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Effects of microbiome on conifer health and resistance to biotic and abiotic stress: A systematic review

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ABSTRACT

The dynamics of plant-microbiome interactions under different stress conditions are important to understand in order to elucidate the mechanisms underlying forest decline and tree mortality. This study aims to evaluate the importance of ectomycorrhizal fungi in alleviating stress and enhancing defense in *Pinus* and *Picea* species. A meta-analysis was performed on primary research articles that assessed effects of ectomycorrhizal fungal on growth and resistance of these tree species. The stress factors studied were drought, pathogen infection, herbivory and pollutant stress. A PRISMA systematic review guideline was used in screening the articles from the two databases Web of Science and SCOPUS. The search produced a total of 1 806 articles, which were further screened by excluding review articles, book chapters, conference papers and other papers that did not include *Pinus* or *Picea* species and ectomycorrhizal fungi. A total of 118 articles were assessed and the statistical analysis was conducted as per factor (growth, survival, biotic and abiotic stress). Most of the published articles were on *Pinus* and a few on *Picea*. Overall, ectomycorrhizal fungi were found to enhance growth but had no effect on survival, though the results are more confined to *Pinus* species. Ectomycorrhizal fungi were not effective in alleviating abiotic and biotic stress. There was high heterogeneity among papers and publication bias in the analysis. As a result my analysis did not provide a concrete conclusion in endorsing ectomycorrhizal fungi as promoting conifer growth, survival and resistance to biotic and abiotic stress. Further research is needed on conifer- soil feedbacks in relation to ectomycorrhizal fungi. Moreover, there is need for conducting more experiments in the field to enable the life strategies of ectomycorrhizal fungi to be brought into sharper focus. This is important because conifer species are of high economic value through producing high quality timber and plays a crucial role in mitigating climate change.

Key words: Ectomycorrhizal fungi, *Pinus*, *Picea*, heterogeneity, publication bias, growth, survival, biotic and abiotic.

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LIST OF ABBREVIATIONS

ECM- Ectomycorrhizal fungi,

AM- Arbuscular mycorrhizal fungi

REML- Random effects model

1. INTRODUCTION

Plants and their associated microbes have been interacting since the colonization of land by ancestral plants 450 million years ago. This assemblage of a plant host and its microbiome is called the holobiont (Baedke et al, 2020). Plant- microbiome relationships can be commensal or mutualistic, i.e. benefiting both partners (Bacon & White, 2016) (Van der Ent et al., 2009).

The microbiome includes organisms found below ground (in the rhizosphere) or above ground (phyllosphere). The rhizosphere is inhabited by a variety of microorganisms including bacteria, fungi, oomycetes, nematodes, protozoa and archaea. Mycorrhiza fungi are the most abundant members of the rhizosphere community with an estimated 80% plant association and have been found in over 200 000 plant species (Dastogeer et al., 2020). They play a major role in terrestrial ecosystems and are major drivers of carbon and nutrient cycles (van der Heijden et al., 2015). In the phyllosphere, microbes are very much affected by changes in temperature and moisture which may affect the plant. In addition to the rhizosphere and phyllosphere there is the endosphere. To colonize this internal compartment, microbiota must penetrate a plant's external boundary and overcome or hide from plant defenses (Bulgarelli et al., 2012). Arbuscular mycorrhizal fungi (AM) and other endophytic fungi are dominant colonizers of the endosphere (Dastogeer et al., 2020).

For trees to flourish they need Nitrogen, Phosphorus and water from soil, but the levels of these nutrients in soil are often too low to sustain tree growth and so the trees rely on ectomycorrhizal symbiosis to help them survive (Martin et al., 2016). Ectomycorrhizal fungi (ECM) can establish mutualistic symbiosis with a wide range of woody plants, including conifers and other gymnosperms, particularly in sites where nutrients are low and limiting (Read et al., 2004).They play a major role in temporal and boreal forests by providing soil nutrients and water in exchange of carbon, helping their host trees tolerating harsh environmental conditions (Policelli et al., 2020).

Figure 1: Mycorrhization of white bark seedlings with ectomycorrhizal fungi

Successful mycorrhizal colonization of white-bark (*Pinus albicaulis*) pine seedlings with a native *Suilloid* species in a greenhouse. White areas are ectomycorrhizal fungi which have colonized the roots (Lonergan, 2013).

Due to their large hyphal network in the soil (Figure1), ECM enhance the absorbing root surface of the plant host for mineral nutrients. In exchange, the plant host provides carbon to the mycorrhizal fungi(Smith, 2008). Additionally, ECM can be host- specific in response to the type of stress, affecting nutrient uptake, and leading to reduced plant growth (Taniguchi T, 2017).

Fluctuating environmental conditions can cause a plant to be attacked by pathogens and subsequent herbivore and or insect attack. In response to these attacks, plants have preformed and inducible defense mechanisms (Iqbal Zahra et al, 2021). Conifers such as Norway spruce can live for more than 500 to 600 years (Castagneri et al., 2013). One factor contributing to the longevity of conifers is their defensive strategies, the mechanisms they evolved against attack from insects and pathogens (Franceschi et al., 2005). In constitutive defense mechanisms, preformed barriers such as the cell wall, epidermal cuticle and the bark, protects the plant from attack and invasion. Preformed defenses can also be chemical defenses in which the tree produces anti-feedants, toxins, proteins and enzymes that are distributed in the bark and wood (Franceschi et al., 2005). Some proteins are specifically targeting certain microbes as shown in the antifungal activity of defensins (Thomma et al., 2002).

Inducible defense mechanisms increase the efficiency of the plant defense system and involve e.g. chemical defenses such as the release of secondary metabolites (phenolics, terpenoids and alkaloids) that can defend the tree against a wide range of pests or herbivore attack (Franceschi et al., 2005) and abiotic stresses such as drought, pollutants and salinity (Rodrigues et al., 2021). Plants respond to these stresses through different ways, for example they can escape from drought by adjusting their life cycle, decreasing the osmotic potential in their cells and upregulating antioxidant defenses. Molecular mechanisms include synthesis of stress proteins, and signalling stress detection (Athar et al., 2022). Several studies have documented the importance of mycorrhizal fungi in counteracting biotic stress in plants, including effects on pathogenic fungi such as *Fusarium*, *Rhizoctona*, *Verticillium*, *Thievalopsis*, *Aphanomyces*, *Phytophtora* and *Pythium* (Whipps, 2004), as well as nematodes from the genera *Heterodera*, *Meloidogyne*, *Pratylenchus* and *Radopholus* (Harrier & Watson, 2004).

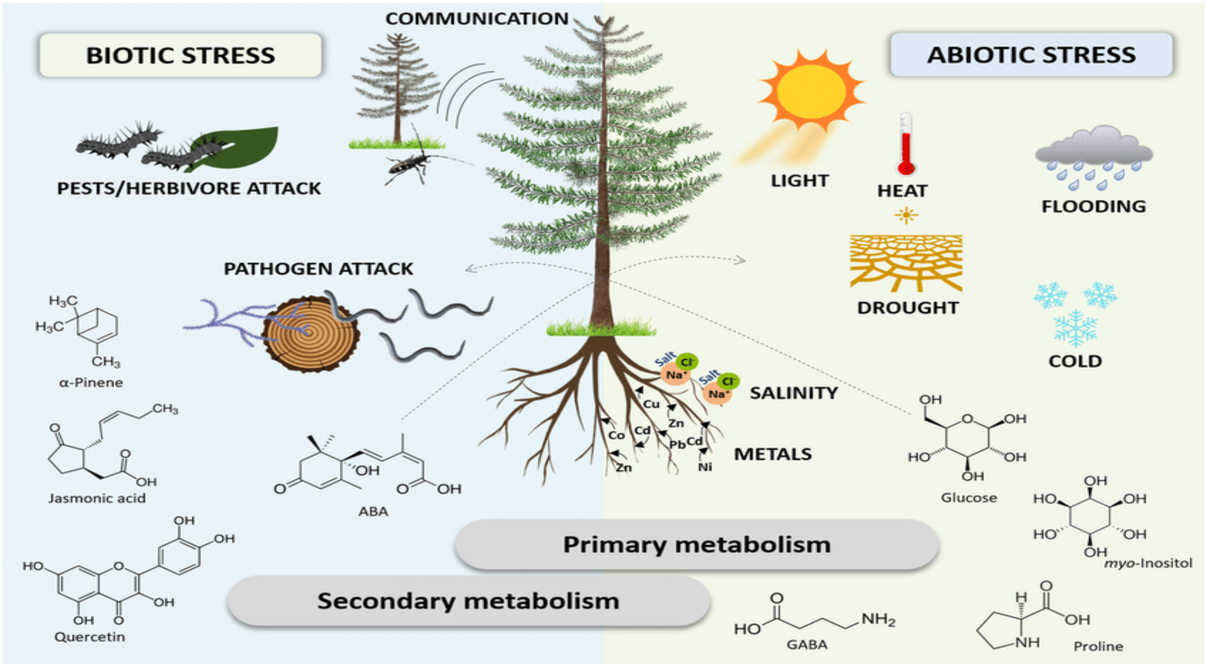


Figure 2: Chemical defense mechanisms of trees

Chemical defense mechanisms of trees by realising secondary metabolites in response to abiotic and biotic stress (Rodrigues et al., 2021).

