CHAPTER 8

Assessment and monitoring of early tree planting success

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Introduction

It cannot be overstated that any assessment of the growth and developmental trend of a certain tree species must be grounded on a good understanding of its optimal growth potential under favorable environmental conditions at the planting site. This enables monitoring to prompt management to adopt supporting measures (termed adaptive measures) when the observed trends diverge from the potential ones (Nichols and Williams, 2006; Le et al., 2012; Hutto and Kowalski, 2006; Susskind et al., 2012). Efficient monitoring thus provides essential experience and knowledge for scaling up or planning future planting initiatives (Kanowski et al., 2010; Derhé et al., 2016; Guariguata and Evans, 2020). Monitoring also generates information that contributes to transparency and accountability (Benayas et al., 2009) and comprehensive reporting to investors on performance.

From these considerations, it is evident that monitoring should be integrated in planning and implementation of tree planting interventions (Field et al., 2007; Lindenmayer and Likens, 2010a, 2010b; McDonald-Madden et al., 2010; Susskind et al., 2012). Moreover, it is crucial to define the scope of monitoring (McDonald–Madden et al., 2010), as this may require different methodological approaches, intensity, and equipment (Hutto and Belote, 2013).

Timing is another aspect of monitoring. Early monitoring (during the initial phases of tree growth and development) allows for the investigation of the correlation among intrinsic factors (i.e., genetics) and extrinsic factors (i.e., environmental) that regulate the growth and development pattern of the tree species under examination. Monitoring planting performance and investigating the biological aspects of tree species' life cycles are not mutually exclusive (Geupel et al., 2011), but rather synergistic processes. They both contribute to selecting tree species capable of exhibiting their optimal growth and development on specific types of sites.

Increasing commitment to monitoring planting performance in forestation (i.e., renewal and restoration) is essential. Given the significant investment of time, effort, and money in forest restoration programs in particular (Menz et al., 2011), it is crucial

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to establish standards of practice for monitoring restoration effectiveness. Over the past 2 decades, the literature on monitoring methodology and objectives, especially in forest landscape restoration initiatives, has expanded considerably, making a comprehensive summary impractical here. Interested readers are encouraged to explore this topic, beginning with the work of Hutto and Belote (2013), which categorizes monitoring into four broad types with different objectives: Surveillance, implementation, effectiveness, and ecological effects.

This chapter is focused mainly on monitoring to characterize early assessment of tree planting performance (i.e., the outcome of planting activities) and therefore will not deal with other outcomes of restoration related to ecosystem services such as soil and biodiversity protection, carbon sequestration, and socioeconomic issues. Rather, we deal with outcomes of efforts by practitioners engaged in planting trees. We intend to draw attention to the importance of extending monitoring beyond the initial outplanting phase until the trees complete their exponential growth phase and enter their mature and reproductive phase. This necessity arises from the awareness that many forestation initiatives have failed due to limiting monitoring activities to the initial phase following the planting of the seedlings, focusing only on early survival. Additionally, we emphasize the efficiency of a reduced number of easily measurable morphological and physiological indicators that reliably indicate the progress of growth and developmental trends (Menz et al., 2011; Abiyu et al., 2016; McDonald et al., 2016; Guariguata and Evans, 2020).

Talking extensively about goals and commitments, and remaining silent about failures

In recent years, many governments and nongovernmental organizations around the world signed the UN Decade on Ecosystem Restoration Declaration and the Bonn Challenge/New York Declaration on Forests, committing all signatories to restore by 2030 a total of 350 million ha (a value exceeding the land area of India) of deforested and degraded land. Most commitments anticipated tree planting where appropriate. These commitments aimed to absorb several billion tons of carbon dioxide from the atmosphere (Chen et al., 2015; Kongsager et al., 2013). Although that will not halt the number of climate disasters annually recorded in various parts of the globe, it certainly could help offset further emission of carbon that steadily continues to be produced by human activities. While planting trees helps offset further carbon emissions (FAO, 2010), only contemporaneous halting of deforestation could have a major impact on the climate crisis (Ehrenberg, 2015; Lewis et al., 2019; Cook-Patton et al., 2021).

There is a discrepancy between commitments and goals on the one side and the real effort and results on the other side in many international, regional, and national programs of forest restoration, afforestation, or reforestation. Media, corporations, and influencers persist in promoting tree planting projects worldwide with overly enthusiastic fervor

(Kumar et al., 2015; Hanson et al., 2015; GPFLR 2019; WRI, 2019; Mwangi and Evans, 2018; IUFRO, 2019), often involving thousands of volunteers in restoration activities. When commitments and high expectations meet reality, unfortunately, many programs fail to achieve their initial targets, in terms of the numbers of planted trees, that have been set to impress the public (Ivetić et al., 2021).

Many large tree planting initiatives lack a monitoring plan, as well as a management plan. They fail to understand that the establishment of a new forest is much more than simply planting seedlings. Although successful planting is crucial, it is just the first step that needs to be followed with years and decades of forest management to be fully successful. As a result of public enthusiasm and support, a billion seedlings are dispersed yearly on lands abandoned by agriculture or in degraded forests, only to be largely forgotten once the volunteers return home or the donor funding terminates. Because of abandonment, the vast majority of these tree planting initiatives fail within a few years (Brèteau-Amores et al., 2023) or fall short of expectations (Dudley et al., 2005), discouraging investors and raising doubts about the worth of tree planting (https://spades.life/).

Unfortunately, a rigorous estimate of global tree planting failures is impossible as such failures are rarely reported, leading to a positive bias toward tree planting activities (Thomas et al., 2015; Dudley et al., 2005). Even in regular forestry practice, success is not guaranteed. In Sweden, for instance, less than 80% of regeneration areas met the requirements to be considered successful, and in southern Finland, less than 60% met the threshold (Nilsson et al., 2010).

In case of failure, the usual outcome is to look for someone to blame, investigate the reason for failure, or both. The best outcome is to start a learning process and identify the drivers and causes of failure that can be avoided in the future. In Serbia, for example, the responsible government body will not pay out subsidies for tree planting if a certain threshold is not reached (Table 8.1). In the US, landowners are asking for reimbursement for their loss if the survival rate is below 50%; too often, low survival is due to mistakes made after the seedlings leave the nursery (South et al., 2023). In Ukraine, forest plantings with a survival rate of 25% or less are considered dead and are subject to write-off (Taras Parpan, contribution to the questionnaire[1]). However, there are also other, positive, examples like in France, where if mortality is due to abiotic factors (or to exceptional drought), the contractor is not liable, and some funding programs maintain the subsidies despite failure (Catherine Collet, contribution to the questionnaire).

Another consequence of failure is the loss of enthusiasm and support from stakeholders for planting projects, as tree planting activities often depend on this type of commitment.

[1] We surveyed PEN-CaFORR participants on regeneration practices in their respective countries. Specific answers are credited to the contributor

Table 8.1 Definitions, thresholds, and requirements for planting to be recognized as successful across Europe.

Austria	Forest regeneration is considered assured if it has grown through at least three growth periods, has a sufficient number of plants according to forestry requirements, and there is no discernible threat to further development.
Belgium (Flanders)	The amount of the subsidy for re- and afforestation depends on the surface planted, provided that a maximum planting distance is respected (i.e., a minimum number of plants per ha).
Bosnia and Herzegovina	A sufficient number of plants according to forestry requirements.
Croatia	There is no official definition of planting success. The success is defined by representatives of the contractor and the client inspecting the site and recording it in a written acceptance note.
France	There is no legal definition of planting success. Different rules are usually applied, which may be defined either by the contract written between the landowner and the contractor or by the funding program. Planting success is generally assessed through seedling survival, with a threshold of 80%.
Greece	The minimum seedling survival rate of 70% without irrigation and 90% with irrigation.
Hungary	The forestry authority checks the number and distribution of trees with appropriate quality of target species.
Italy	Differs between regions and autonomous provinces. In Tuscany, for example, the threshold for any planting project is a survival rate of >90%. However, in reclamation of mining areas, success is determined by the specific project requirements and approved by the relevant local authorities.
Latvia	Number of trees per ha planted/survived.
Lithuania	Well-planted plantations are considered to be those whose seedlings were of high quality, the density of plantations is in accordance with the norms, or less than 5% of the specified, planted well, and less than 10% of the planted trees died or were severely damaged.
Norway	The minimum density target of 500–1500 seedlings ha^{-1} according to site index, though optimal target densities are also indicated. Both natural regeneration and planting are allowed. In a conifer plantation, at least 10% of the regeneration should be deciduous species.
Serbia	The minimum number of seedlings per ha depends on environmental conditions.
Spain	Minimum admissible survival rate, expressed in the project.
Turkey	Having an 80% seedling survival.
Ukraine	Success is determined through technical acceptance, inventory of forest cultures and plantations, certification of nonclosed forest cultures, and the transition of forest cultures to forest-covered lands.
United Kingdom	Stocking density and species present after 10 years.

Source: The questionnaire produced by the PEN-CAFoRR Network. Full table is available on request to the authors).

Definition of success and failure of a tree planting initiative

Tree planting for reforestation and forest restoration is traditionally defined as a dynamic process, defined by Grossnickle (2000) as of a set of successive events consisting of three phases: (1) Planting, (2) Establishment, and (3) Transition to adult stage. For practical reasons, however, we split the tree planting process into two phases: (1) Establishment and (2) Building phase that includes both the resumption of growth and development and the transition of the young tree to its adult stage.

Besides examining how monitoring of these two phases can be implemented, we also assess the efficiency of specific monitoring tools that seem to be independent of the type of forestry activities to be monitored and provide indications for supporting, if necessary, sustainable management interventions. The definition of success and failure, the assessment methodology, and the indicators differ depending on the phase of development of the new forest. Although this chapter is focused on the establishment phase, a short overview of assessment of forestation success over a long term gives the reader a context for different measures of success that depend on the forest development phase.

