted to stands of climate-adapted native or nonnative species through underplanting in created gaps or after clearcutting (Dey et al., 2012; Reventlow et al., 2023). Whatever the process for deciding on objectives, it is critical that all stakeholders share an understanding of the initial environmental and social conditions and the desired future conditions.

Forestation objectives, whether aimed at productivity, biodiversity, protection, or restoration, often include secondary objectives. Among these, adaptation to the future climate conditions is increasingly recognized as both a complementary goal and a critical necessity. Productivity as an objective includes timber, biofuel, or non-timber forest products (NTFP such as cork oak, nuts, and medicinals) and, increasingly, carbon for climate change mitigation (Canadell and Raupach, 2008; Yousefpour et al., 2018; Ameray et al., 2021; Brèteau-Amores et al., 2023). Biodiversity often is a primary objective of ecological restoration in protected areas and secondarily, as an aspect of planting mixed species stands to be more resilient (Balieiro et al., 2020; Felton et al., 2022; Messier et al., 2022). Resilience and climate adaptation increasingly are direct and indirect objectives of all forms of forestation (Cumming, 2011; DeRose and Long, 2014; Aquilué et al., 2020; Bose et al., 2020), particularly in climate-smart or climate-adapted forestry and restoration (Bowditch et al., 2020; Hallberg-Sramek et al., 2022; Cooper and MacFarlane, 2023). Prestoration is an emerging term, defined as utilizing species in restoration efforts for which a site represents suitable habitat now and into the future and also seeking to restore ecosystem structure and function in a changing climate (Butterfield et al., 2017; Svensson et al., 2023; Stanturf et al., 2024).

Defining objectives can be a relatively simple exercise when reforesting after a harvest with the same species or a more involved process when creating a new forest, for example, when afforesting former agricultural land (Table 3.2). Increasingly, reforestation or restoration aims for something new; introducing new species or provenances that are better adapted to a changing climate (Dumroese et al., 2015a; Bower et al., 2024) or

Table 3.2 Protection and restoration often focus on ecosystem functions in particular areas of the landscape, such as watersheds, coastal forests, and sensitive soils. Certain areas in a degraded landscape can be targets for restoration, especially afforestation, to restore functionality.

Potential target locations	Advantages of establishing a new forest at this location
Areas that are able to regenerate naturally	The cost of restoration is low (although the costs of protecting these areas may be significant)
Buffer strips planted around remnant patches of natural forests	Protect these remnants from further disturbances, enlarge their effective areas, and soften edge effects (highest priority being given to remnants with endangered or vulnerable species)
Corridors planted between remnant patches of natural forests	Facilitate movement of species and genetic exchange between isolated populations
Corridors or "stepping stones" planted along altitudinal and longitudinal gradients	Facilitate movement of species in response to environmental stresses such as climate change and creation of habitat for forest organisms
Steep slopes	Protect erosion-prone soils
Riparian strips	Protect erosion-prone soils and act as filters to limit sediments and chemicals reaching waterways. Act as corridors for species movement
Areas subject to sheet erosion and with compacted soils	Protect erosion-prone soils and increase infiltration capacity
Groundwater recharge areas in salinity-prone areas	Increase evapotranspiration, thereby increasing depth of water table and decreasing salinity problems
Coastal protection zones	Decrease storm impacts and create habitat for fisheries
Urban areas	Improve recreational opportunities, provide shade to reduce heat stress

Adapted from Lamb, D., Stanturf, J., Madsen, P., 2012. What is forest landscape restoration? In: Stanturf, J., Lamb, D., Madsen, P. (Eds.), Forest Landscape Restoration Integrating Natural and Social Sciences. Springer, Dordrecht, pp. 3–23; Lamb, D., 2014. Large-Scale Forest Restoration. Routledge, London.

establishing more resilient mixtures instead of monocultures (Bauhus et al., 2017; Löf et al., 2023; Kremer et al., 2025). Even in the simplest scenario, reforesting with the same species, the uncertainty of future conditions could challenge the 'business-as-usual' approach and necessitate a reassessment of site conditions.

A practical way to define forest restoration objectives with stakeholders is to begin by asking two key questions: (1) Do we have the conditions we want? (2) Do we want a given condition? Working from a good description of the ecosystem baseline, this leads to four possible objectives of preserving/maintaining or eliminating current conditions or achieving/improving or avoiding future conditions (Fig. 3.1). The answers to these questions could be different in different parts of a large, diverse landscape, so it is important that the baseline description is sufficiently detailed so that stakeholders are working from the same mental picture of the landscape conditions. Only after consensus objectives are agreed to should the question be asked: What are feasible interventions?

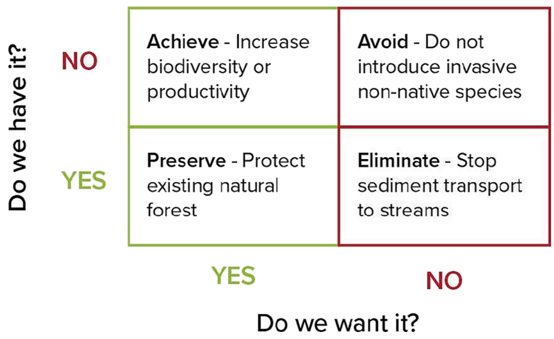

Figure 3.1 Asking two questions, do we have it and do we want it, leads to four possible objective statements, for example, yes/yes: Preserve existing primary forest, or no/no: Avoid introducing nonnative invasive species. Example objectives are given for each combination of answers. Positive objectives are outlined in green, negative objectives in red. *(Credit: John A. Stanturf.)*

Objective-setting becomes especially contentious when the desired future condition is defined as a return to a historic state. Some approaches, especially ecological restoration, equate this with fidelity to a reference ecosystem (SERI, 2004; Goebel et al., 2005; Balaguer et al., 2014; Berglund and Kuuluvainen, 2021). Generally, reference ecosystem conditions should reflect the compositional and structural attributes that have developed after natural disturbances, and the most useful reference conditions are often those that represent the range of "natural" variability associated with the ecosystem (Goebel et al., 2005; Balaguer et al., 2014; Berglund and Kuuluvainen, 2021).