During the past decades, individual studies have generated sufficient evidence on responses of plants to ectomycorrhizal associations that some conclusions can now be made about the nature of these associations. However, the published results are inconsistent to some extent. Some studies recorded positive effects of ectomycorrhizal fungi when administered to conifers(Kennedy et al., 2007) and others reported negative microbial responses(Herol et al., 2022) . However, there has been not enough quantitative synthesis that allows us to determine the effect of ectomycorrhizal fungi on conifer (*Pinus* or *Picea)* health, survival and defense. More systematic knowledge can be achieved through a meta-analysis, which is a method to summarise results of multiple independent studies, identifying conflicting published studies (Koricheva & Gurevitch, 2013), highlighting research gaps in data, and identifying common methodological problems (Lortie & Callaway, 2006).

1.1 AIM

Hitherto, most information on beneficial effects of mycorrhizal plant-fungal interactions has been gathered on arbuscular mycorrhizal fungi (AM) known to form symbiotic associations with many crop plants. Less attention has been given to ectomycorrhizal fungi (ECM) that are specific for symbioses with woody plants. There is thus a need for understanding the complex relationship between woody plants and their microbiota (particularly ectomycorrhizal fungi) in enhancing defense to biotic and abiotic stress. This need is especially pressing for forest trees such as the conifers which are crucial for future forest productivity and forest restoration.

1.2 OBJECTIVES

The main objective of this thesis is to evaluate to what extent ectomycorrhizal fungi in enhance growth and resistance to biotic and abiotic stress of conifers in the genera *Pinus* and *Picea*. I do this by conducting a meta-analysis of published primary research articles that have manipulated ectomycorrhizal fungi and other variables that has assessed its effect on growth and resistance to biotic and abiotic stress.

1.3 RESEARCH QUESTIONS

- Is there is scientific evidence that ectomycorrhizal fungi enhance plant growth, survival and defense to biotic and abiotic stress?
- Does the experiment location or growth condition affect the outcome of results?

2.0 METHOD

2.1 Literature search

The meta-analysis was performed in concordance with the PRISMA systematic review guidelines (BMJ, 2021) (Figure 3). A literature search was performed using the databases; Web of Science (https://www.webofscience.com/) and SCOPUS (https://www.scopus.com/). Terms used to search Web of Science were: ALL= (holobiont OR mi?crobiome OR ectomycorrhiz*) AND (spruce OR pine OR conifer OR gymnosperm) AND (health or resistance or growth or stress)). The search terms used in SCOPUS were: TITLE-ABS-KEY ((holobiont OR mi?crobiome OR ectomycorrhiz*) AND (spruce OR pine OR conifer OR gymnosperm) AND (health OR defense OR resistance OR growth OR stress)) AND (LIMIT-TO (DOCTYPE, "ar")). Initially, the two searches identified 1 806. Abstracts and meta data for all articles were imported into Rayyan (https://www.rayyan.ai/), a web-tool to help researchers working on systematic reviews, so they could be individually reviewed. Each article was reviewed by two independent reviewers (me and one of my supervisors). Articles that did not deal with *Picea* or *Pinus*, ECM and/or the effects of ECM on conifer growth, survival, abiotic stress or biotic stress were excluded. Most articles that were published in the 1980s and 1990s were in accessible online, thus they were excluded for the meta-analysis.

Additionally, articles for which there was no online access, that were not written in English, or were not primary research articles were excluded. In the end, 118 articles were found suitable for meta-analysis. Of these 118 studies, only 112 articles had enough statistical data or other key information required to perform the meta-analysis (Figure 3).

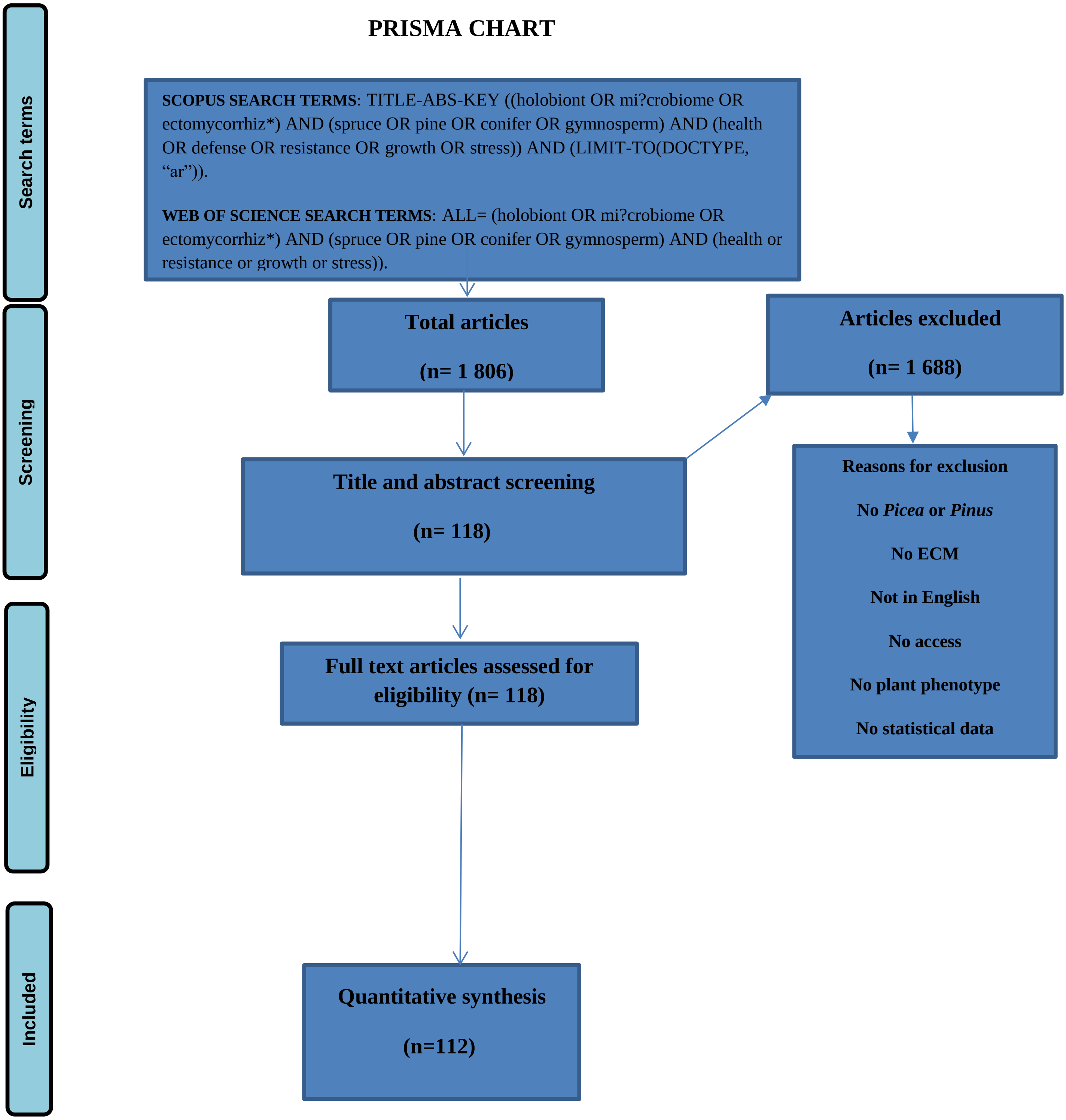


Figure 3: Prisma chart describing the screening process.

PRISMA chart describing the search protocol and screening process used to identify and select published research articles for this systematic review.

