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How can my research paper be useful for future meta-analyses on forest restoration plantations?

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Abstract   Statistical meta-analysis is a powerful and useful tool to quantitatively synthe-size the information conveyed in published studies on a particular topic. It allows identify-ing and quantifying overall patterns and exploring causes of variation. The inclusion of published works in meta-analyses requires, however, a minimum quality standard of the reported data and information on the methodology used. Our experience with conducting a meta-analysis on the relationship between seedling quality and field performance is that nearly one third of the apparently relevant publications had to be discarded because essen-tial data, usually statistical dispersion parameters, were not properly reported. In addition, we encountered substantial difficulty to explore the effect of covariates due to the poor description of nursery cultivation methods, plantation location, and management in a sig-nificant proportion of the selected primary studies. Thus, we present guidelines for improv-ing methodology detail and data presentation so that future forest restoration-oriented research can be more readily incorporated into meta-analyses. In general, research studies should report data on means, sample size, and any measure of variation even if they are not statistically significant. The online availability of raw data is the best practice to facili-tate the inclusion of primary research on meta-analyses. Providing full information about the production of nursery seedlings, such as plant material and experimental conditions, is essential to test whether these procedures might have an effect on seedling quality. In addition, detailed information about field trials such as site climate, soil preparation tech-niques, previous land use, or post-plantation management, is needed to elucidate whether seedling quality is context-dependent. Thus, we provide a detailed checklist of important

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information that should be included when reporting forest restoration research involving the use of nursery-produced seedlings. All this will help to quantitatively synthetize current state-of-knowledge and thus contribute to the advancement of the forest restoration discipline.

Introduction

More than 2 billion hectares of our planet are in need of forest restoration (Minnemeyer et al. 2011). Outplanting seedlings will play a major role in this restoration effort (Stanturf et al. 2014). In addition, future restoration activities will be necessarily focused on harsh sites (Oliet and Jacobs 2012). While defining the appropriate seedling stocktype to meet these needs can be achieved through a variety of methods, including the Target Plant Concept (Dumroese et al. 2016), an understanding of the interplay of nursery production techniques and factors influencing outplanting sites is necessary to ensure forest restoration is most effective. Crucial to this understanding, and subsequent success is seedling quality, an often overlooked factor in many studies. A quality seedling has high potential to survive and grow adequately after outplanting under particular environmental conditions (Duryea 1984), and reflects the integration of multiple physiological and morphological attributes (Ritchie 1984) that drive the seedling's ability to become established (Grossnickle 2012).

Since early in the twentieth century forest researchers and practitioners have been intrigued by the plant attributes that affect seedling performance after outplanting. Starting with the pioneering work of Wakeley (1954) initiated in the 1930s on the effect of seedling morphological attributes on outplanting performance, a vast number of studies assessing seedling quality attributes have been published. These studies have covered a wide range of species and forest ecosystems, and numerous morpho-physiological attributes (Duryea 1985) determined by different nursery cultivation practices. Despite several qualitative reviews on seedling quality have been published (Ritchie and Dunlap 1980; Ritchie 1984; Duryea 1985; Wilson and Jacobs 2006; Grossnickle 2012, 2017; Grossnickle and El-Kassaby 2015), to the best of our knowledge, this discipline lacks any quantitative review. This is unfortunate because several topics on seedling quality and forest plantations are controversial, such as the relationship between outplanting survival and seedling size (Trubat et al. 2008; Villar-Salvador et al. 2012). In addition, these processes are likely the result of the interactions of several factors, such as species, stocktype, and local climate that limit the capacity of qualitative reviews to describe general trends. Therefore, quantitative reviews based on statistical approaches are needed to increase our ability to synthetize and generalize the vast amount of knowledge on the interaction of seedling quality and outplanting site characteristics accumulated during the past 70 years. This is pivotal to guide new forest restoration research and to provide decision-makers with evidence-based support (Stewart 2010).

Meta-analysis is a powerful, informative, and unbiased tool to quantitatively summarize evidence for a particular research question (Koricheva and Gurevitch 2014). This technique integrates several statistical methods for combining results from independent, primary studies in order to identify general patterns and to evaluate factors that may cause heterogeneity in outcomes among studies (Koricheva et al. 2013). Therefore, the application

of meta-analysis techniques to the wealth of studies on seedling quality and outplanting performance may help untangle the contradictory results in this topic, such as the above-mentioned relationship between seedling morphological attributes and their post-planting survival (Grossnickle 2012), and thus contribute to the advancement of the forest restoration discipline. The inclusion of primary studies on meta-analysis strongly relies, however, on the appropriate reporting of data and an exhaustive description of the methodology used, study characteristics, and location (Hillebrand and Gurevitch 2013; Gerstner et al. 2017). In this regard, the establishment of high quality standards in reporting results and methodology of published studies would increase the soundness and quality of future meta-analyses.