Strict adherence to reference systems as the desired endpoint for restoration presents several difficulties, such as when no references exist because of long-term human modifications that have eliminated or greatly altered natural ecosystems. Although relatively untouched forests may exist, the conditions that formed the candidate reference stands might no longer exist, for example, in areas of high ungulate populations that have selectively browsed on some species, emphasizing the importance of understanding land use history and ecosystem legacies (Higgs et al., 2014; Johnstone et al., 2016; Jõgiste et al., 2017). Existing "natural" stands may not represent general (or target site) conditions; they could exist because they are marginal, inaccessible, or on sites of low productivity. The idea of using past conditions as a target for restoration assumes a stable future climate, an assumption known as climate stationarity (Millar et al., 2007); this perspective could result in a forest poorly adapted to emerging climatic realities (Harris et al., 2006; Perring et al., 2013; Volpe et al., 2024).

Operational factors

The primary objective of production versus protection sets limits on the intensity of management and can affect the choice of forestation method (natural regeneration, seeding, or planting). The gradient of management intensity in European forest management is summarized in Table 3.3. Operational factors must be considered within the framework of this management intensity gradient.

Table 3.3 Current intensity typical of European forest management types and characteristics related to forestation and stand establishment.

Intensity Example	PassiveStrict nature reserve	LowClose-to-nature	MediumMultiple objective	HighIntensive, even-aged	IntensiveShort rotation
Characteristic					
Regeneration	Natural, colonization	Natural, enrichment	Natural, planting, seeding	Natural, planting, seeding	Planting, seeding, coppicing
Plant material	Potential native vegetation	Native or site-adapted	Improved (traditional breeding)	Improved (traditional breeding)	Improved (traditional or GMO)
Nurse/secondary species	Yes	Yes	Temporary	No	No
Mechanical site preparation	No	Minimal or some	Possible	Possible	Yes
Soil amendments	No	No	Possible	Possible	Yes
Pesticides	No	No	If necessary	Possible	Possible

Adapted from Duncker, P.S., Barreiro, S.M., Hengeveld, G.M., Lind, T., Mason, W.L., Ambrozy, S., Spiecker, H., 2012. Classification of forest management approaches: A new conceptual framework and its applicability to European forestry. Ecology and Society 17. https://doi.org/10.5751/ES-05262-170451; Stanturf, J.A., Callaham, M. (Eds.), 2020. Soils and landscape restoration. Academic Press, London.

Biophysical conditions

Assessing site conditions relevant to forestation can follow two complementary approaches: (1) identifying sites with conditions favorable for the desired species, or (2) identifying factors that limit regeneration establishment and development and prescribing appropriate site preparation, species, and stock types. The first approach is useful for planning efforts such as afforestation, siting a new processing facility, or seeking suitable sites for assisted migration (for example, Perdue et al., 2019; Stanturf et al., 2019). Generally, the second approach is more common, because forestation typically occurs on already identified or available sites. While the second approach is site-specific and prescriptive, the first is broader and aimed at locating generally suitable areas. For either approach, both surface and subsurface conditions are critical for forestation success.

We distinguish between site potential and site suitability (Fig. 3.2). On the one hand, site potential is the sum of the environmental factors plus legacies that affect tree survival, establishment, and growth. Site potential is not fixed; management can alter some aspects of the site and, together with other factors, produce the desired ecosystem services (including production). Site potential can be assessed independent of trees (Gholz and Boring, 1991; Morris and Campbell, 1991; Ryan et al., 2002). On the other hand, site suitability incorporates the traits of the species of interest and management inputs that favor the species with site potential (e.g., Werden et al., 2018; Kretz et al., 2025). Off-site limiting factors—such as natural hazards, regulatory constraints, and possibly climate change—are also considered.

Oliver and Larson (1996) described the initiation stage of stand development that corresponds with Grubb's (1977) concept of the regeneration niche. Among other features, they note that seedlings, due to their small size, are greatly affected by even subtle differences in microsite conditions (Oliver and Larson, 1996). Microsite conditions can change rapidly as the biogeochemical cycle, particularly nitrogen cycling, is still

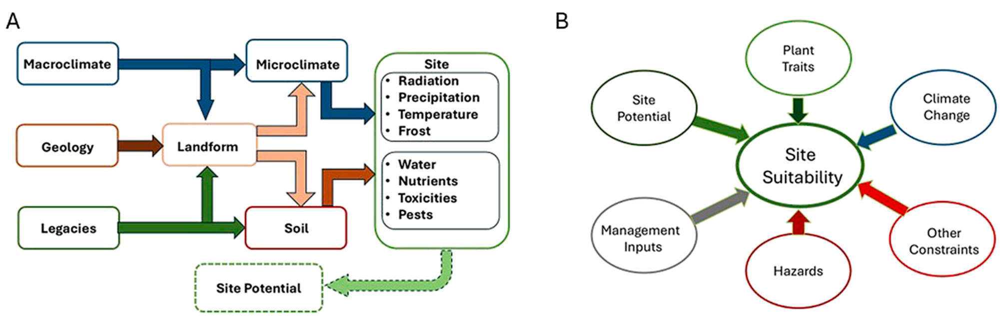

Figure 3.2 Site potential (A) versus site suitability (B). Site potential is based primarily on physical factors and is a component of site suitability that encompasses a broader set of biophysical and socioeconomic factors, including the traits (tolerances and requirements) of the target tree species. *(Credit: John A. Stanturf.)*

Table 3.4 Environmental factors that could influence species choice, seedling survival, establishment, and growth. Individual or combinations of factors can have a positive, negative, or neutral effect. Variations and extremes in many factors are of greater interest than averages.