2.2 Data extraction

I read each of the 118 articles included in the meta-analysis and harvested data that could be used to calculate effect sizes (See Appendix E). The effect of ECM on tree growth, survival, biotic, and abiotic was investigated. The data parameters used in the study include seedling height, stem diameter, shoot length, and stem length, root length, survival and mortality (See Appendix B, C, D and A). For articles that did not provide data in the text, tables, or supplementary data files, Image J image analysis software (https://imagej.net/ij/) was used to derive data from figures. Mean and standard deviation or standard error values from data graphs were determined by measuring pixels and scaling these to the y-axis units. I also recorded additional factors that could influence the effect sizes. These possibly moderating factors were tree genus, tree age, ECM genus, soil type, and growth condition and stress type. Soil types were grouped into four categories: field, composite, sandy and media. Soil from the forest or field was categorised as field. Nursery soils, i.e. various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media. Studies that were conducted under controlled environments were coded as growth facility (greenhouse, glass house, lab, and nursery) and those which were carried out in the field were coded as field. Stress types were coded as heavy metals, pathogen infection, drought and insect attack.

2.3 Effect size standardisation and normalisation

Effect sizes were calculated following the method presented in the Hard- boiled synthesis protocols (Lajeunesse, 2016). Data extracted from the literature was normalised and calculated using the following formulae and steps:

1. The difference of **δ** between the means (X) of ECM treatment (T) and control was calculated:

$$\boldsymbol{\delta = X_T - X_C} \qquad \textbf{(1)}$$

(X_T and X_C are treatment and control means)

2. The homogenised variance **(σ)** of the means of treatment and control was calculated:

$$\boldsymbol{\sigma = \sqrt{}\ ((N_T\text{-}1)\ SD^2_{T+}\ (NC\text{-}1)\ SD^2_C/N_T - N_C} \qquad \textbf{(2)}$$

(N_T and N_C are treatment and control sample size)

3. I then standardised delta relative to sigma :-

   δ/σ (delta/sigma) **(3)**

4. and estimated data variance of effect size.

   $Var(\delta)=1/N_T+1/N_C+\delta^2/2(N_T+N_C)$ **(4)**

5. performed bias correction:

   $J = 1-(3/4 \times (4x (N_T+N_C-2)-1))$ **(5)**

   (J is the bias correction)

6. Calculated delta (**δ**)

   $\delta = X_T-X_C/\sigma \times J$ **(6)**

7. Calculated variance of the delta

   $\delta = \sqrt{Var\ \delta} * j^2$ **(7)**

8. And finally calculated effect size from Var δ.

   $Var(\delta) = 1/N_T + 1/N_C + \delta 2/2(N_T+N_C) \times j2$ **(8)**

   EFFECT SIZE

   $(\delta) = X_T-X_C/\sigma$

Data that were presented as proportions or percentages were converted to log response ratios (log RR) using the following formulae and steps:

1. Risk ratio (RR) was first calculated:

$RR= P_{treatment}/P_{control}$ **(9)**

(P is the proportion)

2. Response ratios were then transformed to log RR using the formulae:

$RR = LN(RR)$ **(10)**

3. and standard errors for log risk ratios were calculated.

$SE\ log\ RR= (1/K_{T+}1/K_C - 1/N_T+1/N_C)$ **(11)**

(N_T and N_C are treatment and control sample size, and K is the number of events e.g., dead plants)

2.4 Data modelling and determination of pooled effect size

The overall effect of ECM fungi on their host was estimated using the METAFOR package by Viechtbauer (2010) in R (R version 4.2.3), by fitting a three level meta-analysis random effects model (Harrer et al., 2021). Level 1(ε) were individual data points (effects) within studies. In level 2 **ζ(2)**, the individual data points that were clustered (K) by study. In level 3 **ζ(3),** the effect sizes from all studies were pooled into an overall estimated effect size (average). 2.

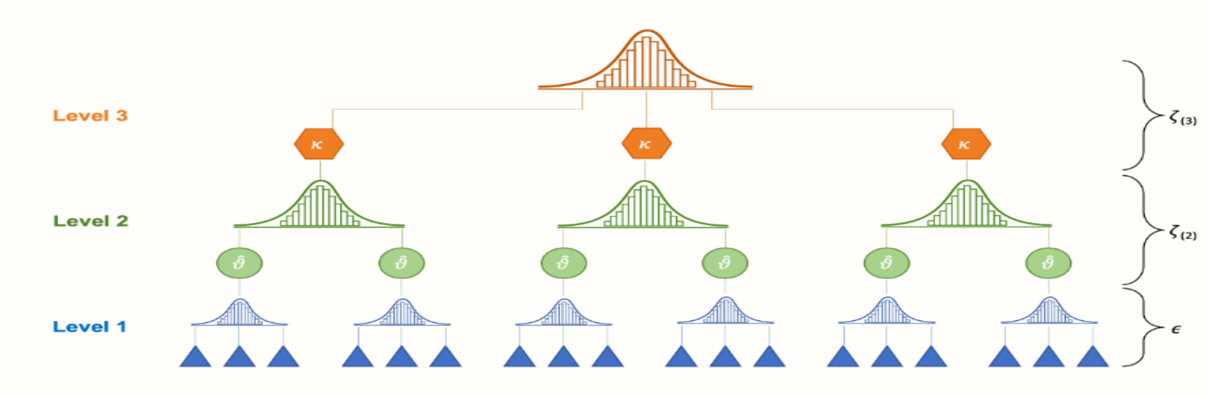


Figure 4: Three level meta-analysis model

Diagram of a three level meta-analysis model used in this study (Harrer et al., 2021). Level 1shows data points of individual studies and their effect sizes. Level 2 shows effect sizes of subgroup studies aggregated together where each study contributes only one effect size. Level 3 is the overall true pooled effect size from subgroups in level

The model equation used was:

$$\hat{\theta}_{ij}=\mu+\zeta_{(2)ij}+\zeta_{(3)j}+\epsilon_{ij}$$

Where $\hat{\theta}_{ij}$ is an estimate of the true effect size, **μ** is the true effect, **i** are some effect size nested in cluster which can be a subgroup **j**$\zeta_{(2)ij}$ and $\zeta_{(3)j}$ represent heterogeneity within clusters. The function used to run the model in R was:

```
full. Model <- rma.mv (yi = effect size,
                V = var. d,
                slab = author,
                data =x,
                random = ~ 1 | author/es.id,
                test = "t",
                method = "REML")
```

Where yi is the calculated individual effect size and V is the calculated variance delta. The author is representing individual studies (level 2) and es.id is representing individual effects (level 1).

The estimated pooled effect size was also transformed to a normal correlation to facilitate, easy interpretation of results using the function: **convert_z2r ()**.

Additional factors (moderators) such as soil type, growth condition, tree age, stress type and tree genus were assessed for their overall effects on the pooled effect size using the equation:

$$\hat{\theta}_{ij}=\theta+\beta x_i+\zeta_{(2)ij}+\zeta_{(3)j}+\epsilon_{ij}$$

Where **θ** is the intercept and **β** the regression weight of a predictor variable for instance soil type.

These factors were specified in **rma.mv ()**, using the mods argument. A three- level moderator model was used using the above equation:

```
mod. model <- rma.mv (yi = effect size, V = var. d,
                      slab = author,
                      data = data x,
                      random = ~ 1 | author/es.id,
                      test = "t",
                      method = "REML",
                      mods = ~ moderator x)
```

Where yi is the effect size and V is the variance delta.

2.5 Distribution of variance across levels

Higgin's and Thompson's I^2 statistic was used to quantify heterogeneity between study levels based on Cochran's Q. This is defined as the percentage of variability in the effect sizes in which the sampling error is not the cause. The formular for I^2 used is:

$$I^2 = \frac{Q-(K-1)}{Q}$$

Where K is the total number of studies, and Q is the Cochran's Q, which is the weighted sum of squared differences between individual study effects and the pooled effect across studies, with the weights being those used in the pooling method (Higgins & Thompson, 2002).

2.5 Bias detection

The METAFOR package by Viechtbauer (2010) in R (R version 4.2.3) was used to create funnel plots to evaluate bias in the study and to determine the validity of the results, using the function: **funnel()**.