Success and failure of the establishment phase

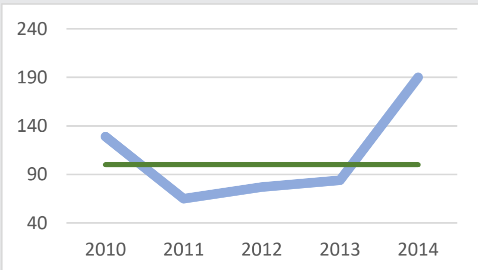
Seedlings enter the establishment phase when they start to respond to site conditions, their roots establish contact with the surrounding soil, and the seedling begins to use soil resources rather than seed resources for growth (Grossnickle, 2000, 2005). In this phase, both extrinsic (i.e., environmental stresses) and intrinsic (i.e., seedling genetic properties) factors play a critical role in conditioning seedling survival and the onset of growth and development. In a practical sense, the establishment phase is sometimes called the 'regeneration stage'. Unfortunately, there is still no consensus on when the establishment phase should be concluded. In some cases, the establishment phase ends when seedlings reach a specific size threshold (e.g., height of 1.3 m as suggested by Nilsson et al., 2010). Alternatively, the end is considered to coincide with the formation of a relatively closed tree canopy (Kanowski and Catterall, 2007), or after a specific period of time (3–5 years) after outplanting. Because the tree canopy is incomplete during the establishment phase, the level of competition with other plants increases and exacerbates the effect of a number of environmental stresses (Grossnickle, 2000). Both these two conditions could be prejudicial for seedling survival at early stages.

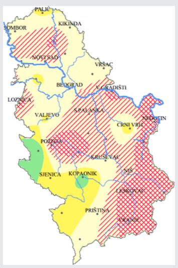
A seedling is considered to be established when it starts to grow using the environmental resources after surviving any transplanting stress. This is the reason why survival is the most common measure of early success in forestation programs. Other measures include seedling growth and the area planted compared to the target area. Based on the importance of these three indicators, we can define early success in any planting project (Box 8.1).

BOX 8.1 Example of analysis of the factors responsible for failure or success of *Pinus nigra* seedling establishment (Vladan Ivetic; and students).

a) Review of records (pictures and video) gathered during the planting operations can be very helpful in case of failure or high seedling mortality. For example, it is possible to understand from the analysis of records if mechanical damage and improper planting depth (shallow planting) were caused by workers.

b) Cross-referencing the data of damage exhibited by the seedlings with the recorded climate data can deduce any interactions. For example, despite that the symptoms of drought are sometimes easily recognized, a cross-reference with climate data helps in deriving the correct conclusion. The picture on the left (below), taken in 2011, shows a dead seedling when precipitation (blue line) was only 65% of the normal average (green line in the middle) (adapted from Ivetić, 2015). Records of extreme drought (right, area marked with hatched red lines, https://www.hidmet.gov.rs/data/agro/SPI.pdf).

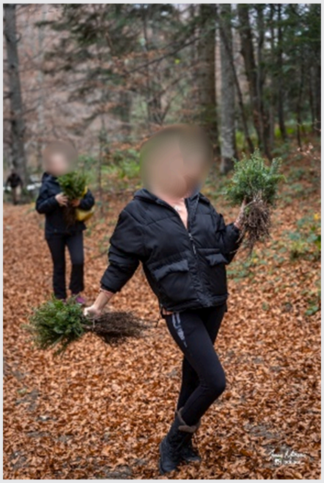




Box 8.1 Example of analysis of the factors responsible for failure or success of *Pinus nigra* seedling establishment (Vladan Ivetic; and students).—cont'd

c) Evidence of death caused by improper planting. Pictures taken in March 2015 (left) and in August 2015 (right).

d) Evidence of a proper or improper manipulation of seedlings during planting. Seedlings are maintained with their root system protected in a bucket filled with a mixture of water and humus (left) and seedlings with roots unnecessarily exposed to sunlight and air before planting (right).



In some European countries, planting success is defined by law or official rules, while in others it depends on specific project requirements, or it is subject to the agreement established between the different parties involved in the decision processes. This situation explains why in Europe there is a commonly accepted value of "minimal survival rate" as an indicator of the success of the established phase, with values ranging between 70% and 90% (Table 8.1).

To be successful, any program needs to meet the targets and goals set at its initiation and planning phase. If these targets and goals are not achieved, the program is considered a failure, which can have various severity levels, causes, and consequences. A failure can be total when a project needs to be canceled or restarted from scratch, or a program can reach the numbers just below a targeted threshold when a simple action such as extending a deadline or replanting are enough to turn it into a success. The consequences can be numerous and depend on the level of failure; the causes of failure will be discussed more extensively in section 8.5.

Success and failure of the building phase

The success of the building phase can be correctly evaluated only with reference to a well-defined set of ecological criteria, comparison to the characteristics of a reference forest ecosystem, or both. The building phase is successful if it:

- improves ecosystem functions, such as recovery of nutrient cycling, carbon sequestration, water regulation, soil stabilization, and timber production (Blignaut et al., 2014; Hobbs et al., 2011);
- contributes to the reintroduction of species that play strategic roles in the structure and functioning of ecosystems, such as seed dispersers, pollinating insects, and predators (Jones and Schmitz, 2009);
- balances costs and results, allowing the planned ecological and social outcomes to be achieved with the financial investments and human resources made available (Reyers *et al.*, 2012);
- remains economically viable over the long term, generating benefits that outweigh ongoing costs, ensuring continued support and investment from stakeholders (Murcia et al., 2014);
- increases the level of biodiversity in a restored area, measured as an increase in species richness and diversity, establishment of native vegetation communities resembling those of the target ecosystem (Chazdon, 2014);
- involves local community participation in restoration activities, including participation in planning, decision-making, and implementation processes (Bautista et al., 2017);
- contributes to improving the economy of communities through employment opportunities, management practices, and access to the benefits deriving from ecosystem services (Hockings et al., 2000); or
- promotes social well-being and reconnects indigenous people with cultural practices and land heritage (Ban et al., 2013; Bautista et al., 2017).

Contrarily, the Building Phase is considered a failure if it:

- reduces ecosystem functions by failing to restore essential processes, arresting the degradation of soil, water, and air quality, and counteracting the decline of ecosystem resilience to disturbances (Higgs, 2017);
- induces a loss of biodiversity indicated by a decrease in species richness and diversity, or by the dominance of nonnative or invasive species that disrupt the structure and function of the ecosystem (Simberloff et al., 2013);
- contributes to increasing habitat fragmentation by inducing a loss of connectivity between restored areas and by limiting the ability of species to disperse and colonize suitable habitats (Lindenmayer & Fischer, 2006);
- loses community support as a consequence of inadequate communication, consultation, or consideration for the needs, interests, and rights of local communities which leads to cultural erosion and loss of social cohesion (Berkes et al., 2000);
- becomes financially unsustainable by failing to convince stakeholders to provide adequate financial support for the project's management (Suding et al., 2015);
- does not generate tangible economic benefits for local communities or fails to highlight to a wider society the increased economic value of services provided by restored ecosystems (Turner et al., 2016); or
- fails to integrate into the developmental objectives of other sectors such as agriculture, energy, and infrastructure, which would benefit from increased synergy (Chazdon & Brancalion, 2019).

The reasons for failure – Why did seedlings die?

The most fraught moment in the entire operation of tree planting in forestation interventions is the resumption of growth and development of seedlings after outplanting (i.e., the establishment phase). Here, we briefly focus only on the abiotic factors governing establishment.

South et al. (2023) produced a list of over 50 factors not directly related to nursery operations that have been implicated in the low survival of seedlings in tree planting events conducted in North America, Africa, and Europe. The negative effects of most of these factors can be diminished or eliminated by using appropriate techniques (Ivetić and Devetaković, 2016). Here, we focus only on the most important factors affecting seedling survival from drought, improper planting, and damage by browsing, providing examples from different continents.

In Europe, severe droughts occurring between 1942 and 1954 in Spain necessitated large-scale replanting after massive seedling mortality (Vadell et al., 2016). Similarly, during 2010–2014, precipitation in Serbia was reduced to 65% of its normal (30-year) average and seemed to be responsible for reducing the survival rate to 61% for nine of the most used tree species in 90 reforested sites (Ivetić, 2015). In 2018–2020 in France, nearly 89% of the seedlings planted perished mainly due to drought (Boutte, 2020). However, the length of the drought is important; if the drought period is limited to a short time, the risk of excessive seedling mortality is relatively lower than during extended drought (Helenius et al., 2002). In Central Asia (Mongolia), for example, Scots pine (*Pinus sylvestris*) seedling survival in the first year after planting corresponded directly to the number of dry days in May, confirming that humidity and water availability are decisive factors for ensuring a successful tree planting (Sukhbaatar et al., 2020). In the southern USA, an increase in average rainfall has been related to an increase in the seedling survival rate (South et al., 2023).

Improper planting and handling have been observed under boreal conditions that negatively affect the survival of Norway spruce (*Picea abies*) and Scots pine seedlings regardless of planting season, region, or tree species (Pikkarainen et al., 2020). In Serbia, reforestation on 90 sites with nine of the most commonly planted tree species, improper planting induced seedling mortality of 21% (Ivetić, 2015). In Finland, the quality of planting operations and the selection of planting sites has been shown to be the most important factors affecting seedling survival of Norway spruce and Scots pine seedlings, independent of the planting season (Luoranen et al., 2018).

Browsing by a variety of herbivores can affect establishment success. Poor seedling survival was due to browsing for five tree species planted in the High Tatra Mountains in Slovakia (Repáč et al., 2011). A severe effect of browsing on Scots pine seedlings was reported at the beginning of the 2000s in southern Sweden, with a survival rate of Scots pine close to zero (Nilsson et al., 2010). This contrasts sharply with the fact that this tree has been the dominant species planted during the previous decades. In a survey of 90 Serbian reforestation sites, herbivory caused seedling mortality rates higher than 50% for nine commonly planted species (Ivetić, 2015).

These examples of the negative effect of some abiotic and biotic factors on seedling survival after outplanting call attention to the need for a commonly accepted procedure for controlling the events taking place during tree planting. Closely controlling the activities of this important phase could avoid planting failures, suggesting to management the urgent need to intervene with supporting measures, including routine monitoring. During the recent conference 'Reforestation Challenges 2018′ held in Belgrade (Serbia), Ivetić (2018) suggested a monitoring framework that could help operators investigate the factors affecting seedling survival and suggest possible remedies.

The proposed monitoring framework (Fig. 8.1) has operators following a sequence of three actions: (1) evidence gathering, 2) data gathering, and (3) laboratory testing. The first action involves visiting the planting site if establishment failure is suspected to assess possible causes. During this visit, evidence, signs, and symptoms indicating potential damage related to seedling mortality are collected and documented. The timing of

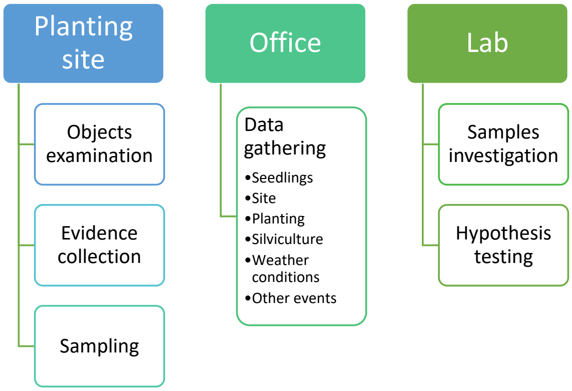


Figure 8.1 A set of procedures for seedling forensics. *((Adapted from Ivetić, 2018).)*

the field visit and evidence gathering is crucial, as signs and symptoms can disappear quickly.