Factors	Description
Physical	
Aboveground	Precipitation, air temperature, relative humidity, solar radiation, wind speed and duration, wildfire risk, and flooding risk Topography: Elevation, convex versus concave, slope, aspect, slope position
Belowground	Surface properties: Texture, structure, crusts, hydrophobicity, compaction, temperature, aeration, impediments (pans, stoniness, and rocks), available soil moisture, drainage, water table, and soil depth
Chemical	
Aboveground	Precipitation chemistry, air quality, pesticides
Belowground	Nutrient availability and balance, toxic substances, soil organic matter (quantity and quality)
Biological	Vegetation (overstory, herbaceous, woody, invasive), soil microorganisms, insects, animals (ungulates, rodents, wild boar, others)

Adapted from Gholz, H.L., Boring, L.R., 1991. Characterizing the site: Environment, associated vegetation, and site potential. In: Duryea, M.L., Dougherty, P.M. (Eds.), Forest Regeneration Manual. Kluwer, Dordrecht, pp. 163–182; and Stanturf, J.A., Callaham, M. (Eds.), 2020. Soils and Landscape Restoration. Academic Press, London.

responding to the previous disturbance (e.g., clearcutting, windthrow, and herbivory) and to changes driven by the growing plants themselves (Table 3.4). Several features stand out: seedlings are small and often face competition from herbaceous vegetation, which can quickly overtop them and reduce light availability. Temperatures at the soil surface may be extremely hot, often many degrees warmer than air temperatures, and a few centimeters higher. Conversely, low temperatures may damage or kill seedlings growing in frost pockets or cause seedlings to be pushed out of the soil by frost heave.

The belowground environment can be just as inhospitable as the soil surface; seedling roots occupy only a small soil volume, and even in seemingly uniform areas, microsite variation can be substantial. Soil moisture in particular can vary considerably over a short distance, and even a change in microrelief of a few cm can mean the roots experiencing either waterlogged or droughty conditions. For many species, the depth of organic layers above mineral soil may be critical to survival. Past activities could create harsh conditions, for example, a dense soil layer caused by repeated plowing to the same depth, i.e., a plow pan. Naturally occurring features such as dense subsoil layers can limit root growth, including fragipans in silty soils (e.g., loess), claypans in central and southern Europe, duripans and calcrete in arid and semiarid regions, or simply rocky soil in boreal moraines and limestone sites. Initially, the small soil volume around the roots of a seedling determines early survival. As the root system expands and a greater soil volume is exploited, the plant gains access to more resources (water and minerals) and is better able to withstand fluctuations such as changing weather. Similarly, the seedling is expanding aboveground, growing taller and outward. Altogether, growth during establishment means a seedling occupies increasingly more space, above- and belowground, until it begins to compete with other tree seedlings.

Climate, geology, and landform define the broad ecological framework within which species selection and forest management options are determined. Geology and landform are fixed features of the landscape, for example, mountains, valleys, plains, plateaus, and coastal formations, such as peninsulas and bays. Their location and characteristics are shaped by factors such as latitude, longitude, elevation, and geologic history. Glaciated versus non-glaciated terrain and surficial geology, the unconsolidated material deposited by erosion, transport, and deposition, provide the finer details of the physical structure of the landscape. The major vegetation zones or biomes in Europe (boreal, temperate, Mediterranean) remain broadly recognizable, but their boundaries are shifting in response to climate change. "Looking to the future" to help select species that will be adapted to future conditions presents another challenge, that of multiple sources of uncertainty and incomplete information. A first approximation of future conditions can be drawn from available climate models, which continue to improve. Modern Earth System Models now simulate not only the atmosphere and oceans, but also interactions and feedback across the broader Earth system. High-resolution regional climate models (RCMs), such as those available from CORDEX,[1] offer regional and local climate change information that approaches the spatial scale needed for forest management decisions, including those related to extreme weather events. However, RCMs depend on global climate models for lateral and lower boundary conditions. Estimating possible future climate conditions for the forestation site can inform both species selection and the identification of key site factors.

Climate

Despite considerable regional variation, much of Europe's macroclimate is classified as temperate. Most of Western Europe has a humid oceanic climate, characterized by cool to warm summers, cool winters, and frequent overcast skies. The climate of Central and Eastern Europe is humid continental with warm to hot summers and cold winters. Further east, areas around the Black Sea and Caspian Sea are semiarid. To the south, a Mediterranean climate dominates with warm to hot, dry summers and cool to mild winters and frequent sunny skies. To the north, Fennoscandia, Iceland, and northern Russia have taiga and subarctic or arctic tundra climates with long, cold winters and short, cool

[1] Copernicus Climate Data Store, https://cds.climate.copernicus.eu/datasets/projections-cordex-domains-single-levels?tab=overview.

summers. In Europe's mountainous regions, elevation-driven temperature and precipitation gradients create distinct microclimates that shape forest composition. Forest vegetation in Europe is broadly correlated with annual temperature and precipitation, and the requirements of economically important species are well understood (San-Miguel-Ayanz et al., 2016).