In this article, we present a specific checklist and guidelines for reporting methodologies, data, and statistical results in forest restoration research involving the use of nursery-produced seedlings. The motivation for this article arises from our experience in conducting a meta-analysis on seedling quality to assess if an overall effect, whether positive or negative, exists between seedling size at outplanting and their survival. Following existing protocols for searching relevant literature (Côté et al. 2013) and after establishing restrictive inclusion criteria, we identified 306 studies for further evaluation. Of these, 94 were discarded because essential statistical data required for the meta-analysis were not reported (mostly measurements of statistical dispersion and sample size). While an assumption may be that missing data should be expected more in the grey literature, 75% of the studies discarded for this reason were published in peer-reviewed journals. In addition, only about half of the 306 studies provided basic information, such as field location, site preparation techniques, post-planting management, or previous land use, which hampers evaluating the influence of these factors on the survival-seedling size relationship.

Researchers are increasingly aware of the importance of reporting metadata in primary studies. Some protocols for reporting data and methodologies have been published during the last few years in other disciplines, such as ecology, evolutionary biology, and medicine (Hillebrand and Gurevitch 2013; Zuur and Ieno 2016; Goodman et al. 2016; Nakagawa et al. 2017). More recently, Gerstner et al. (2017) proposed updated guidelines along with a specific example of proper data reporting for ecological studies. It seems, therefore, appropriate to adapt existing protocols for high-quality publication standards to specific disciplines in order to improve the relevance of future meta-analysis on these topics. While this is our main objective here, we also aim to provide guidelines for improving the impact of seedling quality research, and how it impacts reforestation success, that will be published in the future.

A brief description of the basis of meta-analyses

Meta-analysis was originally developed for social sciences and medicine and since the 1990s has also been used for ecological studies (e.g. Nakagawa and Cuthill 2007; Stewart 2010; Nakagawa and Santos 2012; Koricheva et al. 2013); this recent work provides an up-to-date guide to conducting meta-analyses.

The first step in a meta-analysis consists of a systematic search of the literature in the target topic, based on the combination of relevant keywords and the use of electronic search engines and databases (Côté et al. 2013). The primary databases usually used in biological sciences are Web of Science, SCOPUS, and Google Scholar, yet relevant studies are often published in other traditional distribution channels constituting the so-called

"grey literature". This is an especially significant source of seedling quality and forest restoration research, where a substantial number of studies are published in local journals, conference proceedings, and technical reports. In this regard, specific initiatives such as the Reforestation, Nurseries, and Genetic Resources database (USDA Forest Service and Southern Regional Extension Forestry; https://rngr.net) are extremely useful in reaching grey literature. To ensure work is found in any systematic search, researchers must carefully choose the appropriate keywords, and write an informative title and abstract. The same applies to grey literature even if the strict scientific quality and visibility rules used in formal scientific literature are not enforced.
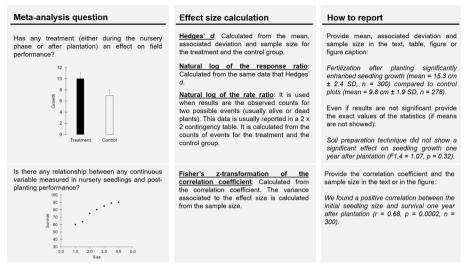
Once relevant studies have been identified, the second step is data extraction and its incorporation into a database. The critical information extracted is an estimate of the magnitude and direction of the outcome of the study. The outcomes of the selected studies must be then expressed on a common and comparable scale, known as effect sizes (Rosenberg et al. 2013). It is also necessary to know from each study the precision associated with the estimation of the effect (e.g. variance, standard error, or confidence interval). This estimation of the precision is used to weigh the contribution of the effect of a study to the overall effect, which is estimated together with a confidence interval. Then, we can evaluate whether the overall effect is significantly different from zero (significant effect) or test if any covariate might explain heterogeneity in the outcomes among studies.

"Effect size thinking" when reporting results

Recently, Parker et al. (2016) reported that about half of published articles lack key information about statistical results, which severely constrains the utility of primary research for meta-analysis. It is therefore imperative to make scientists aware of an "effect size thinking" when reporting data in research studies (Nakagawa and Cuthill 2007). In this context, a clear understanding of the different effect size metrics and their calculation would greatly help to increase the relevance of primary research for meta-analysis.