The second action consists of a desktop analysis of all gathered data, including seedling morphology, site conditions, planting techniques, silviculture operations postplanting, weather conditions during and after planting, and any other relevant data potentially influencing seedling mortality. Analysis of data collected during the field visit (Box 8.1) is essential for investigating the causes of establishment failure, especially if monitoring visits are delayed (South et al., 2023). While seedling quality is considered the most critical factor for successful establishment (Grossnickle and MacDonald, 2018), analysis of data concerning other determining factors affecting seedling growth and development must also be considered.

In very complex situations (South et al., 2023), a third action may be necessary: artificially reconstructing in a laboratory the conditions and events hypothesized to have contributed to seedling mortality.

The methodological approach for monitoring the performance of tree planting initiatives

Monitoring the performance of a tree planting initiative represents a valuable tool that provides producers of planting material with feedback regarding how nursery protocols must be adjusted to increase seedling quality and obtain better performance in the field. In addition, monitoring provides useful indications to forestry operators on the planting methods used (i.e., time of planting, site and soil preparation, planting protocols, protection and supporting measures) and the necessary corrections to methods that ensure the success of the tree planting operations.

The importance of establishing a monitoring timeframe

The timing of when to assess the success or failure of tree planting activities varies considerably across European countries (Table 8.2). Assessments are conducted as early as the end of the first growing season and up to 10 years after outplanting. In some countries, assessment consists of a single event, while in others it is repeated yearly, usually up to 5 years after planting. A single assessment made after the first growing season is usually accepted for practical reasons, for planting to be subsidized or paid for by the funding agency or customer as soon as possible. Such an early and single assessment, however, could miss important information on planting success in the establishment phase, as mortality of seedlings can occur years after the planting. Yet, early assessment is desirable from the perspective of forest nursery operators and planting contractors. For example, in France, there is a strong demand from planting contractors to assess the success of tree planting activities at the beginning of the summer (instead of October) in order to disentangle mortality due to seedling quality from mortality due to summer drought (Catherine Collet, contribution to the questionnaire.) So far, this request has not been granted.

Our comparative analysis of the current monitoring timeframe adopted in several European countries reveals that the early survival rate is the most common performance indicator used in the assessment protocols. However, it cannot be overlooked that there are also additional indicators used in France, Lithuania, Norway, Spain, and Ukraine.

As an example, in Spain (José Ceballos Aranda, contribution to the questionnaire) during the first 5 years following outplanting, monitoring uses additional indicators such as the percentage of dead seedlings being replaced, an evaluation of the vegetative state of seedlings, and verification that the maintenance or complementary works (weeding, harrowing, clearing, pruning, etc.) are implemented. This type of monitoring can be extended to 10 or 20 years.

In Ukraine, monitoring in temporary sample plots is limited to evaluating the growth potential of coniferous species based on the presence of a viable, healthy apical shoot, whereas for deciduous species, growth potential is based on the presence of dormant buds. In the case of mixed forest stands, these indicators are evaluated for all the main tree species (Taras Parpan, contribution to the questionnaire).

in Serbia, monitoring differs between tree species and planting methods. For direct-seeded oak (*Quercus robur*), monitoring is based on indicators sampled after the first growing season. Good performance is considered when seedling height reaches 15–30 cm and at least 1 seedling per square meter. Establishment is considered to be successful when seedlings survive and grow, and supporting species are present in the stand.

Table 8.2 The synopsis of timing and methodology used for assessment of planting success across Europe.

Austria	**Three to 5 years after planting.**
Belgium	Assessment of mortality in years 3 and 4 after planting, expressed as a percentage of the initial number of planted seedlings.
Bosnia and Herzegovina	Assessment of survival rate in 2nd and 5th year after planting, by setting the field plots and counting surviving seedlings. The plot area is 0.05 ha (r = 12.62 m). The distance between plots is 50–100 m.
Croatia	Survival rate between the 2nd and 5th year of the plantation's age.
France	At least 90 days after planting, and after October 1st. Some funding programs require an assessment after 5 years to pay the total amount of subsidies. The usual method is to sample seedlings throughout the planting site, with the following thresholds of the number of seedlings to be sampled: (1) at least 3% of the planted seedlings; (2) in plantings with less than 10,000 seedlings, at least 10% of planted seedlings; or (3) at least 100 planted seedlings, without clear definition on how the sampling should be performed within the planting site. Each seedling should be noted as "alive", dead" or "disappeared". During the survey, the main cause of death is usually recorded.
Greece	In the 2nd year after planting, only seedling survival is measured.
Hungary	Two years after the start of forest regeneration and at the end of the process, the number of tree seedlings was counted.
Italy	At the end of the first growing season, a survival rate of >90% is verified in the field by comparing live seedlings per species with the numbers in documents attached to the project.
Latvia	The number of trees counted in a square area of 25 m^2, then multiplied by 400. The number of sampling plots depends on the regeneration area.
Lithuania	In the seventh year of seedling growth, success is assessed according to the following indicators: quality of seedlings, quality of planting, density of planted areas, and quality of planted area protection. The overall quality is evaluated according to the lowest rating of all indicators. After planting or restoring a forest by seeding, the quality of forest regeneration is not evaluated.
Norway	Species choice and whether it is the right species for the location, method of regeneration, seedling density, possible reasons for seedling mortality, and whether the 10% deciduous regeneration rule is fulfilled.
Serbia	Mapping and measuring the survival rate after the first growing season.
Spain	Annual control during the first 5 years, carried out between October 15th and December 15th of each year. GPS estimations of surfaces according to repopulation stands. Checking working depth using a graduated depth gauge bar. Planting density through standardized plots (mostly circular of 200 m^2) according to a preset sampling mesh. Vegetative state through visual verification of admissibility or inadmissibility.

Continued

Table 8.2 The synopsis of timing and methodology used for assessment of planting success across Europe.—cont'd

Austria	Three to 5 years after planting.
Türkiye	Seedling survival 1 year after planting using subsampling rows.
Ukraine	The inventory is conducted in 1-, 2-, and 3-year-old forest cultures and plantations by inspection, accounting, and measurements on established sample plots in the most characteristic areas. The following is checked: site allocation and plots design, the technology used, the scheme for mixing main and accompanying species and their placement, compliance of forest reproductive material with current standards, and the quality of the work performed.
United Kingdom	Year 9 or 10 after planting. Sometimes earlier in order to have time to make corrections and additional plantings. Trees ha^{-1} using circular plot measurements.

Source: The questionnaire produced by the PEN-CAFoRR Network. Full table is available on request to the authors.

The traditional and innovative monitoring methodologies for analyzing tree planting performance

In a time of changing environments, increased pressure on forests and forestry, and decreasing availability of technical staff, the current protocols for early assessment and monitoring need to be improved. To suggest new approaches to monitoring planting success in Europe that could be widely applied, independent of tree species and environmental conditions, requires a brief summary of the major monitoring methodologies (and their associated equipment) used worldwide. Three overlapping methodologies appear in the literature: (1) Digital tracking (DT), (2) remote sensing (RS), and (3) drone fly-overs (DFOs). RS and DFOs are often considered together as they utilize similar technology (references in Mahamoudou and Arakwiye, 2020; Reytar et al., 2020; Ruiz-Jaén and Aide, 2006; Monie et al., 2013).

In spite of their similarities, these monitoring methods differ in the type of information they provide. RS and DFO are used to investigate indicators that survey community-level parameters (Ruiz-Jaén and Aide, 2006; Monie et al., 2013). DT investigates indicators related to the morphological and physiological properties of individual trees deriving from aspects of their growth and developmental trends (Mahamoudou and Arakwiye, 2020; Reytar et al., 2020). It is reasonable to expect that in the not-too-distant future, RS and DFO methods might achieve improved sensitivity and resolution, allowing remote measurements of the properties of individual trees (Stanturf et al., 2024). An interesting future technological advancement could involve all these methods (DT, RS, DFO) in the "swarming monitoring" approach, where artificial intelligence (AI) manages several monitoring units moving simultaneously among (or above) the trees in a stand.

Digital Tracking (DT)

DT monitoring is regarded as a basic method when measurements involve a random or systematic passage (i.e., ground transects) among plants to measure their traits. However, it is considered an advanced and robust method when traits are measured under more controlled conditions in plants growing in replicated plots.

In both cases, the morphological traits commonly measured include stem height, root collar diameter (RCD), diameter at breast height, number of branches, biomass (stem, branches, and leaves), and leaf area index. The most commonly measured physiological traits include chlorophyll A and B content and their relative ratio, photosynthesis yield, gas exchange, and tissue water potential.

During the first vegetative season following planting, DT measurements are repeated a few times at regular intervals, usually for a few weeks. After the first year, measurements are taken annually or on a multiyear basis.

In recent years, efforts have been made to expedite and automate DT monitoring. One methodology, Automated Stereo Vision, is based on time-lapse image acquisition by special cameras (Aby and Issa, 2023). A potential future improvement of this method could involve the use of remote-controlled uncrewed vehicles equipped with special cameras for capturing photographs at regular intervals. The images are processed by stereo-photogrammetry software trained to detect comparative differences in plant traits such as plant height, leaf area, and number of branches. Additionally, this method is being explored for its ability to detect plant diseases, leaf parasitic attacks, or nutrient deficiencies through analysis of leaf colors.

Remote sensing (RS) and drone fly-overs (DFO)

The field of RS has experienced remarkable advancements, particularly in the capabilities of satellite RS technologies. Modern satellites now offer high-resolution imagery that can discern features down to the scale of a few meters. For example, PlanetScope has been used for tree mortality monitoring (Garrity et al., 2013). In China's Loess Plateau, extensive afforestation projects aim to combat soil erosion and enhance carbon sequestration. The high-resolution imagery from the PlanetScope constellation has been instrumental in monitoring tree survival rates and growth across vast areas. This has provided valuable insights into the success rates of various tree species and planting techniques, enabling the fine-tuning of afforestation strategies to maximize CO_2 sequestration and improve land restoration outcomes (Avtar et al., 2017; Fooladi et al., 2021).