As climate regimes shift, traditional correlations between vegetation and macroclimate become less reliable for guiding species selection. The uncertainty of what the future climate will be and how quickly conditions will change complicates predictions of site conditions and species adaptability. A critical decision must be made under this uncertainty, whether to favor or plant the same suite of species, or instead to seek new species or provenances better adapted to a new climate. New tools have emerged to help guide species selection in forestation (Chapter 4) and should prove useful in determining which site conditions are important (i.e., site potential). For example, the potential distribution of seven ecologically and economically important European tree species has been modeled and used in "SusSelect," a decision support tool that predicts the vulnerability of forest trees to climate change and recommends adapted planting material.[2] Another tool was developed under the SUPERB project[3] to help stakeholders select climate-adapted tree species, species compositions, and provenances for restoration, reforestation, and afforestation projects. The Seed4Forest application[4] allows users to explore species and mixtures suitable under current and projected climates at specific locations. With the tool, a user can examine different species mixtures. Climate-adapted seed sources are recommended. These tools rely on species distribution models.

Species distribution models (SDM) and data (Elith and Leathwick, 2009; Booth, 2018a; Norberg et al., 2019), and climate surface and RCMs (Hijmans et al., 2005; Jacob et al., 2020) are useful for characterizing regional climate, understanding species-climate relationships, and managing forests under climate change (MacKenzie and Mahony, 2021; Yegorova et al., 2025). Because forest vegetation is strongly shaped by moisture and temperature, modern SDMs aim to model likely species distributions under historical, current, or projected future climates. These SDMs use estimated monthly mean maximum temperature, minimum temperature, precipitation, and calculated bioclimatic indices. One such model, BIOCLIM, uses 35 climatic variables (Booth, 2018b) derived from WorldClim data, which provides climate surfaces at 1 km resolution (Hijmans et al., 2005).

[2] Provisioning forest and conservation science with high-resolution maps of potential distribution of major European tree species under climate change; https://metadata-afs.nancy.inra.fr/geonetwork/srv/fre/catalog.search#/metadata/fe79a36d-6db8-4a87-8a9f-c72a572b87e8.

[3] SUPERB project; https://forest-restoration.eu/.

[4] Seed4Forest application; https://app.seed4forest.org/.

Spatial climate analogs help identify the future climate of a specific site by locating regions with comparable conditions today. Climate analogs provide practical insight into adapted species and how forests are managed (Mette et al., 2021; Yegorova et al., 2025). A concerning situation is when novel or no-analog climates emerge (Williams and Jackson, 2007; Williams et al., 2007; Burke et al., 2018), conditions that have no analog in the observational record. For example, Mahony et al. (2017) found in North America that novel climates could emerge in any landscape, including lower topographic positions at all latitudes (Mahony et al., 2017). MacKenzie and Mahony (2021) provide an example of how to address the needs of practitioners. They developed a tree species selection model to support reforestation decisions in British Columbia, Canada, for tree species native to western North America. Their analysis emphasized the species-specific and spatially variable feasibility of reforestation under future climate conditions, as well as the influence of edaphic (soil) site factors. For most species, feasibility declines were greater on relatively dry sites than on wetter sites (MacKenzie and Mahony, 2021).

Of particular interest in assessing site conditions is the likely future meso- and microclimate at a planting site. Europe is the fastest-warming continent in the world, and extreme heat, drought, wildfires, and flooding will worsen under even optimistic global warming scenarios (European Environment Agency, 2024). Increasing temperature in northern Europe and decreasing summer precipitation in southern Europe are likely to impose significant stress on forest ecosystems. Vapor pressure deficit (VPD) has contributed to recent drought-induced plant mortality (Grossiord et al., 2020; Novick et al., 2024). VPD increases primarily due to temperature change (Johnston et al., 2025), with stomatal conductance declining under high VPD and transpiration increasing, leading to reduced photosynthesis and growth. With extended periods of high VPD, there is a risk of carbon starvation and hydraulic failure, eventually resulting in tree mortality (Breshears et al., 2013; McDowell et al., 2022). Over the last 60 years, drought and heat stress have increased in importance as constraints on the growth of Central European forests. Simulations suggest that, at mid-elevations (700–1200 m a.s.l.), forest growth is primarily limited by VPD and temperature. At lower elevations, by contrast, it is constrained by available soil water at the end of the growing season (Trotsiuk et al., 2020; Trotsiuk et al., 2021; Martinez del Castillo et al., 2022).

Wind is a dominant disturbance agent in many European forests, as seen in named storms such as Gudrun, Kyrill, Klaus, Xynthia, and Vaia. Windstorms are extreme meteorological events projected to increase under climate change. Windstorms include cyclones and gales in coastal areas; tornadoes, downbursts, and derechos (straight-line winds) in interior, relatively flat terrain; and severe mountain wind events in higher elevations. Strong winds are a major disturbance in Central Europe (Della-Marta et al., 2009; Martín-Alcón et al., 2010; Panayotov et al., 2011). The risk of economic damage from windstorms has been incorporated into forest management prescriptions

(Hanewinkel et al., 2011; Ferguson, 2015; Eyvindson and Kangas, 2018). Current areas of vulnerability have been mapped from national forest inventory data (Suvanto et al., 2019). The FORWIND database of major wind disturbances in European forests from 2000 to 2018 documents approximately 30% of the reported damaging wind events (Forzieri et al., 2020, 2021).

ForestGALES[5] is a computer-based decision support system and hybrid-mechanistic model that assesses the risk of wind damage to forests. Developed for Britain, it has been validated for several other countries. Although there are three versions that operate at different spatial scales (stand, site, and individual tree), for practical applications, ForestGALES is recommended for use at forest scales, rather than for individual stands. Wind risk at the site level can also be evaluated using the Global Wind Atlas,[6] originally developed for planning wind power projects. It provides wind rose and wind speed data at 10 m resolution.