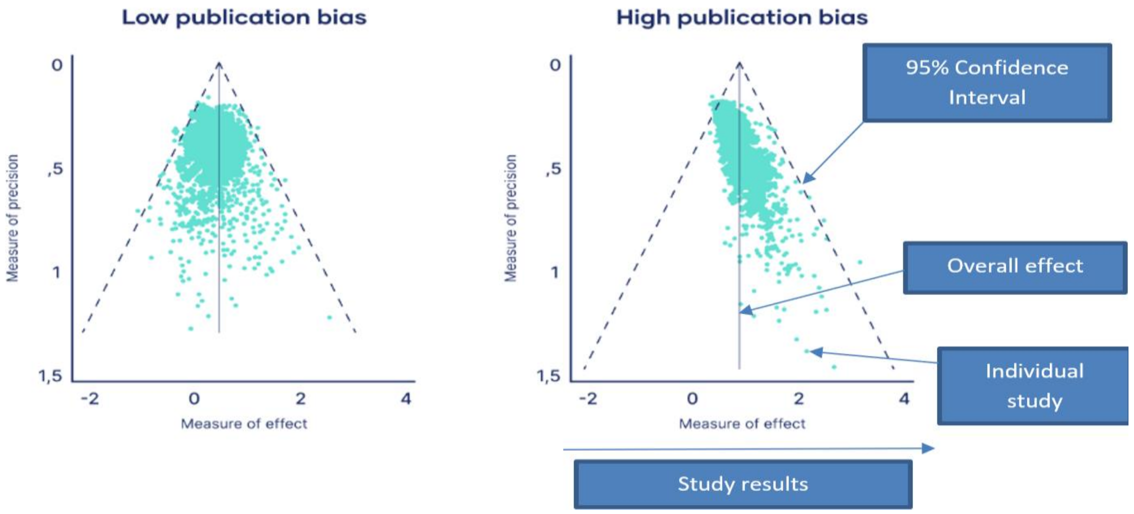


Figure 5: Diagram of a funnel plot

An example of a funnel plot modified from (https://www.scribbr.com/frequently-asked-questions/funnel-plot-publication-bias) Funnel plot showing publication bias of growth studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome (effect size). The outer dashed lines show 95% Confidence Interval limits. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical plot.

3.0 RESULTS

Out of 1806 searched articles, 118 articles were found suitable for meta-analysis but only 112 articles had enough data and other key information required to perform the meta-analysis.

3.1Effects of ECM on conifer tree growth

There are many articles on *Pinus* species compared to *Picea* species. The years with the most articles are 1998, 2004, 2005, 2007 and 2012, and all these years were dominated by *Pinus* species (Figure 6).

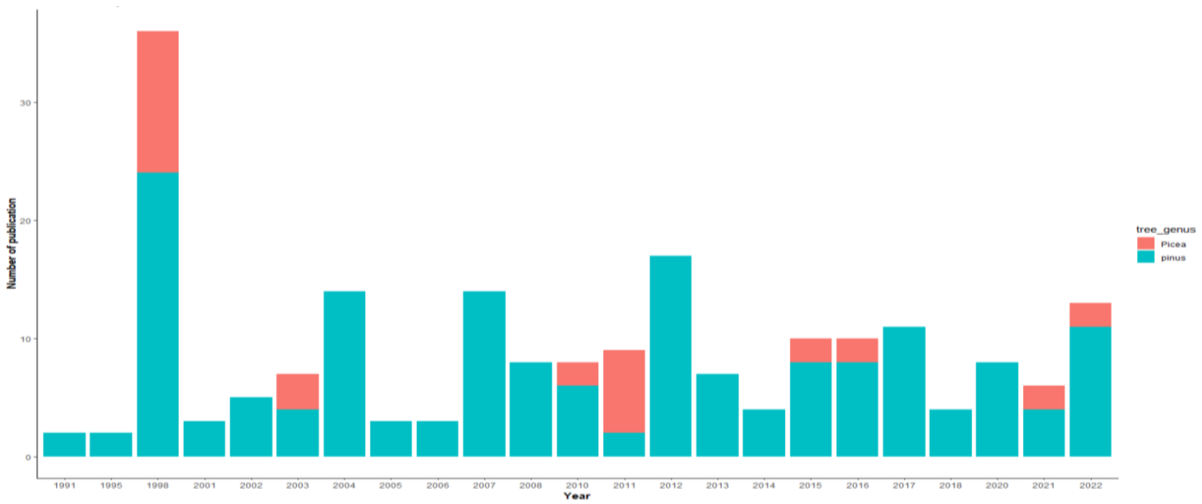


Figure 6: Number of publications on conifer tree growth

Publication year of articles included in the meta-analysis of ECM effect on Pinus and Picea growth.

Growth studies were mostly conducted in a growth facility, and much of the investigation was conducted on *Pinus* (Figure 7). There was a total of 32 studies conducted on *Picea* growth and 172 studies conducted on *Pinus* growth.

Figure 7: Growth conditions under which growth studies in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on Pinus and Picea growth were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to “growth facility” and those which were carried out in the field were allocated to “field”.

The most common ECM genera used were *Suillus, Rhizopogon, Laccaria and Pisolithus*, though ECM was mostly tested on *Pinus* species (Figure 8).

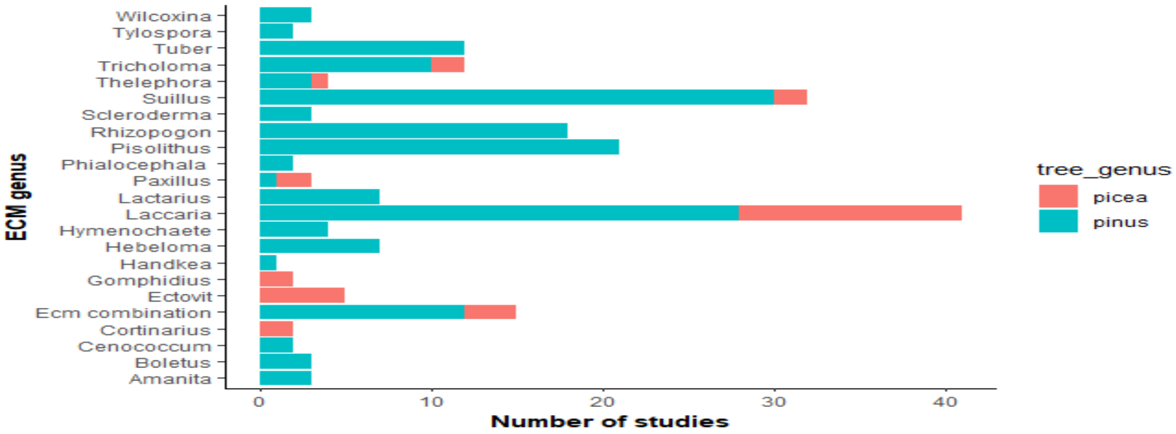


Figure 8: ECM genera which were used for growth studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* growth were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used. Ectovit is a mycorrhizal blend manufactured for commercial use.

The composite soil type was the most used on both *Picea* and *Pinus* species. Sandy was the least used soil type (Figure 8).

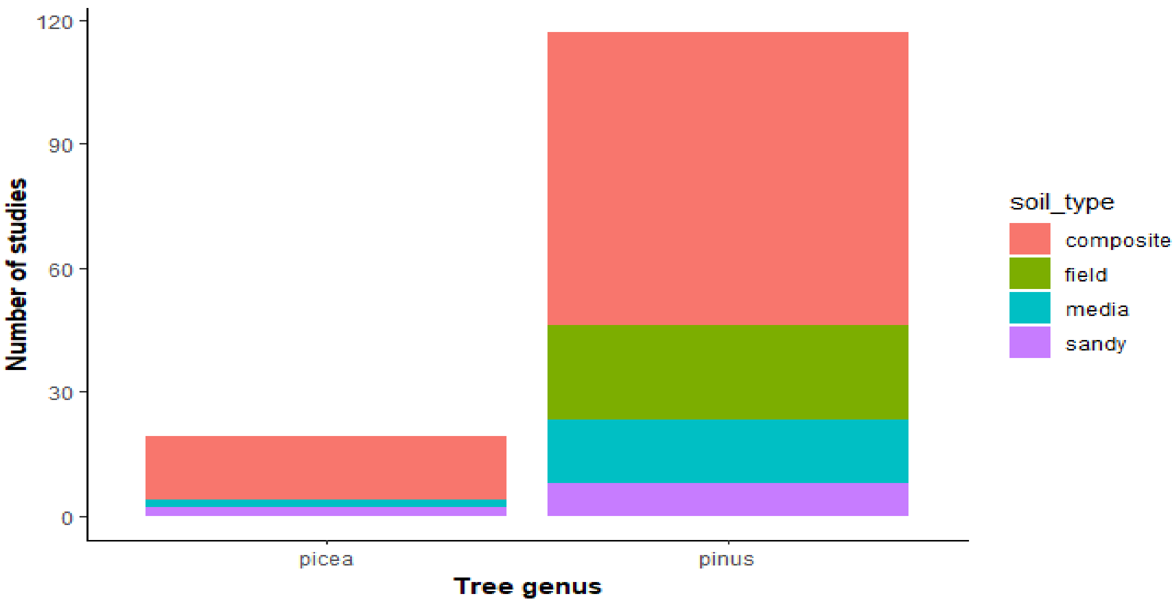


Figure 8: Soil type used on conifer tree growth studies.