In general, research studies should report data on means, sample size, and any measure of variation (Fig. 1), which must be clearly identified in the text or in figures and table captions (e.g. standard error, standard deviation, or 95% confidence interval). In addition, any hierarchical design or data aggregation should be clearly explained (Gerstner et al. 2017). This is of special relevance in seedling quality and forest restoration research because field plantations are often conducted in blocks or plant attributes are usually measured in groups of plants (i.e. composite samples for nutrient analysis). Moreover, researchers often publish only a portion of the results derived from data analysis. This leads to publication bias, especially when only significant results are reported in papers (known as *p*-hacking). Ignoring weak or absent patterns when reporting data might, however, limit our capacity to estimate unbiased overall effects in meta-analysis (Parker et al. 2016). Nowadays, authors have no reason to report only strong or significant relationships because journals allow the incorporation of unlimited pages as electronic supplementary material. In this regard, the inclusion of results in table format as supplementary material and the online availability of raw data, either in the journal website or in global repositories (e.g. Dryad), will contribute to reduce the number of papers discarded because of absent data, to speed the data extraction process, and to improve their accuracy.

The most useful effect sizes for meta-analyses on seedling quality are standardized mean differences, response ratios, odds ratios, and correlation coefficients (Fig. 1) (Rosenberg

Meta-analysis question	Effect size calculation	How to report
Has any treatment (either during the nursery phase or after plantation) an effect on field performance?	**Hedges' *d***: Calculated from the mean, associated deviation and sample size for the treatment and the control group.	Provide mean, associated deviation and sample size in the text, table, figure or figure caption:
	Natural log of the response ratio: Calculated from the same data that Hedges' *d*.	*Fertilization after planting significantly enhanced seedling growth (mean = 15.3 cm ± 2.4 SD, n = 300) compared to control plots (mean = 9.8 cm ±1.9 SD, n = 278).*
	Natural log of the rate ratio: It is used when results are the observed counts for two possible events (usually alive or dead plants). This data is usually reported in a 2 x 2 contingency table. It is calculated from the counts of events for the treatment and the control group.	Even if results are not significant provide the exact values of the statistics (if means are not showed): *Soil preparation technique did not show a significant effect on seedling growth one year after plantation (F1,4 = 1.07, p = 0.32).*
Is there any relationship between any continuous variable measured in nursery seedlings and post-planting performance?	**Fisher's z-transformation of the correlation coefficient**: Calculated from the correlation coefficient. The variance associated to the effect size is calculated from the sample size.	Provide the correlation coefficient and the sample size in the text or in the figure: *We found a positive correlation between the initial seedling size and survival one year after plantation (r = 0.68, p = 0.0002, n = 300).*

Fig. 1 Examples of questions on seedling quality research that can be addressed through meta-analysis (left column). The centre column contains information regarding the effect size used for each type of meta-analysis (rows), and the right column provides examples of proper reporting of data in primary studies for both examples

et al. 2013). Standardized mean differences and response ratios are used to compare mean values of two groups that often represent an experimental treatment and a control (Fig. 1). This is the case, for example, when testing whether a nursery (e.g. fertilization) or field management technique (e.g. ripping) improve seedling field performance. The most common and appropriate metrics for comparing pairs of means are Hedges' *d* and the natural log of the response ratio (Rosenberg et al. 2013). If two groups are compared for binary response variables (e.g. alive *vs* dead) based on a contingency table, the most widely used effect size is the odds ratio. The Pearson's correlation coefficient is the appropriate effect size when the aim is the relationship between two continuous variables (Fig. 1) (e.g. the effect of seedling morphology at outplanting on the field performance). As the distribution of the Pearson's correlation coefficient becomes skewed when it approaches $\pm$ 1, the Fisher's *z*-transformation is used to obtain an effect size with desirable statistical properties. The variance associated to a correlation coefficient is calculated from the sample size, thus it should be always provided when reporting correlation coefficients. One of the advantages of using the Pearson's correlation coefficient as effect size is that it can be calculated from a wide array of other statistics (Lajeunesse 2013), such as Student's *t*, *F*-ratio, χ^2, or Spearman's correlation coefficient among others. An alternative to the exclusion of studies with missing data is the use of imputation methods (Pigott 1994). These methods allow estimating the effect sizes and variances (see Lajeunesse 2013 for an overview) and can contribute to increase the representation of data for meta-analysis.

Reporting metadata in research papers

Meta-analysis not only serves to calculate an overall effect, but also to explore the cause of variation in the magnitude of the outcomes by examining the effect of covariates

(moderators) (Koricheva and Gurevitch 2014). For instance, it might be relevant to assess how precipitation on plantation sites influences the effect of field fertilization on seedling growth. Thus, a detailed description of experimental methods, study design, and study area is crucial to evaluate causes of heterogeneity in the outcomes of primary studies. Despite this seeming obvious, our experience in conducting a seedling quality meta-analysis revealed that many research studies do not include a full description of this basic, above-mentioned information. For example, we found that about half of the studies we finally selected lacked exact geographical coordinates of the plantation site, which is essential for accessing climatic data when they are not provided. Gathering such missing data for a meta-analysis is a time-consuming task that sometimes involves contacting authors, which we found is not always successful. Here we propose a checklist of relevant information about seedling production and outplanting that we believe should be included in the materials and methods of any forest restoration study, especially the effects of seedling quality, in order to make it valuable to future meta-analyses (Table 1).