The evolution of hyperspectral imaging represents a significant leap forward. Unlike traditional imaging technologies, hyperspectral sensors collect information from hundreds of very narrow spectral bands across the electromagnetic spectrum. Among other applications, hyperspectral data has been used for early pest infestation at the tree level (Gao et al., 2023). By using hyperspectral and high-resolution imaging, researchers are actively exploring the creation of indices that can more accurately reflect the phenological changes within forests, track species-specific responses to environmental stressors, or better quantify biomass and carbon storage. For instance, the enhanced vegetation index has been developed to optimize the vegetation signal with improved sensitivity in high biomass regions while minimizing soil and atmosphere influences.

The integration of satellite RS data with other data sources, such as meteorological and socioeconomic data, further enhances forest management practices and could be useful in monitoring. For example, combining RS imagery with real-time weather data helps predict wildfire risks and assess drought stress in forest regions, thereby facilitating proactive management strategies (Szantoi et al., 2016). Additionally, socioeconomic data overlaid with satellite imagery can illustrate how human activities influence forested landscapes, aiding in the development of targeted conservation strategies. An example of successful integration is seen in the Global Forest Watch project, which combines satellite imagery with deforestation alerts and community monitoring data. This integration has empowered stakeholders to detect illegal logging activities swiftly and enforce forest conservation laws more effectively, showcasing the capabilities of RS technology in supporting climate change mitigation (Chen et al., 2019).

In recent decades, ecological research has sought new methods to expedite DT-based monitoring, favoring new RS techniques. Much progress has been made since the advent of aerial photo interpretation and satellite imagery. New sensors are used in RS to utilize airborne, spaceborne, and terrestrial Light Detection And Ranging (LiDAR) technology. Since 2018, this technology has been installed aboard the International Space Station, enhancing analytical capabilities globally through the Global Ecosystem Dynamics Investigation system (Rishmawi et al., 2021). Airplane-mounted LiDAR (ALS) can produce digital terrain models (DTMs) and canopy height models (CHMs) across landscapes.

The considerable flexibility of RS technology recommends it highly for monitoring forests (Almeida et al., 2014), enabling coverage of large areas with a single flight (e.g., over 1000 ha) (van Leeuwen and Nieuwenhuis, 2010). New sensors include high-resolution cameras, laser scanners, and other sensors, including drone-mounted LiDAR (Stanturf et al., 2024). LiDAR detects variations in the biophysical properties of vegetation, expressed through the normalized difference vegetation index (Li et al., 2012; Glenn et al., 2008; Kouadio et al., 2014; White et al., 2014). Studies have demonstrated the successful measurement of changes in chlorophyll content, 2013), aboveground biomass (Montagnoli et al., 2015), tree density, canopy structure and composition, natural seedling recruitment, tree architecture, flowering patterns, and more.

A recent innovation in RS is the use of LiDAR sensors aboard drones (Almeida et al., 2014). This approach, known as Drone Fly-Overs, is poised to revolutionize ecological studies, particularly in forestry, by facilitating monitoring and related forest management activities (Anderson and Gaston, 2013). Another advancement is the use of terrestrial laser scanning (TLS) that captures high-resolution images of the three-dimensional structure of a terrestrial ecosystem; TLS has been used in forest inventory and studies of understory plant diversity and wildfire fuel beds (Loudermilk et al., 2009; Liang et al., 2016; Anderson et al., 2021).

Software used to analyze data collected by RS and DFO methods can provide a DTM (Maguya et al., 2014; Bigdeli et al., 2020), a digital surface model, or a CHM (Liu et al., 2020). The integration of big data analytics in RS has significantly enhanced our ability to monitor and understand terrestrial environments, especially planted forests. The vast amounts of data collected from satellite sensors, such as those from Landsat and the European Space Agency's Sentinel series, are now manageable thanks to advances in big data technologies, including machine learning (ML), deep learning, and cloud computing. Additionally, platforms like Google Earth Engine provide access to extensive archives of satellite imagery and the computational resources needed to conduct large-scale geospatial analyses. This is particularly valuable for tracking forest health and development, and observing the impacts of climate change on forests, facilitating informed decision-making.

Divide monitoring into phases based on morphological and physiological events to be measured and the methodologies to be used

The alarmingly high rate of tree planting failures worldwide is likely underreported due to the lack of a common monitoring procedure. We suggest a new way of monitoring the performance of tree planting initiatives by dividing the stand initiation stage (*sensu* Oliver and Larson, 1996) into phases that differ not only temporally but also in the methods used and the morphological and physiological indicators that best describe the growth and development of the trees.

We distinguish three phases for monitoring tree planting activities aimed at forestation (Fig.8.2), specifically monitoring stand establishment (MSE), monitoring developing phase (MDP), and monitoring adult phase (MAP). This distinction is based on the fact that different growth and development stages of a tree not only require different methodological approaches (DT, RS, or DFO) but also different equipment.

MSE pertains to the growth period between outplanting or seeding and the third year (i.e., the third vegetative season). MDP covers the period when trees exhibit the highest rate of growth and development, normally spanning between 4 and 10 years from outplanting. MAP includes the entire period from the end of stand initiation to stand renewal (rotation or senescence, depending on management).

Furthermore, we have deliberately chosen to refrain from additional differentiations, as the assessment could also be divided based on which objective (i.e., ecosystem services) and economic value are assigned to the planting. However, MAP is treated in

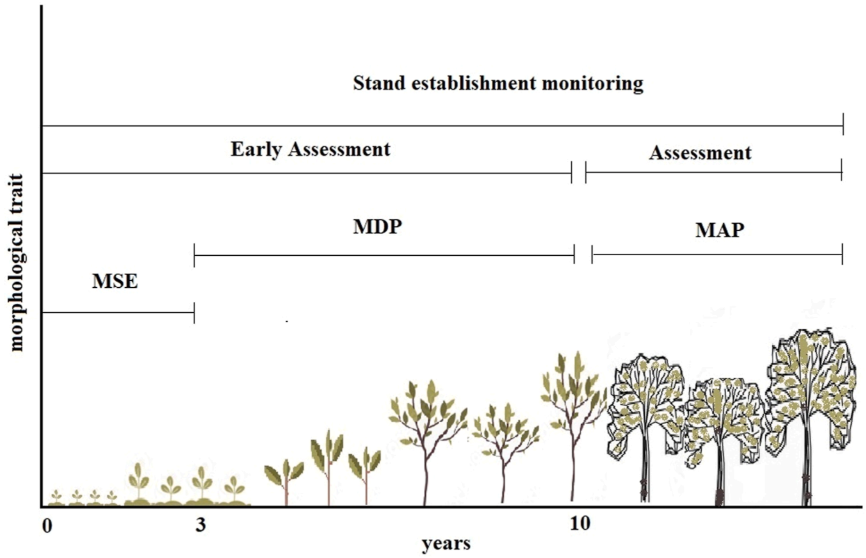


Figure 8.2 Subdivision of monitoring according to early growth and developmental phases. *(Credit: Donato Chiatante)*

other chapters of the book, and for this reason, we intend to focus only on MSE and MDP with greater emphasis on MSE.

Monitoring stand establishment (MSE)

Regardless of the planting method (seeding or planting), the first 3 years are widely recognized as the most precarious time in a plant's life (Hanley et al., 2004). This establishment phase is often characterized by various stressful conditions that threaten seedling survival and may result in regeneration failure. Rudimentary monitoring programs limit measurement to survival/mortality, possibly accompanied by observations of damage (browsing, defoliation, etc.). More information could be collected with the aim of determining the cause of mortality or substandard growth.

MSE is crucial and should consist of a chronosequence or series of observations of seedling growth and development. Presently, the DT methodology described above remains the most reliable method for MSE monitoring. In the future, however, RS and DFO methods could possibly achieve enough reliability for MSE monitoring as well (Samiei et al., 2020).

The graph in Fig. 8.3 represents the potential growth trend expected during the first 3 years (after outplanting or seeding) obtainable using DT when seedlings grow under favorable environmental conditions. This theoretical growth trend should be obtained independently from experimental plots or local averages. Different morphological traits (i.e., stem height, number of branches, RCD, etc.) will have their unique trends. The

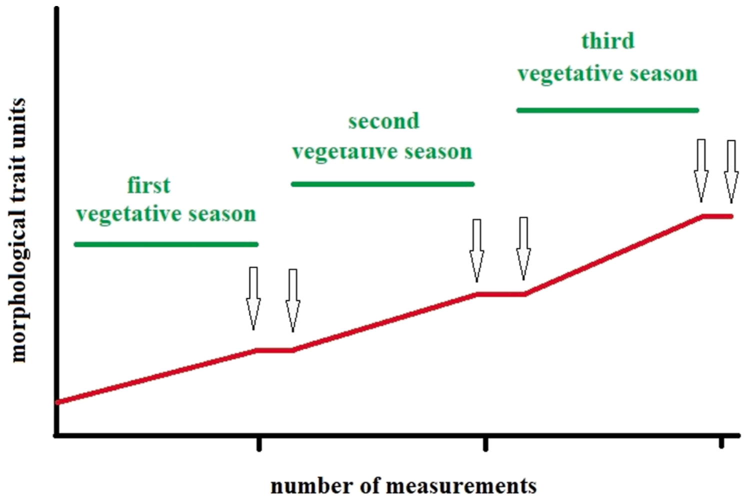


Figure 8.3 Potential growth trend of seedlings after planting and the accumulating number of measurements. *(Credit: Donato Chiatante)*

arrows on the graph indicate the last measurement of the previous growing season and the first of the following growing season. The interval between the two arrows represents the dormancy period between two successive growing seasons, during which no increases occur. Comparing measurements from monitoring actual planting sites to this optimal trend should confirm if the monitored seedlings are subjected to optimal or stressful living conditions. Discrepancies between trends should draw management's attention to the fact that something is impeding the growth of the seedlings and that it is necessary to consider how to intervene to provide support.

A widely accepted, consistent, and reliable protocol for MSE monitoring is not available. There is a risk that monitoring at this earliest stage becomes a collection of unreliable, useless, or needlessly expensive parameters (Viani et al., 2018). To avoid this risk, there should be an effort to select a limited number of species-specific indicators that relate to management objectives and are sensitive to the kinds of stressors likely to be present.