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled estimated effect size based on the three -level meta -analysis model was 51 (95% CI: 1.73- 100; p=0.04). The large estimated pooled effect size indicates a very strong relationship between ectomycorrhizal fungi and tree growth. There was a high level of heterogeneity between individual studies and within studies. $I^2_{level\ 3}$(overall effect size) was 23.27% and $I^2_{level\ 2}$ (nested effect sizes from individual studies) was 76.73(Figure 10).

There is an indication of publication bias on tree growth factor because the plot is not symmetrical. Excessive number of studies do not fall within 95% confidence interval limit (Figure 9) and thus are statistically significant. Therefore, publications are biased although their studies are significant.

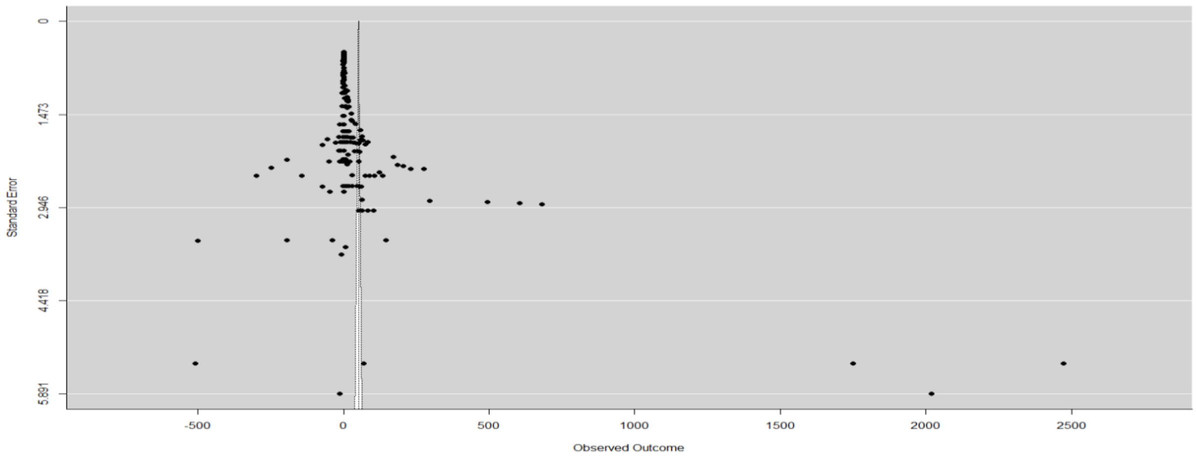


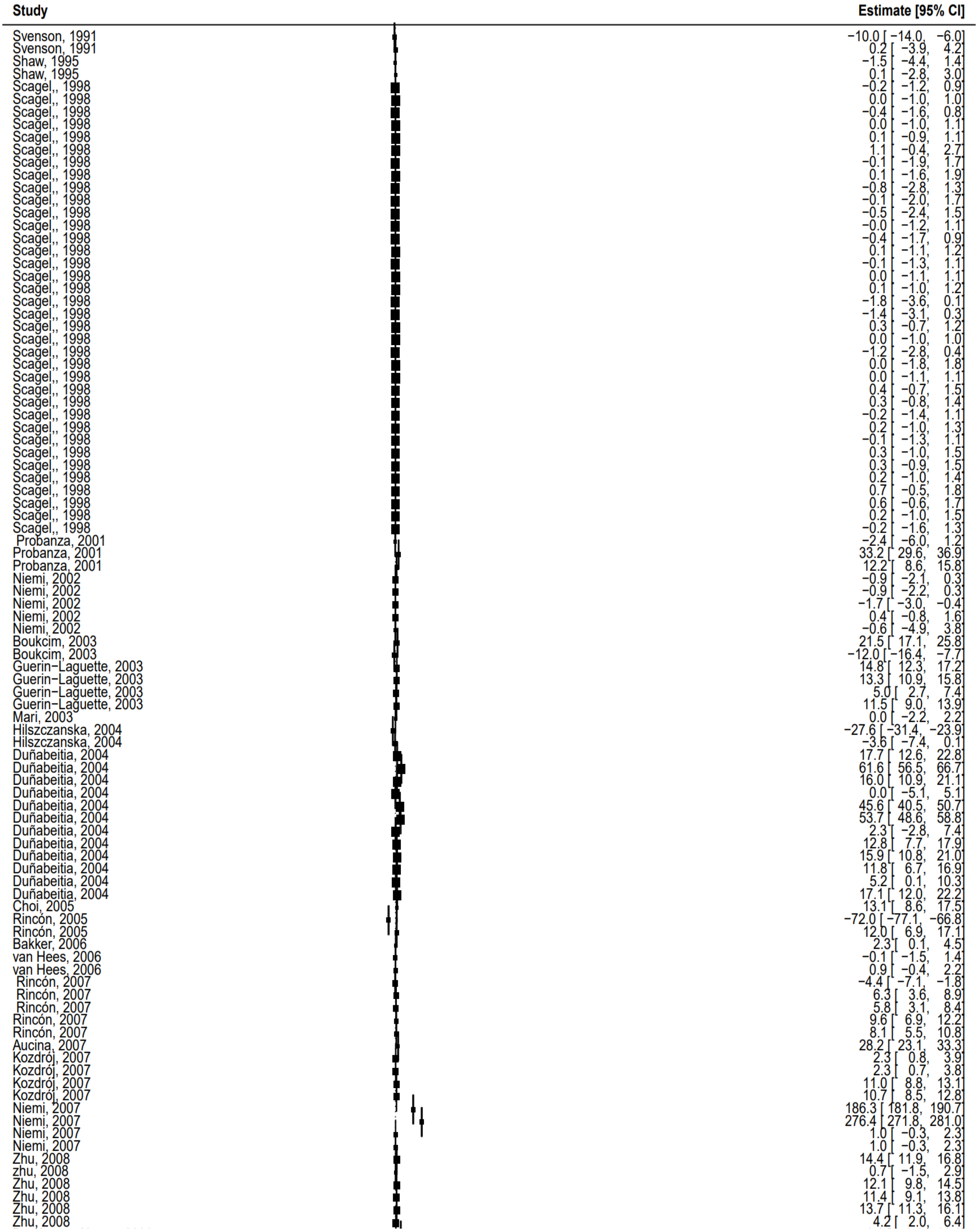
Figure 9: Funnel plot of publication bias of growth studies

Funnel plot showing publication bias of growth studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome (effect size). The outer dashed lines show the 95% Confidence Interval limit. The average effect size is shown by the dashed line in the middle. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted pollen.

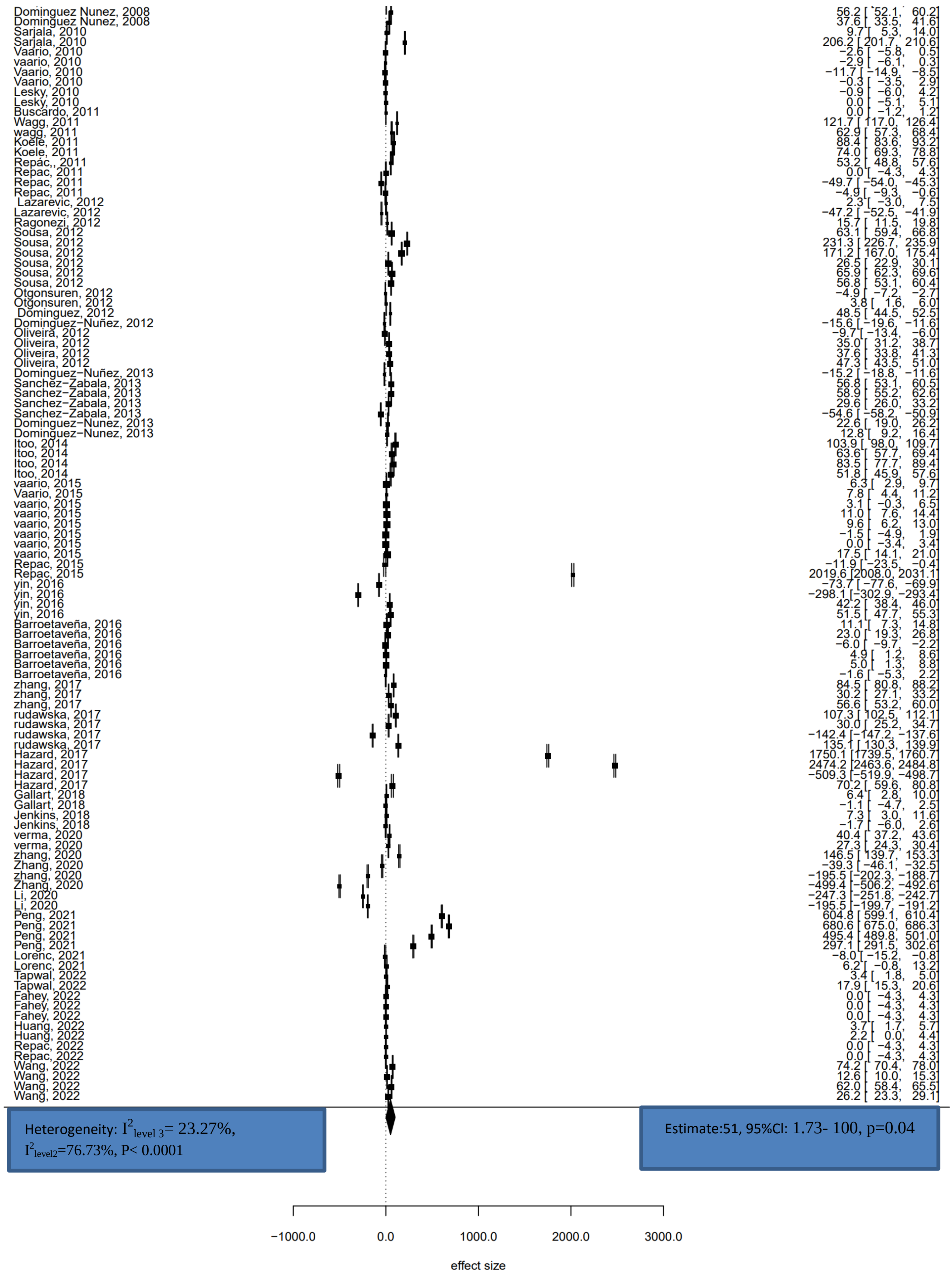
The pooled estimated effects sizes of the moderators were huge indicating a positive moderating effect on the relationship between ectomycorrhizal fungi and conifer tree growth with no significance (P>0.05), except for soil type which had a p value of 0.03 (Table 1).