Information about seedling production in the nursery

Nursery production techniques strongly influence seedling quality (Landis 1989; Dumroese et al. 2008). Providing full information about all steps involved in the production of nursery seedlings is essential to test whether these procedures might have an effect on seedling quality (Table 1). The first thing to describe in detail is the plant material. The species

Table 1 Checklist of the information to be included in the description of the nursery phase in forest restoration studies involving the plantation of seedlings

Reporting information	
Seedling production in the nursery	
Plant material	Species name
	Seed origin (including provenance, site of collection and other relevant information about seed collection)
Seed handling	Seed storage
	Seed selection protocol
	Germination conditions
Seedling growing conditions	Nursery location (coordinates)
	Cultivation density
	Physicochemical characteristics of nursery soil or growing media
	Spatial configuration (blocks)
	Seeding date
	Stocktype notation (e.g. $1 + 0$, $2 + 1$)
	Transplantation date to other seedbeds (bareroot)
	Container type and size
Nursery treatments	Light levels
	Fertilization levels (including type of fertilization, fertilizer formulation, frequency of application and total amount of N, P, K)
	Watering levels (including frequency and total amount supplied)
Other factors	Shoot and root pruning
	Use of growth regulators
	Mycorrhizae inoculation
	Cold storage

name should be from a widely accepted and available taxonomic list, such as *the plant list* (http://www.theplantlist.org/), otherwise it can be difficult to match studies using the same species. The origin of seeds should be described in detail, including the provenance(s) and, if available, collection information such as location, date, and number of mother trees. Seed storage, seed selection protocols, and/or conditions and techniques used for germination are also important procedures to be reported.

Once plant material has been correctly described, ensure a full description of experimental and seedling growing conditions is provided (Table 1). Geographical coordinates of the nursery and the cultivation period will be useful to determine climatic conditions (when not reported) under which seedlings were grown when cultivation is outdoors, as this might influence the seedling quality and post-planting performance (Mollá et al. 2006). The information to be included in the description of seedling growing conditions in the nursery will depend on the planting stock raised. On one hand, bareroot and container seedlings are the two basic stocktypes in forest nurseries with important implications for seedling quality attributes (Grossnickle and El-Kassaby 2015). On the other hand, these two basic stocktypes can be produced in a variety of ways, so specific techniques should be reported in the methodology section. For example, bareroot seedlings can be produced under different cultivation densities in one or various seedbeds (Hahn 1984; Thompson 1984). Thus, for bareroot seedlings stocktype age notation together with the exact dates of seeding and transplantation, as well as the cultivation density during each stage of production should be reported. Container seedlings can be grown in a wide variety of container types differing in volume and density (Dominguez-Lerena et al. 2006). Therefore, information on container density, volume, and dimensions (width, length, and depth) should be provided. This is particularly important for stocktype trials to ensure that confounding of independent factors is not an issue (Pinto et al. 2011). In addition, the spatial configuration of containers in the nursery (blocks), and the physico-chemical characteristics of growing media used for filling containers must also be detailed (type of substrate, pH, nutrient content).

Irrespective of the stocktype, studies should contain information about the environmental conditions under which seedlings were grown (Table 1). Specifically, light level (especially if shaded), watering, and fertilization regime. These cultivation factors, together with container volume and cultivation density strongly influence seedling morpho-physiological attributes and consequently outplanting performance (Van den Driessche 1982; Villar-Salvador et al. 2004; Dumroese et al. 2005; Dominguez-Lerena et al. 2006; Puértolas et al. 2009; Andivia et al. 2014). Therefore, nursery cultivation treatments and procedures should be thoroughly described. For example, works testing different fertilization treatments should report information about the complete fertilization formulation, concentration, application frequency, and schedule (e.g. constant, exponential, late-season fertilization), and the total amount of nitrogen (N), phosphorous (P) and potassium (K) applied to each seedling during the cultivation. Irrigation and fertilization, when not independent variables, should be applied to avoid confounding (Dumroese et al. 2011, 2015). In addition, other common cultivation procedures applied during the nursery phase, such as seeding date, shoot and root pruning, use of growth regulators, mycorrhizae inoculation, or cold storage should also be reported.

Information about field plantation and management

Field trials are crucial for validating the suitability of nursery treatments and the identification of the seedling functional attributes that predict outplanting performance. Seedling quality interacts with plantation practices and site conditions to determine the success of a

forest restoration program. In this context, the use of covariates related to site climate, soil preparation techniques, previous land use, or post-plantation management as moderators in meta-analyses is important for understanding if controversial issues on seedling quality are context-dependent (Table 2). This information is, however, not always available in research studies on seedling quality, in part because some plantation techniques and management strategies are so entrenched among forest practitioners that they are assumed and therefore go unreported in many research studies.