Microclimate is complex and influenced by landform characteristics, including elevation, aspect, exposure, and insolation. Position in the landscape can determine the risk of cold air drainage and frost pockets that can be mitigated by vegetation. Seedlings of frost-sensitive species such as Douglas-fir, for example, can be protected by planting with a nurse species (Malmqvist et al., 2018; Chakraborty et al., 2019). Temperature at the soil surface can exceed air temperature measured just a few centimeters above, especially under direct sun and sparse cover (Table 3.4). Temperature, combined with variation in albedo, wind patterns, evaporation, and soil texture, leads to variation in soil moisture (Stralberg et al., 2020). Climate change, particularly heat waves, drought, and increased VPD, can affect establishment and growth (Rabarijaona et al., 2022; Mirabel et al., 2023; Novick et al., 2024), and reduced stocking levels at planting or through thinning could improve stress tolerance.

Geology and landform

Europe's surficial geology is broadly divided into highlands and mountains in the south, and a vast northern plain that extends from the British Isles in the west to the Ural Mountains in the east (Plant et al., 2005). Part of the northern plain is submerged beneath seas, including the Celtic Sea, the North Sea, the Baltic Sea, and the Barents Sea. Mountain chains delimit these two regions; the Pyrenees and the Alps-Carpathians bisect the northern lowlands and southern highlands. The northern plains are bounded by the Scandinavian Mountains and the mountainous parts of the British Isles in the west, and the southern highlands by the Mediterranean and Black Seas.

[5] ForestGales, https://www.forestresearch.gov.uk/tools-and-resources/fthr/forestgales/.
[6] Global Wind Atlas, https://globalwindatlas.info/en/.

The Scandinavian Shield of hard, Precambrian metamorphic and igneous rocks found in Sweden, Finland, and parts of Norway and Russia has bedrock dating back over 2.5 billion years. Glacial activity during the Last Glacial Maximum (LGM) reshaped the surface of these ancient rocks, resulting in a distinctive landscape that includes elongated lakes and boulder fields deposited by retreating glaciers. Large ice sheets covered much of northern Europe, including areas in the British Isles, Germany, Poland, and Russia (Svendsen et al., 2004). Ice covered the Alps and Pyrenees as well, leaving behind significant sand and gravel deposits. During the LGM, strong easterly winds drove aeolian processes that deposited sand belts and loess belts beyond the Fennoscandian and Alpine ice sheets, and along the Atlantic coast (Haase et al., 2007).

To the south, the Central European Plains stretch from France to Russia, characterized by relatively flat, low-lying terrain (Plant et al., 2005). This landscape formed primarily during the Cenozoic era, influenced by sediment deposition from rivers, the retreat of glaciers, and subsidence due to tectonic activity. Farther south, the Alps are a relatively young formation, dating back to the Tertiary period (now called the Paleogene and Neogene periods, from roughly 66 to 2.6 million years ago). The characteristic high peaks and deep valleys of the alpine landscape were formed by the collision of the African and Eurasian tectonic plates. This mountain-building process is also responsible for many other major ranges in Europe.

The Mediterranean Basin, bordered by the Alps, Pyrenees, and Atlas mountain ranges, includes the Mediterranean Sea with numerous islands and deep-sea basins (Plant et al., 2005). Shaped by the African plate moving toward the Eurasian plate, the basin has complex geology shaped by tectonic activity, sea level changes, and sedimentation. The diverse geology and macroclimate of Europe account for the varied regional landforms and soils.

Topographic variation across Europe can be assessed using EuroDEM, a digital elevation model at 30 m resolution that maps bare-earth heights, excluding vegetation and built structures.[7] Digital elevation model data are useful for describing landforms (Deng, 2007). More detailed mapping of surface features is becoming cost-effective using uncrewed aerial vehicles (i.e., drones); see Chapter 6 for more information on emerging technologies.

Soils

Forests in Europe are typically located on soils historically considered marginal for agriculture (e.g., infertile, rocky, wet, or at higher elevations). The following characterizations are from Vanmechelen et al. (1997), and descriptions of soil groups can be found in (IUSS Working Group WRB, 2015) and summarized in Table 3.5. Many forest soils in

[7] https://www.mapsforeurope.org/datasets/euro-dem.

Table 3.5 Characteristics of common soil orders found on European forest sites with general management implications.

Soil order	Characteristics	Management implications
Alisols	Strongly acid soils that have accumulation of high-activity clays in the subsoil.	Highly acidic, poorly drained, prone to aluminum toxicity and water erosion.
Arenosols	Sandy soils with limited soil profile development. Generally infertile due to poor water and nutrient retention. Good permeability.	Susceptible to drought and nutrient deficiencies, prone to erosion, especially in areas with high winds or rainfall.
Cambisols	Young soils, developed in medium and fine-textured materials derived from a wide range of rocks.	Neutral to weakly acidic, good fertility, good physical properties. Found mostly in alluvial, colluvial, and aeolian deposits.
Gleysols	Hydric soils, saturated with groundwater for extended periods, leading to a characteristic gleyic color pattern.	Low-lying river basins and regions where groundwater is near the surface.
Histosols	Primarily composed of organic matter, often referred to as bogs, moors, peats, and mucks. They form in areas with poor drainage.	Commonly found in boreal, subarctic, and low arctic regions, as well as other poorly drained areas.
Leptosols	Very shallow soils, often with hard rock close to the surface or high gravel content.	Frequently found in mountainous areas, on rocky slopes, and along riverbanks where gravel deposits accumulate. Vulnerable to erosion, desiccation, and waterlogging.
Lixisols	Strongly weathered soils with a subsurface accumulation of low-activity clays.	Low fertility and high base saturation. Susceptible to erosion, especially on sloping land.
Luvisols	Moderately weathered soil, with an accumulation of clay in a subsurface horizon (argic horizon).	Cool temperate regions, areas with contrasted dry and wet seasons, moderate drainage, and generally fertile.
Planosols	Light-colored, coarse-textured surface horizon abruptly overlying a dense, clay-rich subsoil.	Found in seasonally wet areas, with limited permeability that can lead to water stagnation.
Podzols	Acidic, often infertile soils with a distinct profile (light-colored leached layer and a dark, accumulated layer). Mostly good drainage.	Commonly found in forested areas with cool, humid climates (boreal zone and coniferous forests).
Regosols	Weakly developed soil found on unconsolidated materials.	Sand dunes, river floodplains (recent alluvial deposits), and steep slopes.