Table 1: Overview of estimated pooled effect sizes of growth factor moderators using a three level meta-analysis random effects model.

Moderator	**Estimate**	**Standard error**	**T value**	**Degrees of freedom**	**P value**	**Lower confidence interval**	**Higher confidence interval**
ECM	17.1264	166.6966	0.1027	180	0.9183	-311.8045	346.0573
Soil type	74.3559	34.3555	2.1643	199	0.0316	6.6084	140
Growth conditions	44.2207	43. 3697	1.0196	202	0.309	-41.2948	129.73
Tree age	31.227	32.1408	0.9716	202	0.3324	-32.1475	94.6015
Tree genus	71.552	55.2014	1.2962	202	0.1964	-32.2927	180.3971



Study
Estimate [95% CI]
Svenson, 1991 −10.0 [−14.0, −6.0]
Svenson, 1991 0.2 [−3.9, 4.2]
Shaw, 1995 −1.5 [−4.4, 1.4]
Shaw, 1995 0.1 [−2.8, 3.0]
Scagel,, 1998 −0.2 [−1.2, 0.9]
Scagel,, 1998 0.0 [−1.0, 1.0]
Scagel,, 1998 −0.4 [−1.6, 0.8]
Scagel,, 1998 0.0 [−1.0, 1.1]
Scagel,, 1998 0.1 [−0.9, 1.1]
Scagel,, 1998 1.1 [−0.4, 2.7]
Scagel,, 1998 −0.1 [−1.9, 1.7]
Scagel,, 1998 0.1 [−1.6, 1.9]
Scagel,, 1998 −0.8 [−2.8, 1.3]
Scagel,, 1998 −0.1 [−2.0, 1.7]
Scagel,, 1998 −0.5 [−2.4, 1.5]
Scagel,, 1998 −0.0 [−1.2, 1.1]
Scagel,, 1998 −0.4 [−1.7, 0.9]
Scagel,, 1998 0.1 [−1.1, 1.2]
Scagel,, 1998 −0.1 [−1.3, 1.1]
Scagel,, 1998 0.0 [−1.1, 1.1]
Scagel,, 1998 0.1 [−1.0, 1.2]
Scagel,, 1998 −1.8 [−3.6, 0.1]
Scagel,, 1998 −1.4 [−3.1, 0.3]
Scagel,, 1998 0.3 [−0.7, 1.2]
Scagel,, 1998 0.0 [−1.0, 1.0]
Scagel,, 1998 −1.2 [−2.8, 0.4]
Scagel,, 1998 0.0 [−1.8, 1.8]
Scagel,, 1998 0.0 [−1.1, 1.1]
Scagel,, 1998 0.4 [−0.7, 1.5]
Scagel,, 1998 0.3 [−0.8, 1.4]
Scagel,, 1998 −0.2 [−1.4, 1.1]
Scagel,, 1998 0.2 [−1.0, 1.3]
Scagel,, 1998 −0.1 [−1.3, 1.1]
Scagel,, 1998 0.3 [−1.0, 1.5]
Scagel,, 1998 0.3 [−0.9, 1.5]
Scagel,, 1998 0.2 [−1.0, 1.4]
Scagel,, 1998 0.7 [−0.5, 1.8]
Scagel,, 1998 0.6 [−0.6, 1.7]
Scagel,, 1998 0.2 [−1.0, 1.5]
Scagel,, 1998 −0.2 [−1.6, 1.3]
Probanza, 2001 −2.4 [−6.0, 1.2]
Probanza, 2001 33.2 [29.6, 36.9]
Probanza, 2001 12.2 [8.6, 15.8]
Niemi, 2002 −0.9 [−2.1, 0.3]
Niemi, 2002 −0.9 [−2.2, 0.3]
Niemi, 2002 −1.7 [−3.0, −0.4]
Niemi, 2002 0.4 [−0.8, 1.6]
Niemi, 2002 −0.6 [−4.9, 3.8]
Boukcim, 2003 21.5 [17.1, 25.8]
Boukcim, 2003 −12.0 [−16.4, −7.7]
Guerin−Laguette, 2003 14.8 [12.3, 17.2]
Guerin−Laguette, 2003 13.3 [10.9, 15.8]
Guerin−Laguette, 2003 5.0 [2.7, 7.4]
Guerin−Laguette, 2003 11.5 [9.0, 13.9]
Mari, 2003 0.0 [−2.2, 2.2]
Hilszczanska, 2004 −27.6 [−31.4, −23.9]
Hilszczanska, 2004 −3.6 [−7.4, 0.1]
Duñabeitia, 2004 17.7 [12.6, 22.8]
Duñabeitia, 2004 61.6 [56.5, 66.7]
Duñabeitia, 2004 16.0 [10.9, 21.1]
Duñabeitia, 2004 0.0 [−5.1, 5.1]
Duñabeitia, 2004 45.6 [40.5, 50.7]
Duñabeitia, 2004 53.7 [48.6, 58.8]
Duñabeitia, 2004 2.3 [−2.8, 7.4]
Duñabeitia, 2004 12.8 [7.7, 17.9]
Duñabeitia, 2004 15.9 [10.8, 21.0]
Duñabeitia, 2004 11.8 [6.7, 16.9]
Duñabeitia, 2004 5.2 [0.1, 10.3]
Duñabeitia, 2004 17.1 [12.0, 22.2]
Choi, 2005 13.1 [8.6, 17.5]
Rincón, 2005 −72.0 [−77.1, −66.8]
Rincón, 2005 12.0 [6.9, 17.1]
Bakker, 2006 2.3 [0.1, 4.5]
van Hees, 2006 −0.1 [−1.5, 1.4]
van Hees, 2006 0.9 [−0.4, 2.2]
Rincón, 2007 −4.4 [−7.1, −1.8]
Rincón, 2007 6.3 [3.6, 8.9]
Rincón, 2007 5.8 [3.1, 8.4]
Rincón, 2007 9.6 [6.9, 12.2]
Rincón, 2007 8.1 [5.5, 10.8]
Aucina, 2007 28.2 [23.1, 33.3]
Kozdrój, 2007 2.3 [0.8, 3.9]
Kozdrój, 2007 2.3 [0.7, 3.8]
Kozdrój, 2007 11.0 [8.8, 13.1]
Kozdrój, 2007 10.7 [8.5, 12.8]
Niemi, 2007 186.3 [181.8, 190.7]
Niemi, 2007 276.4 [271.8, 281.0]
Niemi, 2007 1.0 [−0.3, 2.3]
Niemi, 2007 1.0 [−0.3, 2.3]
Zhu, 2008 14.4 [11.9, 16.8]
zhu, 2008 0.7 [−1.5, 2.9]
Zhu, 2008 12.1 [9.8, 14.5]
Zhu, 2008 11.4 [9.1, 13.8]
Zhu, 2008 13.7 [11.3, 16.1]
Zhu, 2008 4.2 [2.0, 6.4]