Furthermore, we suggest that reliable monitoring is obtained only when trends of different traits are compared. This comparative analysis reflects the knowledge that there are intrinsic and extrinsic factors that affect plant hormone allocation to different plant organs, with consequent induction of anomalies in the normal development of the organs. For example, stem branching is controlled by variations in hormone concentrations, the gene expression of which can be altered by environmental factors. Therefore, if monitoring relied solely on identifying a trend obtained from the measurements of a single parameter, incomplete information regarding the overall development of the plant under consideration would be obtained, and incorrect conclusions could be made about causes of mortality or suboptimal growth (Yi et al., 2022).

Most examples of monitoring that have reported the use of MSE have focused on aboveground morphological traits (stem, branches, and leaves). The most common traits measured (besides survival) are stem height and RCD. Only a few published studies reported measurements on both above- and belowground morphological traits (but see Byambadorj et al., 2021a, 2021b, 2022; Nyam-Osor et al., 2021; Montagnoli *et al.*, 2022). Monitoring the trend of morphological root traits, such as length, volume, diameter, and branching, would be essential for assessing the coordination between above- and belowground organ growth. Insufficient water availability in shallow soil layers may hinder further growth of aboveground organs, even after an initial normal trend (Montagnoli *et al.*, 2022). Despite the time-consuming effort required for measuring root traits, the information obtained is crucial for understanding the progress of seedling establishment.

A scenario that illustrates when meticulous MSE, including root development analysis, could be useful could begin with monitoring indicating mortality or suboptimal growth without any apparent aboveground damage. An investigation of belowground (i.e., root system) growth might indicate root deformity caused by improper planting, lack of available soil moisture, possibly a soil layer impeding root growth, or an abrupt increase in soil pH that interfered with nutrient uptake in conifers. In some cases, prompt management intervention might address the problems. Education and better supervision of planting crews, temporary irrigation support (i.e., adaptive support) to prevent seedling growth from stalling, or switching to broadleaves could be effective responses.

This type of MSE monitoring provides insights into above- and belowground growth and development patterns, crucial for assessing the suitability of tree species for future stand establishment on sites with specific soil characteristics. Models of tree fitness in forestry scenarios supported by AI will enhance our ability to predict “the right tree for the right site”.

Monitoring developing phase (MDP)

After the establishment phase, tree seedlings enter a period of rapid growth and development. Although consensus eludes as to when a seedling transitions to a sapling (Kitajima and Fenner, 2000), we propose that this transition occurs after the third year of a plant’s life. Thus, MDP represents the phase when trees leave the establishment phase and begin to resemble true trees in their youthful appearance. This phase precedes the transition to adulthood, including reproductive maturity (Groover, 2017), which necessitates the MAP type of monitoring described earlier.

The efficiency and reliability of MDP monitoring hinge upon a thorough understanding of the life cycle of the tree species being monitored. Organogenesis in higher plants follows rhythmic activity patterns of stem apex meristems, root apex meristems, vascular cambium meristems, and cork cambium in the primary and secondary (woody) bodies (Mathieu et al., 2008).

The coordinated activity of these meristems determines a species-specific growth and development trend, resulting in a relative growth rate (RGR). Regardless of the parameter used, RGR typically follows a sigmoidal curve with phases known as LAG, LOG, and STATIONARY. The LAG phase is characterized by a slow increase in the parameter, followed by the LOG phase, where exponential increments occur. The STATIONARY phase begins when the increments reach an equilibrium.

In a tree's life cycle, this sigmoidal RGR trend aligns with key events: 1) the conclusion of the establishment phase, 2) the initiation of juvenile body construction, and 3) the transition to the adult phase. MDP's significance lies in its investigation of this sigmoidal trend, distinguishing it from MSE and MAP.

The activities of meristematic tissues are influenced by both natural (intrinsic and extrinsic) and anthropogenic factors (Huijser and Schmid, 2011). As a result, the RGR often undergoes alterations due to various environmental stressors such as windstorms, frost, avalanches, landslides, and attacks by fungi, bacteria, parasites, among others. Additionally, MDP allows for the investigation of how management activities like site preparation, transplanting methods, and support measures such as irrigation and fertilization can affect RGR (Fischer et al., 2002).

From a methodological perspective, MDP can utilize all the methods described above (DT, RS, DFO) either separately or in combination. An example illustrating how the RGR trend can be influenced was demonstrated by Byambadorj et al. (2021a, 2021b, 2022). In their study of poplar (*Populus sibirica*) and elm (*Ulmus pumilla*) plantations in Mongolia, they observed that the growth curves derived from MDP measurements over a 10-year period, including stem height, RCD, and biomass, exhibited a sigmoidal trend. Interestingly, they found that the highest growth increments occurred when trees were irrigated with an average amount of water, rather than the maximum amount.

Artificial intelligence and machine learning in assessment of establishment success

AI and ML algorithms have great potential for applications in the automation of many operations in forestry, including tree planting. Growing research on the use of AI and ML in forestry and in general has been reviewed by Liu et al. (2018), Shivaprakash et al. (2022), Stamatopoulos et al. (2024), and Buchelt et al. (2024).

Automated planting systems in forestry are currently experimental (e.g., Hansson et al., 2024) but better developed for agronomic activities. Farming systems are highly instrumented with multiple sensors that could be useful for very early monitoring. These methods have seen significant development in agriculture due to the reduced presence of other plant species surrounding the observed plant, enabling clear images of germinating seeds, cotyledon emergence, and the development of the first leaves (Chen et al., 2018; Zhao et al., 2018; Jiang et al., 2019; Kipp et al., 2014; Sankaran et al., 2015). However, their application in forestry is challenging, and further improvements may be necessary, potentially involving the integration of AI and deep neural networks (LeCun et al., 2015; Kamilaris and Prenafeta-Boldu, 2018).

Automation using uncrewed aerial vehicles (UAVs), AI, and ML for tree planting (or seeding) is already commercially available, but the technology needs further development to establish itself as a standard practice for both planting and assessment of planting success (Stanturf et al., 2024). One example is DroneSeed, a pioneer in the use of UAVs for forest restoration by seeding. DroneSeed started with using swarms of drones for direct seeding but evolved into Mast Reforestation (https://www.mastreforest.com/, accessed on 29 May 2024), now offering broader but more traditional solutions in forest restoration. Besides aerial seeding, Dendra (https://dendra.io/, accessed on 29 May 2024) uses ML technology to provide complete counts that identify and quantify every tree, shrub, and grass on a specific site. Picterra (https://picterra.ch/, accessed on 30 May 2024) offers a no-code platform for users to autonomously build geospatial AI models at scale up to 95% faster, for seedlings detection and survival rate monitoring.

To assess establishment success, automation by drones can be used for acquiring a vast quantity of pictures and video clips for ML- and AI-driven identification of live versus dead or damaged seedling (=survival) and target species versus competitive vegetation (=number of seedlings per area unit). There are many available services that use advanced AI and ML for an image-based identification of species, like PlantSpot (https://plantspot.app/, accessed on 29 May 2024), FloraIncognita (https://floraincognita.com/, accessed on 29 May 2024), Pl@ntNet (https://identify.plantnet.org/sr, accessed on 29 May 2024), and PlantSnap (https://www.plantsnap.com/, accessed on 29 May 2024). PictureThis (https://www.picturethisai.com/) even uses an AI-powered diagnostic tool for recognizing symptoms and signs of damage.

Techniques combining ML and AI with robotic platforms and artificial vision systems have been used successfully for remote forest health assessment, and this field of application is developing rapidly (Estrada et al., 2023). Another development with planting applications is the acquisition of data on site conditions by harvesters that could be used to guide planting decisions in subsequent reforestation of the site.

Perhaps the most developed solution to be used for assessment of establishment success was developed by byteLAKE (https://bytelake.com/en/, accessed on 29 May 2024). By using a large number of images acquired by a drone, they trained neural networks to count young trees (for survival) and detect anomalies (i.e., drying out) with accuracy of over 90%.

To collect data needed for establishing the causes of failure, the Internet-of-Things (IoT) devices and the Wireless sensor networks (WSNs) can be used. WSNs can be deployed in forests by drones (Farinha et al., 2020). Treevia (https://treevia.com.br/inventario-florestal/) developed sensors (50 g in weight and 4 cm in length), with an elastic strip that can be fitted to a seedling of 1 cm diameter that can stretch up to 1 m for diameter increment measurements. Further miniaturization will allow the use of different sensors to be placed even on smaller seedlings. Equipped with appropriate sensors and deployed on planting sites, these devices can provide real-time data and build a database regarding all environmental variables that induce seedling mortality. Equipped with a motion detection sensor and appropriate camera, these devices can document the damage due to herbivory. Used in this way, the IoT and WNS (when supported by AI), provide an opportunity for timely actions aimed at preventing seedling mortality and regeneration failure.

Guidelines for best practices in monitoring the performance of tree planting

Based on concepts previously discussed, we propose some simplified guidelines that any monitoring program aimed at evaluating the performance of tree planting activities in the context of afforestation, reforestation, and restoration should adopt.

Duration of the monitoring activity

Performance monitoring should be considered a continuous activity that begins with outplanting and extends throughout the duration of the project. It should consist of repeated assessments scheduled at fixed intervals. Recording the trends in growth and development of the planted or seeded material by measuring morphological and physiological parameters should be integral to monitoring. The information gathered through monitoring should be used to predict the performance of the tree planting activity and, if necessary, call for management support interventions. The data collected during monitoring should also be used to improve nursery culturing protocols to increase seedling quality, refine site and soil preparation as well as planting techniques, and disseminate best practices among nursery managers, forestry contractors, and forest managers.

Indicators used for performance evaluation

For cost-effectiveness, the number of indicators to be measured during assessment of a tree planting activity should be limited to the best predictors of plant growth and development. At a minimum, indicators must include survival percentage, seedling height, RCD, and root system traits (length, diameters, biomass). The growth and developmental trends of seedlings should be related to planting patterns, types of soil preparation, planting depth, climate factors, and human activities present in the site. The reasons for failure should be well investigated and documented.

Methods

Mapping the site and georeferencing monitoring plots and seedlings represent good practice for efficient monitoring. The measurement of survival rates and growth trends should be conducted in circular or linear plots following a stratified sampling design. The number of plots to monitor should be related to financial capacity, homogeneity of conditions, and variability of the indicators to be measured. To enable continuous monitoring, sample seedlings/trees could be permanently marked with stakes, plastic or aluminum tags, or paint. Alternatively, a comprehensive database of a stand from ALS or TLS could digitally geocode individual plants to guide subsequent measurements. In addition to recording all measured data, fixed point pictures and video clips should be georeferenced. When monitoring is entrusted to autonomous data collection technologies as described above, the number and type of devices and sensors should be related to financial availability, site conditions, and management needs. In case of tree planting failure, seedling forensics should be applied to draw science-based conclusions to correct protocols and avoid making the same errors again.