Europe are coarse-textured (Ballabio et al., 2016), predominantly sandy, associated with aeolian or marine deposits, at low elevations (below 500 m). Above 500 m elevation, medium-textured soils are dominant. Sandy Podzols are widespread in the boreal zone and account for roughly 25% of forest soils in Europe. The majority are Haplic Podzols, mainly found in Sweden and Norway, while Ferric Podzols are more common in Finland and Lithuania.

Many forest soils, particularly recently formed ones such as Leptosols and Regosols, contain coarse fragments near the surface. Leptosols are often found in mountainous areas. Conversely, sandy soils such as Arenosols are frequently stone free; Haplic Arenosols are very common in Sweden. Older soils (those with a longer history of soil formation) usually have low amounts of coarse fragments. Typical of these soils are the Planosols, Luvisols, Alisols, and Lixisols.

Cambisols are a large group of soils with Dystric, Gleyic, and Humic Cambisols found in humid areas, and Eutric and Calcaric Cambisols are common in drier areas such as southern Europe. Few forest soils in Europe are clayey textured, but clayey textures are common for Cambisols, Leptosols, Luvisols, and Gleysols. Gleysols are generally wet soils that occur in alluvial plains or have slowly permeable subsoils.

Histosols are organic soils largely confined to cool and cold climates, with subgroups distinguished by the degree of decomposition of the organic materials. Terric Histosols have the most decomposed matter and occur twice as often as Fibric Histosols, which have less decomposed organic materials.

Available forest soil information varies by country. The HoliSoils[8]–Holistic management practices, modeling and monitoring for European forest soils–project is developing a harmonized soil monitoring framework. Soil property maps for Europe at 100 m resolution are being developed and will be publicly available through ISRIC, World Soil Information, possibly in2025.[9] The datasets contain the following soil properties (for the 0–30 cm depth): soil organic carbon content, pH in water, total nitrogen, bulk density (oven dry), coarse fragments (volumetric), soil inorganic carbon content, sand, silt, clay, as well as soil organic carbon stocks, soil inorganic carbon stocks, and soil nitrogen stocks. These maps, once publicly available, will be useful for broad-scale planning. However, field inspection will remain necessary to identify fine-scale features such as subsurface impeding layers or microtopographic variation in drainage or stoniness.

Phosphorus fertility is increasingly recognized as a limiting factor for forest growth across Europe (Jonard et al., 2015; Talkner et al., 2015). Phosphorus availability may be limited by low content in mineral soil or by fixation (Binkley and Fisher, 2019). While foliar sampling is a common method for assessing P-availability in established

[8] https://holisoils.eu/project/.

[9] https://data.isric.org/geonetwork/srv/api/records/b3d7c844-cbee-4b0f-8431-3a9373f5a59a.

stands, it is impractical on bare planting sites. Standardized soil testing methods are lacking for P-availability in forest soils but are under development (Fäth et al., 2019). Nevertheless, seedling requirements have received even less attention, but greenhouse experiments have shown that angiosperm seedlings (i.e., *Fagus sylvatica* and *Acer pseudoplatanus*) exhibited enhanced shoot length in phosphorus-rich soil (Doan et al., 2025). Afforestation of former agricultural sites may benefit from residual P from fertilizer (De Schrijver et al., 2012).

Competing vegetation and pests

Depending on previous land use, the forestation site could have diverse vegetation that potentially competes with or facilitates the new target trees. The size, growth habit, density, and growth rate of other plants influence target trees in different ways. Competition and facilitation are the net effect of negative (resource uptake) and positive (stress amelioration, hydraulic lift, protection against herbivores, disperser attractors) interactions between plants (Callaway and Walker, 1997; García-Cervigón et al., 2013). If negative interactions prevail and competition arises, the opposite happens with facilitation. Generally, grasses (graminoids) and herbaceous species adversely affect desired tree seedlings (Balandier et al., 2006). The suite of competing species often differs on afforestation sites from the groundcover on harvested forest sites. In boreal forests, especially, mosses and ferns make natural regeneration and direct seeding difficult as they can form a dense layer that hampers seedling establishment (Zackrisson et al., 1997). Competition indeed is critical in many scenarios, but in dry climates, high mountains, and under scenarios of high browsing pressure by large herbivores, competition is less important, and some shrubs, for instance, can facilitate the establishment of other plants (some tree overstories also can facilitate seedlings). Competition control strategies include physical disruption by mechanical site preparation (Löf et al., 2012, 2015) and, where allowed, by herbicides (Chapter 6). Facilitation strategies include keeping shrubs on sites or introducing nurse species (Löf et al., 2014, Chapter 6).

In boreal, montane, and lowland forests, shrubs and invasive tree species can form dense layers that impede seedling establishment (Balandier et al., 2006; Bylak et al., 2025). They can originate as sprouts from stumps and roots of plants in the previous stand or from seed. Control treatments are necessary to allow target trees to establish and grow. However, later in stand development, they often become an important food source for wildlife (Balandier et al., 2006). Similarly, graminoids and forbs provide habitat for vertebrates and invertebrates, as well as contributing to biodiversity. Spot control of competing vegetation during stand establishment is the most cost-effective and least disruptive form of site preparation, when effective (Balandier et al., 2006).