A detailed field site description is essential in any experimental and observational study. In the context of quantitative reviews, field site information can be used as covariates or to group primary studies (Table 2). Climate is a primary determinant of plantation performance (Squeo et al. 2007). The inclusion of the exact geographical coordinates is of great help to access mapped climate information, such as in the WorldClim database, but also to evaluate if a geographical bias exists in the selection of primary studies or in their outcomes. Even if the exact geographical location is included in the study, it is also helpful to provide climate data from local weather stations that might cover the specific conditions at the plantation site, and especially during the period evaluated. Beside climatic data, other information related to elevation, soil, slope (including aspect), or vegetation and presence of herbivores that might affect the plantation outcome would provide a detailed picture of the environmental context in which the plantation is conducted. Previous land-use (cropland or woodland) or degradation history in the area might also help to interpret results of individual primary studies or to use this information as moderators in the meta-analysis.

Site preparation and plantation techniques determine forest plantation success (South et al. 2001; Palacios et al. 2009). These field techniques aim to improve soil conditions for improving water infiltration and rooting, controlling competing vegetation, and reducing animal damage, among others (Archibold et al. 2000; South et al. 2001; Querejeta et al. 2001). Main soil preparation techniques include mechanical site preparation, prescribing burning,

Table 2 Checklist of the information to be included in the description of the field plantation in forest restoration studies

Reporting information	
Plantation and management	
Site description	Exact location (coordinates)
	Climatic conditions
	Soil conditions
	Elevation
	Slope and orientation
	Vegetation and herbivores in the area
	Previous land use
Site preparation and plantation	Site preparation technique (including brief description of the intensity and the machinery)
	Planting technique (hand or machine)
	Planting date
	Planting density
	Planting depth
	Spatial design
	Use and description of tube shelters
Plantation management	Weeding (including frequency, intensity, timing, and method)
	Fertilization and irrigation (including frequency, timing, and total amount)
	Other activities such as replanting, pruning, or thinning

mulching, and the use of herbicides (Löf et al. 2012). A correct description of the techniques implemented before outplanting seedlings would enable the grouping of studies for meta-analysis or to facilitate further meta-analysis in this topic (Table 2). Among aforementioned soil preparation techniques, mechanical site preparation is the most widely used in forest plantations. Mechanical site preparation involves, however, a wide range of different techniques, intensities, and machinery, which makes it difficult to group studies according to this covariate if detailed descriptions are not reported. Recently, Löf et al. (2012) reviewed the state-of-knowledge concerning the use of mechanical site preparation in forest restoration projects and grouped techniques into three main categories: scarification, mounding, and sub-soiling/ripping. Other techniques, not included in this classification, like mowing, drum chopping, blading, and piling can be considered as low intensity interventions, whereas deep plowing and terracing can be considered as very high intensity interventions.

Date of outplanting should also be included in the plantation description because it affects seedling outplanting performance, especially in cold and arid environments (Radoglou and Raftoyannis 2002; Palacios et al. 2009; Yang et al. 2013). Providing the exact date of plantation and first field evaluation of seedling performance makes it possible to assess the effect of climatic conditions in a meta-analysis. Planting density and planting depth should be included because they have implications for seedling performance (Hainds 2004; Zhao et al. 2011; Oliet et al. 2012). Information about how the seedlings were outplanted (e.g. hand or machine) and if confounding techniques were avoided (Pinto et al. 2011) is also essential. Moreover, the spatial design of the plantation field, and any obvious plot heterogeneity (e.g. different slope orientations) must be described. The date at which performance measurements were conducted is important to know exactly the period under evaluation. Finally, the use of ecotechnologies, such as tree shelters, organic amendments, mulching, and hydrogels (Piñeiro et al. 2013) should be described in detail. Specifically, tree shelters should be fully described because their size, ventilation, and light transmission have an influence on seedling survival and growth (McCreary and Tecklin 2001; Vázquez de Castro et al. 2014).

Once seedlings are outplanted, several management and maintenance activities can be conducted that strongly impact their performance. Weeding is a widespread maintenance activity in forest plantations but can vary with site environmental conditions, planting density, and the species of weeds and outplanted seedlings (Gómez-Aparicio 2009; Kabrick et al. 2015). Thus, weeding information regarding intensity, frequency, timing, and method should be included. Fertilization and irrigation can be done at outplanting and/or after the start of the plantation (Rey-Benayas 1998; Casselman et al. 2006). In both cases information should include when the practice was initiated, subsequent frequency, and the total amount applied per plant. For fertilization practices, the type and formulation of the fertilizer should be provided. Other maintenance and management activities, such as replanting, pruning, or thinning should also be informed.