Dominguez Nunez, 2008 56.2 [52.1, 60.2]
Dominguez Nunez, 2008 37.6 [33.5, 41.6]
Sarjala, 2010 9.7 [5.3, 14.0]
Sarjala, 2010 206.2 [201.7, 210.6]
Vaario, 2010 −2.6 [−5.8, 0.5]
vaario, 2010 −2.9 [−6.1, 0.3]
Vaario, 2010 −11.7 [−14.9, −8.5]
Vaario, 2010 −0.3 [−3.5, 2.9]
Lesky, 2010 −0.9 [−6.0, 4.2]
Lesky, 2010 0.0 [−5.1, 5.1]
Buscardo, 2011 0.0 [−1.2, 1.2]
Wagg, 2011 121.7 [117.0, 126.4]
wagg, 2011 62.9 [57.3, 68.4]
Koele, 2011 88.4 [83.6, 93.2]
Koele, 2011 74.0 [69.3, 78.8]
Repác,, 2011 53.2 [48.8, 57.6]
Repac, 2011 0.0 [−4.3, 4.3]
Repac, 2011 −49.7 [−54.0, −45.3]
Repac, 2011 −4.9 [−9.3, −0.6]
Lazarevic, 2012 2.3 [−3.0, 7.5]
Lazarevic, 2012 −47.2 [−52.5, −41.9]
Ragonezi, 2012 15.7 [11.5, 19.8]
Sousa, 2012 63.1 [59.4, 66.8]
Sousa, 2012 231.3 [226.7, 235.9]
Sousa, 2012 171.2 [167.0, 175.4]
Sousa, 2012 26.5 [22.9, 30.1]
Sousa, 2012 65.9 [62.3, 69.6]
Sousa, 2012 56.8 [53.1, 60.4]
Otgonsuren, 2012 −4.9 [−7.2, −2.7]
Otgonsuren, 2012 3.8 [1.6, 6.0]
Dominguez, 2012 48.5 [44.5, 52.5]
Dominguez−Nuñez, 2012 −15.6 [−19.6, −11.6]
Oliveira, 2012 −9.7 [−13.4, −6.0]
Oliveira, 2012 35.0 [31.2, 38.7]
Oliveira, 2012 37.6 [33.8, 41.3]
Oliveira, 2012 47.3 [43.5, 51.0]
Dominguez−Nuñez, 2013 −15.2 [−18.8, −11.6]
Sanchez−Zabala, 2013 56.8 [53.1, 60.5]
Sanchez−Zabala, 2013 58.9 [55.2, 62.6]
Sanchez−Zabala, 2013 29.6 [26.0, 33.2]
Sanchez−Zabala, 2013 −54.6 [−58.2, −50.9]
Dominguez−Nunez, 2013 22.6 [19.0, 26.2]
Dominguez−Nunez, 2013 12.8 [9.2, 16.4]
Itoo, 2014 103.9 [98.0, 109.7]
Itoo, 2014 63.6 [57.7, 69.4]
Itoo, 2014 83.5 [77.7, 89.4]
Itoo, 2014 51.8 [45.9, 57.6]
vaario, 2015 6.3 [2.9, 9.7]
Vaario, 2015 7.8 [4.4, 11.2]
vaario, 2015 3.1 [−0.3, 6.5]
vaario, 2015 11.0 [7.6, 14.4]
vaario, 2015 9.6 [6.2, 13.0]
vaario, 2015 −1.5 [−4.9, 1.9]
vaario, 2015 0.0 [−3.4, 3.4]
vaario, 2015 17.5 [14.1, 21.0]
Repac, 2015 −11.9 [−23.5, −0.4]
Repac, 2015 2019.6 [2008.0, 2031.1]
yin, 2016 −73.7 [−77.6, −69.9]
yin, 2016 −298.1 [−302.9, −293.4]
yin, 2016 42.2 [38.4, 46.0]
yin, 2016 51.5 [47.7, 55.3]
Barroetaveña, 2016 11.1 [7.3, 14.8]
Barroetaveña, 2016 23.0 [19.3, 26.8]
Barroetaveña, 2016 −6.0 [−9.7, −2.2]
Barroetaveña, 2016 4.9 [1.2, 8.6]
Barroetaveña, 2016 5.0 [1.3, 8.8]
Barroetaveña, 2016 −1.6 [−5.3, 2.2]
zhang, 2017 84.5 [80.8, 88.2]
zhang, 2017 30.2 [27.1, 33.2]
zhang, 2017 56.6 [53.2, 60.0]
rudawska, 2017 107.3 [102.5, 112.1]
rudawska, 2017 30.0 [25.2, 34.7]
rudawska, 2017 −142.4 [−147.2, −137.6]
rudawska, 2017 135.1 [130.3, 139.9]
Hazard, 2017 1750.1 [1739.5, 1760.7]
Hazard, 2017 2474.2 [2463.6, 2484.8]
Hazard, 2017 −509.3 [−519.9, −498.7]
Hazard, 2017 70.2 [59.6, 80.8]
Gallart, 2018 6.4 [2.8, 10.0]
Gallart, 2018 −1.1 [−4.7, 2.5]
Jenkins, 2018 7.3 [3.0, 11.6]
Jenkins, 2018 −1.7 [−6.0, 2.6]
verma, 2020 40.4 [37.2, 43.6]
verma, 2020 27.3 [24.3, 30.4]
zhang, 2020 146.5 [139.7, 153.3]
Zhang, 2020 −39.3 [−46.1, −32.5]
zhang, 2020 −195.5 [−202.3, −188.7]
Zhang, 2020 −499.4 [−506.2, −492.6]
Li, 2020 −247.3 [−251.8, −242.7]
Li, 2020 −195.5 [−199.7, −191.2]
Peng, 2021 604.8 [599.1, 610.4]
Peng, 2021 680.6 [675.0, 686.3]
Peng, 2021 495.4 [489.8, 501.0]
Peng, 2021 297.1 [291.5, 302.6]
Lorenc, 2021 −8.0 [−15.2, −0.8]
Lorenc, 2021 6.2 [−0.8, 13.2]
Tapwal, 2022 3.4 [1.8, 5.0]
Tapwal, 2022 17.9 [15.3, 20.6]
Fahey, 2022 0.0 [−4.3, 4.3]
Fahey, 2022 0.0 [−4.3, 4.3]
Fahey, 2022 0.0 [−4.3, 4.3]
Huang, 2022 3.7 [1.7, 5.7]
Huang, 2022 2.2 [0.0, 4.4]
Repac, 2022 0.0 [−4.3, 4.3]
Repac, 2022 0.0 [−4.3, 4.3]
Wang, 2022 74.2 [70.4, 78.0]
Wang, 2022 12.6 [10.0, 15.3]
Wang, 2022 62.0 [58.4, 65.5]
Wang, 2022 26.2 [23.3, 29.1]
Heterogeneity: I2level 3= 23.27%,
I2level2=76.73%, P< 0.0001
Estimate:51, 95%CI: 1.73- 100, p=0.04
−1000.0
0.0
1000.0
2000.0
3000.0
effect size

Figure 9: Forest plot of the overall effects of ECM on growth

Forest plot of the overall effects of Ectomycorrhizal fungi on *Pinus* and *Picea* growth. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall effect of the study.

3.2 Effect of ECM on conifer resistance to abiotic stress

In contrary to *Pinus* species, from the year 1991 to 2022, there are scanty recorded studies of *Picea* species (only recorded three times). The total number of articles was high in 2004, 2007 and 2012, followed by a substantial decrease in 2005 and later.