In large parts of Europe, the large pine weevil, *Hylobius abietis,* damages young forest stands and hampers the successful regeneration of coniferous forests by planting (Galko et al., 2022). Insecticide applications have been the most effective and least expensive way to protect seedlings against *H. abietis*, but their use in European forestry is restricted and may become banned. Silvicultural practices can reduce feeding damage by *H. abietis* on planted seedlings. These include weed removal, delayed restocking, planting mixed forests, and especially planting in mineral soil achieved by site preparation such as scarification, mounding, or soil inversion (Örlander and Nilsson, 1999; Nordlander et al., 2011; Lalík et al., 2021). Physical barriers, such as protective wax coatings applied to seedlings, have also proven effective (see Chapter 6).

Phytophthora cinnamomi is another soilborne pathogen that causes significant damage to European forests, particularly in warmer regions (Domínguez-Begines et al., 2020). In Iberia, *P. cinnamomi* has caused mortality of evergreen oaks, including *Quercus suber* (cork oak) and *Q. ilex* (holm oak), and chestnuts and eucalyptus. *P. cinnamomi* primarily infects tree roots, causing root rot. This weakens the tree and increases vulnerability to other stressors. Early symptoms are the yellowing of leaves in angiosperms and reddening of conifer needles. *P. cinnamomi* thrives in warm, wet soils, and climate warming is expected to allow the pathogen to thrive in previously cooler regions. Regular monitoring for signs of infection is essential. Good hygiene practices are also necessary to prevent the spread of the pathogen (e.g., avoiding movement of infected soil and equipment and diseased nursery stock). Until disease-resistant material is available, poorly drained and/or infected areas should be avoided or allowed to regenerate naturally (Sena et al., 2018).

Sociological context

All forestation involves a sociological context with inevitable trade-offs (Höhl et al., 2020; Holl and Brancalion, 2022). At the site level, land use zoning, nature protection, and forest practices regulations could directly affect the choice of species, site preparation methods, and even the planting design. Other entities may hold use-rights, including rights-of-way for powerlines, pipelines, or vehicle access. In many countries, particularly in Scandinavia, the public has the right to access forest land for recreation, berry picking, and mushroom collection (Turtiainen and Nuutinen, 2012; Sténs and Sandström, 2013). Regulations (e.g., accepted species lists and seed zones) vary considerably among EU nations. National and EU measures, such as current regulations on nonnative species (Brus et al., 2019; Pötzelsberger et al., 2020), conflict with the introduction of new species. The new Nature Restoration Regulation[10] must also be considered, as it could place additional restrictions on forest practices (Perissi, 2025).

[10] Regulation (EU) 2024/1991 of the European Parliament and of the Council of 24 June 2024 on nature restoration and amending Regulation (EU) 2022/869; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32024R1991&qid=1722240349976.

Table 3.6 Other potential constraints that could influence species choice, seedling survival, establishment, and growth. Individual or combinations of factors can have a positive, negative, or neutral effect.

Other potential constraints	
Regulatory	Land use zoning Forest practices, nonnative species regulations Rare or endangered species Other nature protections Disruption of wildlife migration routes or foraging areas Riparian buffers
Off-site	Altered runoff (quantity and quality), erosion, stream sedimentation, pesticide drift
Social concerns	Aesthetics Hunting leases Recreation Rights-of-way Community relations Potential vandalism, encroachment

Adapted from Gholz, H.L., Boring, L.R., 1991. Characterizing the site: Environment, associated vegetation, and site potential. In: Duryea, M.L., Dougherty, P.M. (Eds.), Forest Regeneration Manual. Kluwer, Dordrecht, pp. 163–182; Stanturf, J.A., Callaham, M. (Eds.), 2020. Soils and Landscape Restoration. Academic Press, London.

Potential regulatory and land use constraints that could affect forestation are summarized in Table 3.6. These factors vary widely across Europe and often differ in their application to public versus private land. Some regeneration practices, such as mechanical site preparation and chemical vegetation control, may be permitted on private but not public land, or allowed for afforesting farmland but restricted for reforesting forest land. Logistical concerns, such as site location and accessibility, can be consequential when planting seedlings. The proximity to the nursery influences transportation costs and also may affect seedling vitality if seedlings are transported long distances or improperly stored. Proper seedling handling is critical to forestation success. Access to the site for planting and maintenance is essential. Equipment and personnel must be able to reach the site efficiently to ensure timely operations. Maintaining fences requires periodic visits to ensure their integrity. Proximity of the site to urban or peri-urban settings could lead to conflicts when moving equipment to and from the site (e.g., damage to pavement, buildings, or roads). Tree species selection should account for mature tree size to avoid future problems with utilities (overhead and underground lines). Sites near settlements may face risks of vandalism or encroachment, which should be considered during planning.

Guidelines

Successful forestation depends on manipulating vegetation and getting the right tree in the right place, for the right purpose. The following lists the most important site characteristics to consider. Measures to mitigate some of these factors through site preparation and post-planting tending are discussed in Chapters 6 and 7. As the understanding of the environmental constraints on forest growth under climate change (e.g., drought, heat waves, wind and snow storms, wildfire, pests) improves, spatially and temporally detailed risk maps (e.g., Stritih et al., 2024) should become increasingly available to support forest managers in species selection and site evaluation.