Conclusions

Here we provide general and specific recommendations for a comprehensive reporting of methodologies, data, and statistical results in seedling quality and forest restoration research. Following these guidelines when writing a manuscript will not only facilitate the work of researchers involved in meta-analyses but also will increase the options for a primary study to be included in these reviews. Thus, including this information should be seen by authors as an opportunity to increase the visibility, scope, relevance, and pragmatic usefulness of their studies. Independently of whether a study is included in a meta-analyses,

these recommendations are good practices for research reliability and confidence. For example, these guidelines can be used as a checklist to follow during the writing of the material and method section in any forest restoration study.

The identification of relevant studies and the comprehensive reporting of data and methods are critical steps in the elaboration of a meta-analysis. Increasing the detail of methodology and data (including metadata) accessibility will promote the quality and value of subsequent reviews. In conclusion, the establishment of quality standards and guidelines for data and method reporting in published studies on seedling quality and outplanting performance will ensure the greatest number of studies will be included in any meta-analysis. This will better answer fundamental questions important to any phase of the forest restoration chain.

References

Andivia E, Fernández M, Vázquez-Piqué J (2014) Assessing the effect of late-season fertilization on Holm oak plant quality: insights from morpho-nutritional characterizations and water relations parameters. New For 45:149–163. https://doi.org/10.1007/s11056-013-9397-1

Archibold OW, Acton C, Ripley EA (2000) Effect of site preparation on soil properties and vegetation cover, and the growth and survival of white spruce (*Picea glauca*) seedlings, in Saskatchewan. For Ecol Manag 131:127–141. https://doi.org/10.1016/S0378-1127(99)00205-4

Casselman CN, Fox TR, Burger JA et al (2006) Effects of silvicultural treatments on survival and growth of trees planted on reclaimed mine lands in the Appalachians. For Ecol Manag 223:403–414

Côté IM, Curtis PS, Rothstein HR, Stewart GB (2013) Gathering data: searching literature and selection criteria. In: Koricheva J, Gurevitch J, Mengersen K (eds) Handbook of meta-analysis in ecology and evolution, Princeton, pp 37–51

Dominguez-Lerena S, Herrero Sierra N, Carrasco Manzano I et al (2006) Container characteristics influence *Pinus pinea* seedling development in the nursery and field. For Ecol Manag 221:63–71. https://doi.org/10.1016/j.foreco.2005.08.031

Dumroese RK, Page-Dumroese DS, Salifu KF, Jacobs DF (2005) Exponential fertilization of *Pinus monticola* seedlings: nutrient uptake efficiency, leaching fractions, and early outplanting performance. Can J For Res 35:2961–2967. https://doi.org/10.1139/x05-226

Dumroese RK, Luna T, Landis TD (2008) Nursery manual for native plants: a guide for tribal nurseries. Agriculture Handbook 730, US Department of Agriculture, Forest Service, Washington, DC

Dumroese RK, Page-Dumroese DS, Brown RE (2011) Allometry, nitrogen status, and carbon stable isotope composition of Pinus ponderosa seedlings in two growing media with contrasting nursery irrigation regimes. Can J For Res 41:1091–1101

Dumroese RK, Montville ME, Pinto JR (2015) Using container weights to determine irrigation needs: a simple method. Native Plants J 16:67–71

Dumroese KR, Landis TD, Pinto JR et al (2016) Meeting forest restoration challenges: using the target plant concept. Reforesta 1:37–52

Duryea ML (1984) Nursery cultural practices: impacts on seedling quality. In: Duryea ML, Landis TD, Perry CR (eds) Forestry nursery manual: production of bareroot seedlings. Springer, Dordrecht, pp 143–164

Duryea ML (ed) (1985) Evaluating seedling quality: principles, procedures, and predictive abilities of major tests. Forest Research Laboratory, Oregon State University, Corvallis

Gerstner K, Moreno-Mateos D, Gurevitch J et al (2017) Will your paper be used in a meta-analysis? Make the reach of your research broader and longer lasting. Methods Ecol Evol 8:777–784. https://doi.org/10.1111/2041-210X.12758

Gómez-Aparicio L (2009) The role of plant interactions in the restoration of degraded ecosystems: ameta-analysis across life-forms and ecosystems. J Ecol 97:1202–1214. https://doi.org/10.1111/j.1365-2745.2009.01573.x

Goodman SN, Fanelli D, Ioannidis JPA (2016) What does research reproducibility mean? Sci Transl Med 8:341ps12. https://doi.org/10.1126/scitranslmed.aaf5027

Grossnickle SC (2012) Why seedlings survive: influence of plant attributes. New For 43:711–738. https://doi.org/10.1007/s11056-012-9336-6