References

Abiyu, A., Teketay, D., Glatzel, G., Gratzer, G., 2016. Seed production, seed dispersal and seedling establishment of two afromontane tree species in and around a church forest: Implications for forest restoration. For. Ecosyst. 3.

Aby, G.R., Issa, S.F., 2023. Safety of automated agricultural machineries: A systematic literature review. Safety 9 (1), 13. https://doi.org/10.3390/safety9010013.

Almeida, P., Altobelli, A., D'Aietti, L., Feoli, E., Ganis, P., Giordano, F., Napolitano, R., Simonetti, C., 2014. The role of vegetation analysis by remote sensing and GIS technology for planning sustainable development: A case study for the santos estuary drainage basin (Brazil). Plant Biosyst. 148, 540–546.

Anderson, K., Gaston, K., 2013. Lightweight unmanned aerial vehicles will revolutionize spatial ecology. Front. Ecol. Environ. 11, 138–146. https://doi.org/10.1890/120150.

Anderson, C.T., Dietz, S.L., Pokswinski, S.M., 2021. Traditional field metrics and terrestrial LiDAR predict plant richness in southern pine forests. For. Ecol. Manag. 491, 119118. https://doi.org/10.1016/j.foreco.2021.119118 [and others].

Avtar, R., Kumar, P., Oono, A., Saraswat, C., Dorji, S., Hlaing, Z., 2017. Potential application of remote sensing in monitoring ecosystem services of forests, mangroves and urban areas. Geocarto Int. 32, 874–885. https://doi.org/10.1080/10106049.2016.1206974.

Ban, N.C., Mills, M., Tam, J., Hicks, C.C., Klain, S., Stoeckl, N., Bottrill, M.C., Levine, J., Pressey, R.L., Satterfield, T., Chan, K.M., 2013. A social–ecological approach to conservation planning: embedding social considerations. Frontiers in Ecology and the Environment, 11, 194–202. https://doi.org/10.1890/110205.

Bautista, E.G., Kim, J., Kim, Y., Panganiban, M.E., 2017. Farmer';s perception on farm mechanization and land reformation in the Philippines. Journal of the Korean Society of International Agriculture, 29(3), 242–250. https://doi.org/10.12719/KSIA.2017.29.3.242.

Berkes, F., Colding, J., Folke, C., 2000. Rediscovery of traditional ecological knowledge as adaptive management. Ecological Applications 10, 1251–1262. https://doi.org/10.1890/1051-0761(2000)010[1251:ROTEKA]2.0.CO;2.

Benayas, J.M.R., Newton, A.C., Diaz, A., Bullock, J., 2009. Enhancement of biodiversity and ecosystem services by ecological restoration: A meta-analysis. Science 325, 1121–1124. https://doi.org/10.1126/science.1172460.

Bigdeli, B., Gomroki, M., Pahlavani, P., 2020. Generation of digital terrain model for forest areas using a new particle swarm optimization on LiDAR data. Surv. Rev. 52 (371), 115–125. https://doi.org/10.1080/00396265.2018.1530331.

Blignaut, J.N., Aronson, J., De Wit, M., 2014. The economics of restoration: looking back and leaping forward. Annals of the New York. Academy of Sciences, 1322(1), 35-47.

Boutte, B., 2020. Réussite des Plantations Forestières de l'année 2020: 2020 est la Plus Mauvaise Année au Niveau de la Reprise des Plantations Forestières Depuis 2007. Rapport, Bilan de la Santé des Forêts en 2020, Mars 2021. Ministère de l'Agriculture et de l'Alimentation, Département de la Santé des Forêts. https://agriculture.gouv.fr/suivi-sanitaire-d.

Brèteau-Amores, S., Brunette, M., Andrés-Domenech, P., 2023. A cost assessment of tree planting failure under extreme drought events in France: What role for insurance? Forests 14, 308. https://doi.org/10.3390/f14020308.

Buchelt, A., Adrowitzer, A., Kieseberg, P., Gollob, C., Nothdurft, A., Eresheim, S., Tschiatschek, S., Stampfer, K., Holzinger, A., 2024. Exploring artificial intelligence for applications of drones in forest ecology and management. For. Ecol. Manag. 551, 121530. https://doi.org/10.1016/j.foreco.2023.121530.

Byambadorj, S.-O., Park, B.B., Hernandez, J.O., Tsedensodnom, E., Byambasuren, O., Montagnoli, A., Chiatante, D., Nyam-Osor, B., 2021a. Effects of irrigation and fertilization on the morphophysiological traits of Populus sibirica Hort. Ex Tausch and Ulmus pumila L. in the semiarid steppe region of Mongolia. Plants 10, 2407. https://doi.org/10.3390/plants10112407.

Byambadorj, S.-O., Chiatante, D., Akhmadi, K., Lunten, J., Ochirbat, B., Park, B.B., Scippa, G.S., Montagnoli, A., Nyam-Osor, B., 2021b. The effect of different watering regimes and fertilizer addition on the growth of tree species used to afforest the semi-arid steppe of Mongolia. Plant Bios 155 (4), 969–981. https://doi.org/10.1080/11263504.2020.1779845.

Byambadorj, S.-O., Nyam-Osor, B., Park, B.B., Avirmed, T., Scippa, G.S., Chiatante, D., Montagnoli, A., Dimitrova, A., 2022. Afforestation of Mongolian steppe: Patterns of biomass partitioning in *Populus sibirica* and *Ulmus pumila* trees in response to management supporting measures. Plant Bios 156 (4), 969–981. https://doi.org/10.1080/11263504.2021.1985002.

Chazdon, R.L., 2014. Second Growth: The Promise of Tropical Forest Regeneration in an Age of Deforestation. University of Chicago Press, Chicago. https://doi.org/10.7208/chicago/9780226118109.001.0001.

Chazdon, R., Brancalion, P., 2019. Restoring forests as a means to many ends. Science 365,24-25. https://doi.org/10.1126/science.aax9539.

Chen, Y.Q., Liu, Z.F., Rao, X.Q., Wang, X.L., Liang, C.F., Lin, Y.B., Zhou, L.X., Cai, X.A., Fu, S.L., 2015. Carbon storage and allocation pattern in plant biomass among different forest planting stands in guangdong, China. Forests 6, 794–808. https://doi.org/10.3390/f6030794.

Chen, R., Chu, T., Landivar, J.A., Yang, C., Maeda, M.M., 2018. Monitoring cotton (Gossypium hirsutum l.) germination using ultrahigh-resolution UAS images. Prec Agric. 19 (1), 161–177.

Chen, Y., Guerschman, J.P., Cheng, Z., Guo, L., 2019. Remote sensing for vegetation monitoring in carbon capture storage regions: A review. Appl. Energy 240, 312–326. https://doi.org/10.1016/j.apenergy.2019.02.027.

Cook-Patton, S.C., Drever, C.R., Griscom, B.W., Hamrick, K., Hardman, H., Kroeger, T., , … Ellis, P. W., 2021. Protect, manage and then restore lands for climate mitigation. Nat. Clim. Change 11 (12), 1027–1034. https://doi.org/10.1038/s41558-021-01198-0.

Derhé, M.A., Murphy, H., Monteith, G., Menéndez, R., 2016. Measuring the success of reforestation for restoring biodiversity and ecosystem functioning. J. Appl. Ecol. 53, 1714–1724.

Dudley, N., Mansourian, S., Vallauri, D., 2005. Forest landscape restoration in context. In: Mansourian, S., Vallauri, D. (Eds.), Forest restoration in landscapes. Springer, New York, NY, USA, pp. 3–7.
Ehrenberg, R., 2015. Global forest survey finds trillions of trees. Nature 525 (7568), 170–171. https://doi.org/10.1038/nature.2015.18287.
Estrada, J.S., Fuentes, A., Reszka, P., Auat Cheein, F., 2023. Machine learning assisted remote forestry health assessment: A comprehensive state of the art review. Front. Plant Sci. 14. https://doi.org/10.3389/fpls.2023.1139232.
FAO, 2010. Forests and climate change in the Asia–Pacific region. In: Forest and climate change working paper 7, 126. Food and agriculture Organization of the United Nations, Rome, Italy.
Farinha, A., Zufferey, R., Zheng, P., Armanini, S.F., Kovac, M., 2020. Unmanned aerial sensor placement for cluttered environments. IEEE Rob. Autom. Lett. 5 (4), 6623–6630. https://doi.org/10.1109/LRA.2020.3015459.
Field, S.A., O'Connor, P.J., Tyre, A.J., Possingham, H.P., 2007. Making monitoring meaningful. Aust. Ecol. 32, 485–491.
Fischer, A., Lindner, M., Abs, C., Lasch, P., 2002. Vegetation dynamics in central European forest ecosystems (near-natural as well as managed) after storm events. Folia Geobot. 37, 17.32.
Fooladi, M., Golmohammadi, M.H., Safavi, H.R., Singh, V.P., 2021. Fusion-based framework for meteorological drought modeling using remotely sensed datasets under climate change scenarios: Resilience, vulnerability, and frequency analysis. J. Environ. Manage. 297, 113283. https://doi.org/10.1016/j.jenvman.2021.113283.
Gao, B., Yu, L., Ren, L., Zhan, Z., Luo, Y., 2023. Early detection of dendroctonus valens infestation at tree level with a hyperspectral UAV image. Remote Sens. 15, 407. https://doi.org/10.3390/rs15020407.
Garrity, S.R., Allen, C.D., Brumby, S.P., Gangodagamage, C., McDowell, N.G., Cai, D.M., 2013. Quantifying tree mortality in a mixed species woodland using multitemporal high spatial resolution satellite imagery. Remote Sens. Environ. 129, 54–65. https://doi.org/10.1016/j.rse.2012.10.029.
Geupel, G.R., Humple, D., Roberts, L.J., 2011. Monitoring decisions: Not as simple as they seem? Trends Ecol. Evol. 26, 107.
Glenn, E.P., Huete, A.R., Nagler, P.L., Nelson, S.G., 2008. Relationship between remotely-sensed vegetation indices, canopy attributes and plant physiological processes: What vegetation indices can and cannot tell us about the landscape. Sensors 8, 2136–2160.
GPFLR, 2019. Global partnership on forest and landscape restoration: Case studies. https://www.forestlandscaperestoration.org/.
Groover, A., 2017. Age-related changes in tree growth and physiology. In: eLS. John Wiley & Sons, Ltd: Chichester. https://doi.org/10.1002/9780470015902.a0023924.
Grossnickle, S.C., MacDonald, J.E., 2018. Seedling quality: History, application, and plant attributes. Forests 9 (5), 283. https://doi.org/10.3390/f9050283.
Grossnickle, S.C., 2000. Ecophysiology of northern spruce species: The performance of planted seedlings. NRC Research Press, Ottawa.
Grossnickle, S.C., 2005. Importance of root growth in overcoming planting stress. New For 30, 273–294. https://doi.org/10.1007/s11056-004-8303-2.
Hanley, M.E., Fenner, M., Whibley, B.D., 2004. Early plant growth: identifying the endpoint of the seedling phase. New Phytol. 163, 61–67. https://doi.org/10.1111/j.1469-8137.2004.01094.x.
Hanson, C., Buckingham, K., DeWitt, S., Laestadius, L., 2015. In: The Restoration diagnostic: A method for developing forest landscape restoration strategies by rapidly assessing the status of key success factors. International Union for Conservation of Nature, Gland, Switzerland.
Hansson, L.J., Sten, G., Rossander, M., Lideskog, H., Manner, J., van Westendorp, R., Li, S., Eriksson, A., Wallner, A., Rönnqvist, M., 2024. Autoplant—autonomous site preparation and tree planting for a sustainable bioeconomy. Forests 15, 263. https://doi.org/10.3390/f15020263.
Helenius, P., Luoranen, J., Rikala, R., Leinonen, K., 2002. Effect of drought on growth and mortality of actively growing Norway spruce container seedlings planted in summer. Scand. J. For. Res. 17 (3), 218–224. https://doi.org/10.1080/028275802753742882.
Higgs, E., 2017. Novel and designed ecosystems. Restor Ecol, 25, 8-13. https://doi.org/10.1111/rec.12410
Hill, M.J., 2013. Vegetation index suites as indicators of vegetation state in grassland and savanna: An analysis with simulated SENTINEL 2 data for a North American transect. Remote Sens. Environ. 137, 94–111. https://doi.org/10.1016/j.rse.2013.06.004.