Local climate:

- Temperature: Both average and extreme temperatures affect key physiological processes like photosynthesis, respiration, and transpiration. Different tree species have specific temperature tolerances.
- Rainfall: The annual amount, seasonal distribution, and reliability of rainfall are critical for soil moisture availability, especially for young seedlings. Prolonged droughts or excessive rainfall leading to waterlogging can be detrimental.
- Sunlight: The duration and intensity of sunlight influence photosynthesis. Some species thrive in full sun, while others grow better or tolerate shade. Site aspect (the direction a slope faces) can significantly affect sunlight exposure and temperature.
- Wind: Strong or persistent winds can cause physical damage to trees, cause erosion, increase water loss through transpiration, and affect temperature. Windbreaks may be necessary in exposed areas.
- Relative Humidity: Affects the rate of evapotranspiration and overall tree water stress.
- Wildfire: Increased fire risk affects species suitability, regeneration strategies, and site preparation requirements (e.g., fuel reduction).

Soil:

- Soil Type and Texture: Soil texture influences water holding capacity, aeration, drainage, and nutrient availability. Coarse-textured soils (e.g., sandy, rocky) have low moisture-holding capacity, while fine-textured soils (e.g., clayey) may retain moisture or cause waterlogging. Ideal textures are loamy soils.
- Organic Matter (OM) Content: Contributes to soil structure, water retention, and nutrient supply. High OM facilitates invasions by exotic plants. Very high organic matter content may signal waterlogging, while coarse-textured soils often have low OM content.
- Soil pH: The acidity or alkalinity of the soil affects nutrient availability and the activity of soil microorganisms. Different tree species have optimal pH ranges (generally, conifers tolerate low pH, while angiosperm trees require neutral to basic pH).
- Effective Soil Depth: The depth of the soil suitable for root penetration is crucial for anchorage, water uptake, and nutrient acquisition. Shallow soils, impeding layers, and waterlogging can limit tree growth and stability.

- Soil Moisture and Drainage: Soil must retain adequate moisture for tree growth but also allow for sufficient drainage to prevent waterlogging, which can lead to root rot. Soil maps may indicate drainage class.
- Soil Nutrients: The availability of essential nutrients (e.g., nitrogen, phosphorus, potassium, and micronutrients) directly impacts tree vigor and growth. Soil tests will be needed to determine nutrient levels and pH; base saturation is more informative than pH but requires chemical analysis.
- Soil Compaction: Compacted soils restrict root growth, water infiltration, and aeration, hindering tree establishment and development. Past land use, such as construction or heavy vehicle traffic (including harvesting equipment), can cause compaction.

Topography:

- Slope: The steepness of the land influences soil erosion, water runoff, soil depth, and accessibility for planting and maintenance.
- Aspect: The direction a slope faces affects the amount of sunlight received, temperature, and soil moisture. South-facing slopes in Europe are generally warmer and drier than north-facing slopes.
- Elevation: Influences temperature, precipitation, and the length of the growing season.

Hydrology:

- Water Table Depth: The depth and seasonal fluctuations of the groundwater table can be critical, especially for species with deep rooting habits or species intolerant of waterlogged conditions. Mottling of soil indicates anaerobic conditions from a high water table or ponding caused by an impeding layer.
- Proximity to Water Bodies: Nearby ponds, lakes, or streams can influence local humidity and water availability but may also pose risks of flooding or competition from riparian vegetation. Regulations requiring buffers along water courses may constrain management activities.
- Drainage Patterns: Understanding how water flows across the site is important for identifying areas prone to erosion or waterlogging. Skid trails and roads should be planned and constructed to avoid causing erosion.

Existing vegetation:

- Competition and Facilitation: Existing vegetation (grasses, shrubs, and other trees) can compete with newly planted trees for light, water, and nutrients or facilitate seedlings by ameliorating stresses. Site preparation and post-planting tending to manage competing vegetation is often necessary, but should minimize disruption.
- Indicator Species: The type and condition of existing native vegetation can provide clues about the site's potential and limitations for tree growth. However, in degraded areas, current vegetation may not be a reliable indicator.

- Allelopathy: Some plants release chemicals that can inhibit the growth of other plants, which could affect seedling survival.

Biotic factors:

- Pests and Diseases: The presence of insects, pathogens, or fungi that can harm the selected tree species needs to be assessed. Choosing resistant species or implementing protective measures may be required.
- Wildlife: Animals such as deer, moose, wild boar, rabbits, rodents, and livestock can browse on or damage young seedlings. Protective measures might be necessary (e.g., tree shelters, fencing, or repellents).

Regulations:

- Nature protections: National or local laws to protect nature (endangered species, biodiversity, wildlife habitat, and riparian buffers) may limit species choices or other management actions.
- Zoning and forest practices: Land use zoning, forest practices, and nonnative species regulations may limit species selections and types of forest management.

Social influences:

- Public perception, aesthetics: Consider blending edges of new plantings with low vegetation to avoid abrupt linear patterns.
- Community involvement and relations: Public lands often have public participation requirements, and private owners should maintain good relations with neighbors and stakeholders.
- Potential for vandalism or encroachment: Especially near settlements, trespass may be a concern.
- Hunting leases: Many landowners derive significant financial returns by leasing hunting rights, but high ungulate populations hinder regeneration.
- Recreation: Free public access to forests is common in some countries, including berry and mushroom gathering.
- Rights-of-way: Utilities and other landowners may have legal rights of access through forest land.

Site location and accessibility:

- Proximity to Nursery: Reduces transportation stress on seedlings and logistical costs.
- Accessibility for Planting and Maintenance: Ease of access for equipment and personnel is important for efficient operations.
- Proximity to Infrastructure: In urban or peri-urban settings, considerations include conflicts with pavement, utilities (overhead and underground lines), buildings, and roads. Tree species selection should account for mature tree size to avoid future problems.

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