Grossnickle SC (2017) Why seedlings grow: influence of plant attributes. New For. https://doi.org/10.1007/s11056-017-9606-4

Grossnickle SC, El-Kassaby YA (2015) Bareroot versus container stocktypes: a performance comparison. New For. https://doi.org/10.1007/s11056-015-9476-6

Hahn P (1984) Plug + 1 seedling production. In: Duryea ML, Landis TD, Perry CR (eds) Forest nursery manual: production of bareroot seedlings. Springer, Dordrecht, pp 165–181

Hainds MJ (2004) Determining the correct planting depth for container-grown longleaf pine seedlings. Gen Tech Rep SRS–71, US Department of Agriculture, Forest Service, South Res Sta, Asheville NC, pp 317–318

Hillebrand H, Gurevitch J (2013) Reporting standards in experimental studies. Ecol Lett 16:1419–1420. https://doi.org/10.1111/ele.12190

Kabrick JM, Knapp BO, Dey DC, Larsen DR (2015) Effect of initial seedling size, understory competition, and overstory density on the survival and growth of *Pinus echinata* seedlings underplanted in hardwood forests for restoration. New For. https://doi.org/10.1007/s11056-015-9487-3

Koricheva J, Gurevitch J (2014) Uses and misuses of meta-analysis in plant ecology. J Ecol 102:828–844. https://doi.org/10.1111/1365-2745.12224

Koricheva J, Gurevitch J, Mengersen K (eds) (2013) Handbook of meta-analysis in ecology and evolution. Princeton University Press, Princeton

Lajeunesse MJ (2013) Recovering missing or partial data from studies: a survey of conversions and imputations for meta-analysis. In: Koricheva J, Gurevitch J, Mengersen K (eds) Handbook of meta-analysis in ecology and evolution, Princeton, pp 195–206

Landis TD (1989) Mineral nutrients and fertilization. In: Landis TD, Tinus RW, McDonald SE, Barnett JP (eds) The container tree nursery manual, vol 4, seedling nutrition and irrigation. US Department of Agriculture, Forest Service, Washington, pp 1–67

Löf M, Dey DC, Navarro RM, Jacobs DF (2012) Mechanical site preparation for forest restoration. New For 43:825–848. https://doi.org/10.1007/s11056-012-9332-x

McCreary DD, Tecklin J (2001) The effects of different sizes of tree shelters on blue oak (*Quercus douglasii*) growth. West J Appl For 16:153–158

Minnemeyer S, Laestadius L, Sizer N et al (2011) A world of opportunity. World Resource Institute, Washington

Mollá S, Villar-Salvador P, García-Fayos P, Peñuelas Rubira JL (2006) Physiological and transplanting performance of *Quercus ilex* L. (holm oak) seedlings grown in nurseries with different winter conditions. For Ecol Manage 237:218–226. https://doi.org/10.1016/j.foreco.2006.09.047

Nakagawa S, Cuthill IC (2007) Effect size, confidence interval and statistical significance: a practical guide for biologists. Biol Rev 82:591–605. https://doi.org/10.1111/j.1469-185X.2007.00027.x

Nakagawa S, Santos ESA (2012) Methodological issues and advances in biological meta-analysis. Evol Ecol 26:1253–1274. https://doi.org/10.1007/s10682-012-9555-5

Nakagawa S, Noble DWA, Senior AM, Lagisz M (2017) Meta-evaluation of meta-analysis: ten appraisal questions for biologists. BMC Biol 15:18. https://doi.org/10.1186/s12915-017-0357-7

Oliet JA, Jacobs DF (2012) Restoring forests: advances in techniques and theory. New For 43:535–541

Oliet JA, Artero F, Cuadros S et al (2012) Deep planting with shelters improves performance of different stocktype sizes under arid Mediterranean conditions. New For 43:925–939. https://doi.org/10.1007/s11056-012-9345-5

Palacios G, Navarro Cerrillo RM, del Campo A, Toral M (2009) Site preparation, stock quality and planting date effect on early establishment of Holm oak (*Quercus ilex* L.) seedlings. Ecol Eng 35:38–46. https://doi.org/10.1016/j.ecoleng.2008.09.006

Parker TH, Forstmeier W, Koricheva J et al (2016) Transparency in ecology and evolution: real problems, real solutions. Trends Ecol Evol 31:711–719. https://doi.org/10.1016/j.tree.2016.07.002

Pigott TD (1994) Methods for handling missing data in research synthesis. The handbook of research synthesis. Russell Sage Foundation, New York, pp 163–175

Piñeiro J, Maestre FT, Bartolomé L, Valdecantos A (2013) Ecotechnology as a tool for restoring degraded drylands: ameta-analysis of field experiments. Ecol Eng 61:133–144. https://doi.org/10.1016/j.ecoleng.2013.09.066