Hobbs, R., Hallett, L., Ehrlich, P., Mooney, H., 2011. Intervention Ecology: Applying Ecological Science in the Twenty-first Century, BioScience, 61(6), 442–450. https://doi.org/10.1525/bio.2011.61.6.6.

Hocking, M., Stolton, S., Dudley, N., 2000. Evaluating Effectiveness: A Framework for Assessing the Management of Protected Areas. IUCN, Gland, Switzerland and Cambridge, UK. 121pp.

Huijser, P., Schmid, M., 2011. The control of developmental phase transitions in plants. Development 138 (19), 4117–4129. https://doi.org/10.1242/dev.063511.

Hutto, R.L., Belote, R., 2013. Distinguishing four types of monitoring based on the questions they address. For. Ecol. Manag. 289, 183–189. https://doi.org/10.1016/j.foreco.2012.10.005.

Hutto, R.L., Kowalski, S., 2006. Northern Region Landbird Monitoring Program: A USFS-university of montana partnership designed to provide both short-term and long-term feedback for land managers. In: Aguirre-Bravo, C., Pellicane, P.J., Burns, D.P., Draggan, S. (Eds.), Monitoring Science and Technology Symposium: Unifying Knowledge for Sustainability in the Western Hemisphere. 2004 September 20–24. Proceedings. U.S.D.A. For. Serv. RMRS-P-42CD, Fort Collins, CO, pp. 936–943.

IUFRO. Forest landscape restoration implementation—progress on the ground: Scientific snapshot analysis project. Available online: https://www.iufro.org/fr/science/special/spdc/netw/analysis (accessed on 22 December 2019).

Ivetić, V., Devetaković, J., Kerkez Janković, I., 2021. Is planting trees good or bad?. In: E3S Web of Conferences. EDP Sciences. https://doi.org/10.1051/e3sconf/202129604012.

Ivetić, V., 2015. Reforestation in Serbia: Success or failure? In: Ivetić, V., Stanković, D. (Eds.), Reforesta 1–12. In: https://www.reforestationchallenges.org/Files/Other/REFORESTATION%20CHALLENGES%20-%20PROCEEDINGS.pdf.

Ivetić, V., Devetaković, j., 2016. "Reforestation Challenges in Southeast Europe Facing Climate Change". Reforesta, vol. 1, no. 1, June 2016, pp. 178-20, https://doi.org/10.21750/10.21750/REFOR.1.10.10

Ivetić, V., 2018. Seedlings forensics and planting site investigations: How to determine the reasons for reforestation failure? In: Ivetić, V., Devetaković, J. (Eds.), Refor. Chall. 30. https://www.reforestationchallenges.org/Files/Other/Reforestation%20Challenges%202018%20BoA.pdf.

Jiang, Y., Li, C., Paterson, A.H., Robertson, J.S., 2019. Deepseedling: Deep convolutional network and Kalman filter for plant seedling detection and counting in the field. Plant Methods 15 (1), 141.

Jones, H.P., Schmitz, O.J., 2009. Rapid Recovery of Damaged Ecosystems. PLoS ONE 4(5), e5653. https://doi.org/10.1371/journal.pone.0005653

Kamilaris, A., Prenafeta-Boldú, F.X., 2018. Deep learning in agriculture: A survey. Comput. Electron. Agric. 147, 70–90.

Kanowski, J., Catterall, C.P., 2007. Monitoring revegetation projects for biodiversity in rainforest landscapes: Toolkit version 1, revision 1. marine and tropical sciences research faculty.

Kanowski, J., Catterall, C.P., Freebody, K., Freeman, A.N.D., Harrison, D.A., 2010. Monitoring revegetation projects in rainforest landscapes: Toolkit version 3. Reef and Rainforest Research Centre Ltd.: Cairns, Australia.

Kipp, S., Mistele, B., Baresel, P., Schmidhalter, U., 2014. High-throughput phenotyping early plant vigour of winter wheat. Eur. J. Agron. 52, 271–278.

Kitajima, K., Fenner, M., 2000. Ecology of seedling regeneration. In: Fenner, M. (Ed.), Seeds: The ecology of regeneration in plant communities. CABI Publishing, Wallingford, UK, pp. 331–359.

Kongsager, R., Napier, J., Mertz, O., 2013. The carbon sequestration potential of tree crop plantations. Mitig Adapt Strat Glob Change 18, 1197–1213.

Kouadio, L., Newlands, N.K., Davidson, A., Zhang, Y., Chipanshi, A., 2014. Assessing the performance of MODIS NDVI and EVI for seasonal crop yield forecasting at the eco-district scale. Remote Sens. 6, 10193–10214.

Kumar, C., Begeladze, S., Calmon, M., Saint-Laurent, C., 2015. Enhancing food security through forest landscape restoration: Lessons from burkina faso, Brazil, Guatemala, Viet Nam, Ghana, ethiopia and the Philippines. International Union for Conservation of Nature, Gland, Switzerland.

Le, D.H., Smith, C., Herbohn, J., Harrison, S., 2012. More than just trees: Assessing reforestation success in tropical developing countries. J. Rural Stud. 28, 5–19. https://doi.org/10.1016/j.jrurstud.2011.07.006.

LeCun, Y., Bengio, Y., Hinton, G., 2015. Deep learning. Nature 521 (7553), 436–444.

Lewis, S.L., Wheeler, C.E., Mitchard, E.T., Koch, A., 2019. Restoring natural forests is the best way to remove atmospheric carbon. Nature 568 (7750), 25–28. https://doi.org/10.1038/d41586-019-01026-8.

Li, A., et al., 2012. Estimating the maximal light use efficiency for different vegetation through the CASA model combined with time-series remote sensing data and ground measurements. Remote Sens. 4 (12), 3857–3876. https://doi.org/10.3390/rs4123857.

Liang, X., Kankare, V., Hyyppä, J., 2016. Terrestrial laser scanning in forest inventories. ISPRS J. Photogrammetry Remote Sens. 115, 63–77. https://doi.org/10.1016/j.isprsjprs.2016.01.006.

Lindenmayer, D.B., Fischer, J., 2006. Habitat fragmentation and landscape change. An ecological and conservation synthesis. CSIRO Publishing, Melbourne, Australia. 344 pp.

Lindenmayer, D.B., Likens, G.E., 2010a. The science and application of ecological monitoring. Biol. Conserv. 143, 1317–1328.

Lindenmayer, D.B., Likens, G.E., 2010b. Improving ecological monitoring. Trends Ecol. Evol. 25, 200–201.

Liu, Z., Peng, C., Timothy, W., Candau, J.-N., Desrochers, A., Kneeshaw, D., 2018. Application of machine-learning methods in forest ecology: Recent progress and future challenges. Environ. Rev. 26. https://doi.org/10.1139/er-2018-0034.

Liu, Q., Fu, L., Chen, Q., Wang, G., Luo, P., Sharma, R.P., He, P., Li, M., Wang, M., Duan, G., 2020. Analysis of the spatial differences in canopy height models from UAV LiDAR and photogrammetry. Remote Sens. 12, 2884. https://doi.org/10.3390/rs12182884.

Loudermilk, E.L., Hiers, J.K., O'Brien, J.J., 2009. Ground-based LiDAR: a novel approach to quantify fine-scale fuelbed characteristics. Int. J. Wildland Fire 18 (6), 676–685. https://doi.org/10.1071/WF07138 [and others].

Luoranen, J., Saksa, T., Lappi, J., 2018. Seedling, planting site and weather factors affecting the success of autumn plantings in Norway spruce and scots pine seedlings. For. Ecol. Manag. 419–420, 79–90. https://doi.org/10.1016/j.foreco.2018.03.040.

Mahamoudou, S., Arakwiye, B., 2020. Improving the monitoring of forest and landscape restoration in Africa. ETFRN NEWS, 60.

Maguya, A.S., Junttila, V., Kauranne, T., 2014. Algorithm for extracting digital terrain models under forest canopy from airborne LiDAR data. Remote Sens. 6, 6524–6548. https://doi.org/10.3390/rs6076524.

Mathieu, A., Cournède, P.H., Barthélémy, D., de Reffye, P., 2008. Rhythms and alternating patterns in plants as emergent properties of a model of interaction between development and functioning. Ann. Bot. 101 (8), 1233–1242. https://doi.org/10.1093/aob/mcm171.

McDonald, T., Gann, G.D., Jonson, J., Dixon, K.W. 2016. International standards for the practice of ecological restoration – including principles and key concepts, Washington, DC: SER.

McDonald-Madden, E., Baxter, P.W.J., Fuller, R.A., Martin, T.G., Game, E.T., Montambault, J., Possingham, H.P., 2010. Monitoring does not always count. Trends Ecol. Evol. 25 (10), 547–550.

Menz, M., Kingsley, D., Hobbs, R., 2013. Hurdles and Opportunities for Landscape-Scale Restoration.Science339,526-527. https://doi.org/10.1126/science.1228334.

Menz, M.H.M., Phillips, R.D., Winfree, R., Kremen, C., Aizen, M.A., Johnson, S.D., Dixon, K.W., 2011. Reconnecting plants and pollinators: Challenges in the restoration of pollination mutualisms. Trends Plant Sci. 16, 4–12.

Monie, K., Florentine, S., Palmer, G., 2013. Recruitment and functionality traits as bioindicators of ecological restoration success in the lurg hills district, victoria, Australia. Ecol. Process. 2.

Montagnoli, A., Fusco, S., Terzaghi, M., Kirshbaum, A., Pflugmacher, D., Cohen, W.B., Scippa, G.S., Chiatante, D., 2015. Estimating forest aboveground biomass by low-density lidar data in mixed broad-leaved forests in the Italia Pre-Alps. For. Ecosyst. 2, 10. https://doi.org/10.1186/s40663-015-0035-6.

Montagnoli, A., Lasserre, B., Terzaghi, M., Byambadorj, S.O., Nyam-Osor, B., Scippa, G.S., Chiatante, D., 2022. Fertilization reduces root architecture plasticity in Ulmus pumila used for afforesting Mongolian semi-arid steppe. Front Plant Sci. 2022 Jul 19, 13, 878299. https://doi.org/10.3389/fpls.2022.878299.

Murcia, C., Aronson, J., Kattan, G.H., Moreno-Mateos, D., Dixon, K., Simberloff, D., 2014. A critique of the 'novel ecosystem' concept. Trends in Ecology and Evolution, 29(10), 548-553. https://doi.org/10.1016/j.tree.2014.07.00.

Mwangi, E., Evans, M., 2018. In: Communities restoring landscapes: Stories of resilience and success. Center for International Forestry Research, Bogor, Indonesia.

Nichols, J.D., Williams, B.K., 2006. Monitoring for conservation. Trends Ecol. Evol. 21, 668–673.

Nilsson, U., Luoranen, J., Kolström, T., Örlander, G., Puttonen, P., 2010. Reforestation with planting in northern Europe. Scand. J. For. Res. 25 (4), 283–294. https://doi.org/10.1080/02827581.2010.498384.

Nyam-Osor, B., Byambadorj, S.-O., Park, B.B., Terzaghi, M., Scippa, G.S., Stanturf, J.A., Chiatante, D., Montagnoli, A., 2021. Root biomass distribution of populus sibirica and Ulmus pumila afforestation stands is affected by watering regimes and fertilization in the Mongolian semi-arid steppe. Front. Plant Sci. 12, 638828. https://doi.org/10.3389/fpls.2021.638828.

Oliver, C.D., Larson, B.C., 1996. Forest Stand Dynamics, Updated Edition 520. John Wiley and Sons, New York.

PikkNew Yorkarainen, L., Luoranen, J., Kilpeläinen, A., Oijala, T., Peltola, H., 2020. Comparison of planting success in one-year-old spring, summer and autumn plantings of Norway spruce and Scots pine under boreal conditions. Silva Fenn. 54 (1), 10243. https://doi.org/10.14214/sf.10243.

Repáč, I., Tučeková, A., Sarvašová, I., Vencurik, J., 2011. Survival and growth of outplanted seedlings of selected tree species on the high Tatra Mts. Windthrow area after the first growing season. J. For. Sci. 57 (8), 349–358. https://doi.org/10.17221/130/2010-JFS.

Reyers, B., O'Farrell, P.J., Nel, J.L. et al., 2012. Expanding the conservation toolbox: conservation planning of multifunctional landscapes. Landscape Ecol 27, 1121–1134. https://doi.org/10.1007/s10980-012-9761-0

Reytar, K., F. Landsberg, F. Stolle, W. Anderson, J. Brandt and M. Matsumoto. 2020. The challenge of tracking how a trillion trees grow. www.wri.org/blog/2020/07/trillion-trees-tracking-challenges.

Rishmawi, K., Huang, C., Zhan, X., 2021. Monitoring key forest structure attributes across the conterminous United States by integrating GEDI LiDAR measurements and VIIRS data. Remote Sens. 13, 442. https://doi.org/10.3390/rs13030442.

Ruiz-Jaén, M.C., Aide, T.M., 2006. An integrated approach for measuring urban forest restoration success. Urban For. Urban Green. 4, 55–68.

Samiei, S., Rasti, P., Ly Vu, J., et al., 2020. Deep learning-based detection of seedling development. Plant Methods 16, 103. https://doi.org/10.1186/s13007-020-00647-9.

Sankaran, S., Khot, L.R., Carter, A.H., 2015. Field-based crop phenotyping: Multispectral aerial imaging for evaluation of winter wheat emergence and spring stand. Comput. Electron. Agric. 118, 372–379.

Shivaprakash, K.N., Swami, N., Mysorekar, S., Arora, R., Gangadharan, A., Vohra, K., Jadeyegowda, M., Kiesecker, J.M., 2022. Potential for artificial intelligence (AI) and machine learning (ML) applications in biodiversity conservation, managing forests, and related services in India. Sustainability 14, 7154. https://doi.org/10.3390/su14127154.

Simberloff, D., Martin, J.L., Genovesi, P., Maris, V., Wardle, D.A,. Aronson, J., Courchamp, F., Galil, B., García-Berthou, E., Pascal, M., Pyšek, P., Sousa, R., Tabacchi, E., Vilà, M., 2013. Impacts of biological invasions: what's what and the way forward. Trends Ecol Evol. 2013 Jan, 28(1), 58-66. https://doi.org/10.1016/j.tree.2012.07.013.

South, D.B., Starkey, T.E., Lyons, A., 2023. Why healthy pine seedlings die after they leave the nursery. Forests 14 (3), 645. https://doi.org/10.3390/f14030645.

Stamatopoulos, I., Le, T.C., Daver, F., 2024. UAV-assisted seeding and monitoring of reforestation sites: a review. Aust. For. 87 (2), 90–98. https://doi.org/10.1080/00049158.2024.2343516.

Stanturf, J.A., Dumroese, R.K., Elliott, S., Ivetić, V., Kleine, M., Lang, M., Löf, M., Madsen, P., Prescott, C., Khokthong, W., Young, T., 2024. Advances in forest restoration management and technology. In: Katila, P., Colfer, C.J.P., Jong, W.d., Galloway, G., Pacheco, P., Winkel, G. (Eds.), Restoring forests and trees for sustainable development - policies, practices, impacts and ways forward. Oxford University Press, Oxford, UK, pp. 299–336. https://doi.org/10.1093/9780197683958.003.0011.

Suding, K., Higgs, E., Palmer, M., Callicott, J.B., Anderson, C.B., Baker, M., Gutrich, J.J., Hondula, K.L., LaFevor, M.C., Larson, B.M., Randall, A., Ruhl, J.B., Schwartz, K.Z., 2015. Committing to ecological restoration. Science. 2015 May 8, 348(6235), 638-640. https://doi.org/10.1126/science.aaa4216.

Sukhbaatar, G., Ganbaatar, B., Jamsran, T., et al., 2020. Assessment of early survival and growth of planted Scots pine (*Pinus sylvestris*) seedlings under extreme continental climate conditions of northern Mongolia. J. For. Res. 31, 13–26. https://doi.org/10.1007/s11676-019-00935-8.

Susskind, L., Camacho, A.E., Schenk, T., 2012. A critical assessment of collaborative adaptive management in practice. J. Appl. Ecol. 49, 47–51.

Szantoi, Z., Brink, A., Buchanan, G., Bastin, L., Lupi, A., Simonetti, D., Mayaux, P., Peedell, S., Davy, J., 2016. A simple remote sensing based information system for monitoring sites of conservation importance. Remote Sens. Ecol. Conserv. 2, 16–24. https://doi.org/10.1002/rse2.14.

Thomas, E., Jalonen, R., Loo, J., Bozzano, M., 2015. Avoiding failure in forest restoration: The importance of genetically diverse and site-matched germplasm. Unasylva 66, 29.

Turner, I.L., Harley, M.D., Drummond, C.D., 2016. UAVs for coastal surveying: Coastal Engineering, v. 114, p. 19-24, https://doi.org/10.1016/j.coastaleng.2016.03.011.

Vadell, E., de-Miguel, S., Pemán, J., 2016. Large-scale reforestation and afforestation policy in Spain: A historical review of its underlying ecological, socioeconomic and political dynamics. Land Use Policy 55, 37–48. https://doi.org/10.1016/j.landusepol.2016.03.017.

van Leeuwen, M., Nieuwenhuis M., 2010. Retrieval of Forest Structural Parameters using LiDAR Remote Sensing. European Journal of Forest Research 129(4): 749–770. https://doi.org/10.1007/s10342-010-0381-4

Viani, R.A.G., Barreto, T.E., Farah, F.T., Rodrigues, R.R., Brancalion, P.H.S., 2018. Monitoring young tropical forest restoration sites: How much to measure? Trop. Conserv. Sci. 7.

White, K., Pontius, J., Schaberg, P., 2014. Remote sensing of spring phenology in northeastern forests: a comparison of methods, field metrics and sources of uncertainty. Remote Sens. Environ. 148, 97–107.

WRI, 2019. Forest landscape restoration is more than planting trees: 3 Case studies from the western US. Available online: https://www.wri.org/blog/2015/07/forest-landscape-restoration-more-planting-trees-3-case-studies-western-us.

Yi, M., Yang, H., Yang, S., Wand, J., 2022. Overexpression of SHORT-ROOT2 transcription factor enhanced the outgrowth of mature auxiliary buds in poplar trees. J. Exp. Bot. 73 (8), 2469–2486. https://doi.org/10.1093/jxb/erac040.

Zhao, B., Zhang, J., Yang, C., Zhou, G., Ding, Y., Shi, Y., Zhang, D., Xie, J., Liao, Q., 2018. Rapeseed seedling stand counting and seeding performance evaluation at two early growth stages based on unmanned aerial vehicle imagery. Front. Plant Sci. 9, 1362.