Pinto JR, Dumroese RK, Davis AS, Landis TD (2011) Conducting seedling stocktype trials: a new approach to an old question. J For 109:293–299

Puértolas J, Benito LF, Peñuelas JL (2009) Effects of nursery shading on seedling quality and post-planting performance in two Mediterranean species with contrasting shade tolerance. New For 38:295–308. https://doi.org/10.1007/s11056-009-9148-5

Querejeta JI, Roldán A, Albaladejo J, Castillo V (2001) Soil water availability improved by site preparation in a *Pinus halepensis* afforestation under semiarid climate. For Ecol Manag 149:115–128. https://doi.org/10.1016/S0378-1127(00)00549-1

Radoglou K, Raftoyannis Y (2002) The impact of storage, desiccation and planting date on seedling quality and survival of woody plant species. Forestry 75:179–190. https://doi.org/10.1093/forestry/75.2.179

Rey-Benayas JM (1998) Growth and survival in *Quercus ilex* L. seedlings after irrigation and artificial shading on Mediterranean set-aside agricultural land. Ann For Sci 55:801–807

Ritchie GA (1984) Assessing seedling quality. In: Duryea ML, Landis TD, Perry CR (eds) Forestry nursery manual: production of bareroot seedlings. Springer, Dordrecht, pp 243–259

Ritchie GA, Dunlap JR (1980) Root growth potential: its development and expression in forest tree seedlings. NZJ For Sci 10:218–248

Rosenberg MS, Rothstein HR, Gurevitch J (2013) Effect sizes: conventional choices and calculations. In: Koricheva J, Gurevitch J, Mengersen K (eds) Handbook of meta-analysis in ecology and evolution, Princeton, pp 61–71

South DB, Rose RW, Mcnabb KL (2001) Nursery and site preparation interaction research in the United States. New For 22:43–58. https://doi.org/10.1023/A:1012079014625

Squeo FA, Holmgren M, Jiménez M et al (2007) Tree establishment along an ENSO experimental gradient in the Atacama desert. J Veg Sci 18:195–202

Stanturf JA, Palik BJ, Dumroese RK (2014) Contemporary forest restoration: a review emphasizing function. For Ecol Manag 331:292–323

Stewart G (2010) Meta-analysis in applied ecology. Biol Lett 6:78. https://doi.org/10.1098/rsbl.2009.0546

Thompson B (1984) Establishing a vigorous nursery crop: bed preparation, seed sowing, and early seedling growth. In: Duryea ML, Landis TD, Perry CR (eds) Forest nursery manual: production of bareroot seedlings. Springer, Dordrecht, pp 41–49

Trubat R, Cortina J, Vilagrosa A (2008) Short-term nitrogen deprivation increases field performance in nursery seedlings of Mediterranean woody species. J Arid Environ 72:879–890. https://doi.org/10.1016/j.jaridenv.2007.11.005

van den Driessche R (1982) Relationship between spacing and nitrogen fertilization of seedlings in the nursery seedling size and out planting performance. Can J For Res 12:865–875

Vázquez de Castro A, Oliet JA, Puértolas J, Jacobs DF (2014) Light transmissivity of tube shelters affects root growth and biomass allocation of *Quercus ilex* L. and *Pinus halepensis* Mill. Ann For Sci 71:91–99. https://doi.org/10.1007/s13595-013-0335-3

Villar-Salvador P, Planelles R, Oliet J et al (2004) Drought tolerance and transplanting performance of holm oak (*Quercus ilex*) seedlings after drought hardening in the nursery. Tree Physiol 24:1147–1155

Villar-Salvador P, Puértolas J, Cuesta B et al (2012) Increase in size and nitrogen concentration enhances seedling survival in Mediterranean plantations. Insights from an ecophysiological conceptual model of plant survival. New For 43:755–770. https://doi.org/10.1007/s11056-012-9328-6

Wakeley PC (1954) Planting the southern pines. Agricultural Monograph 18, US Department of Agriculture, Forest Service, Washington

Wilson BC, Jacobs DF (2006) Quality assessment of temperate zone deciduous hardwood seedlings. New For 31:417–433. https://doi.org/10.1007/s11056-005-0878-8

Yang X, Bauhus J, Both S et al (2013) Establishment success in a forest biodiversity and ecosystem functioning experiment in subtropical China (BEF-China). Eur J For Res 132:593–606

Zhao D, Kane M, Borders BE (2011) Growth responses to planting density and management intensity in loblolly pine plantations in the southeastern USA Lower Coastal Plain. Ann For Sci 68:625–635

Zuur AF, Ieno EN (2016) A protocol for conducting and presenting results of regression-type analyses. Methods Ecol Evol 7:636–645. https://doi.org/10.1111/2041-210X.12577