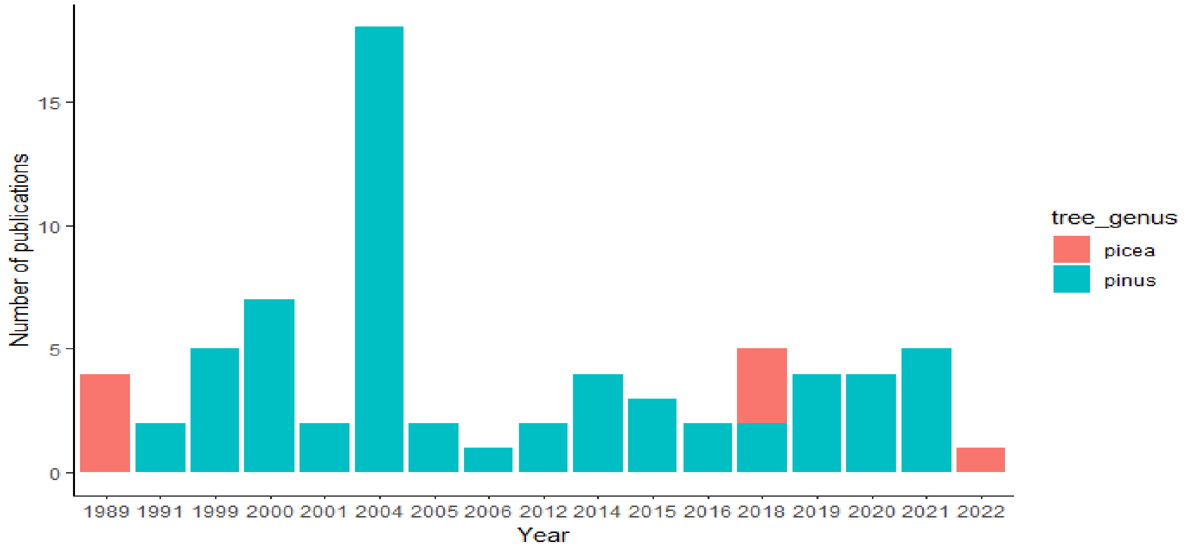


Figure 9: Number of publications on conifer resistance to abiotic stress

Publication year of articles included in the meta-analysis of ECM effect on *Pinus* and *Picea* on abiotic stress.

Growth studies were mostly conducted in a growth facility, and much of the investigation was conducted on *Pinus.* No field studies were conducted on *Picea* (Figure 9).

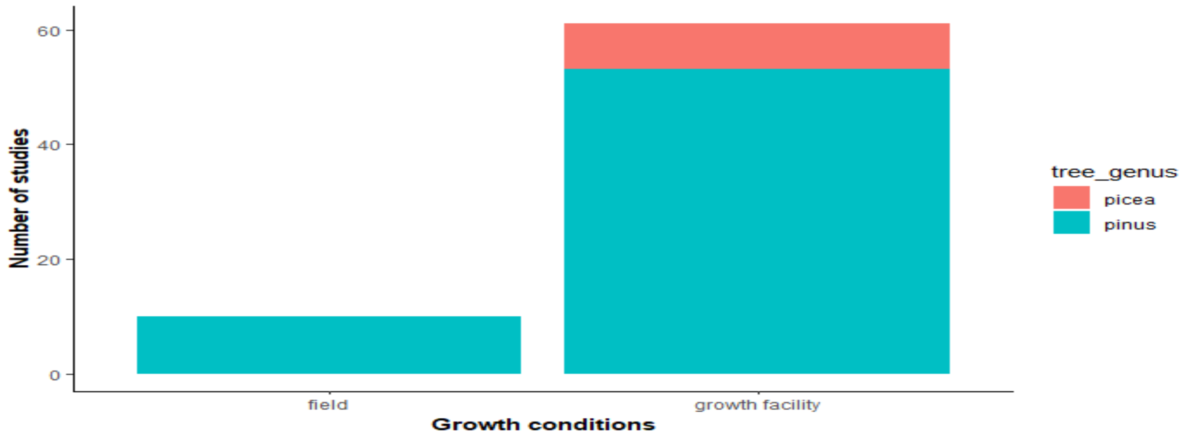


Figure 10: Growth conditions under which studies on abiotic stress in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on abiotic stress were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to "growth facility" and those which were carried out in the field were allocated to "field".

The most common ECM genera used were members of the genus *Suillus* or a combination of different ectomycorrhizal fungi. The most tested tree species were in the genus *Pinus*. (Figure 10).

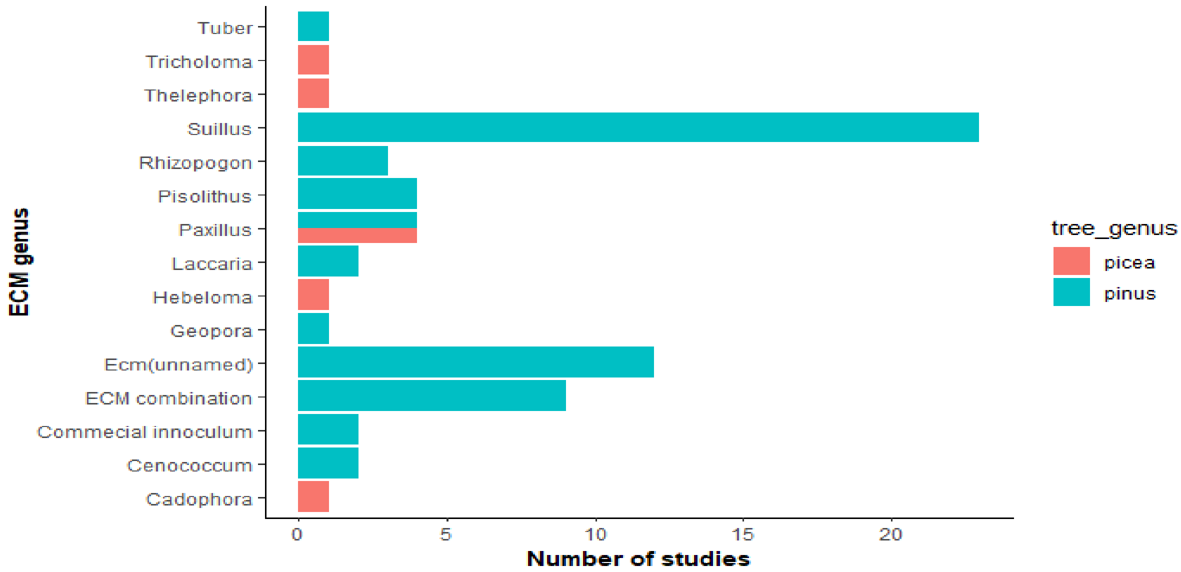


Figure 11: ECM genera which were used for growth studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on abiotic stress were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used.

Soil types: composite, field and sandy were used on both *Pinus* and *Picea* and media soil type was not used on both tree species. The number of studies performed using these three soil types were almost equal on *Pinus* species and on Picea species as well (Figure 12).

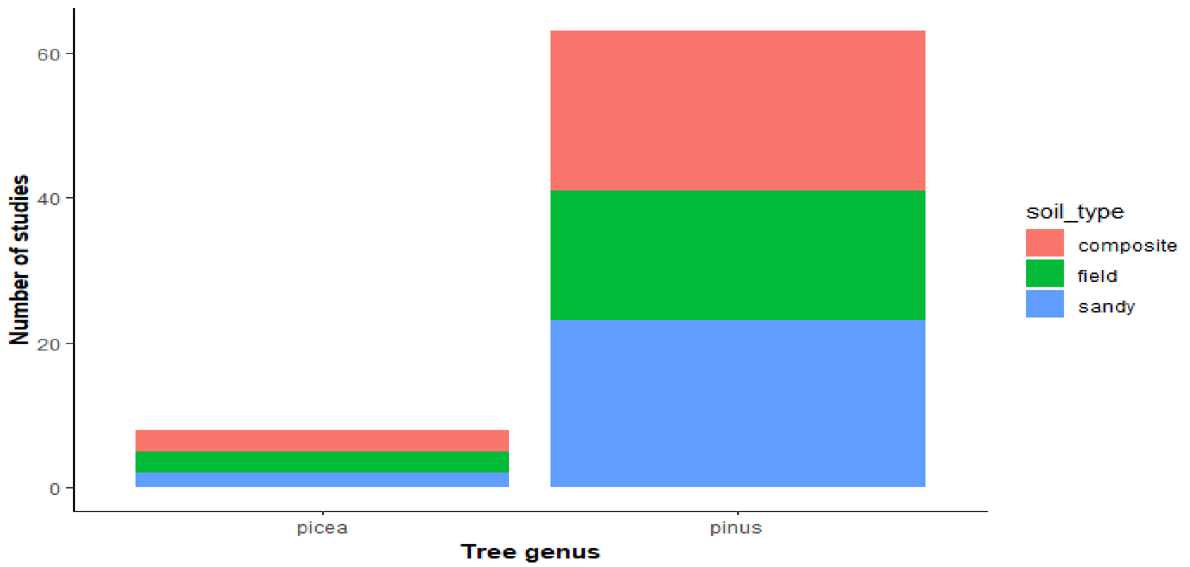


Figure 12: Soil type used on conifer resistance to abiotic stress studies.

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled effect size based on the three- level meta -analysis model was 0.0014 (95% CI: -0.02- 0.02; p=0, 9), indicating a very small effect of ectomycorrhizal fungi on abiotic stress. There is low level of heterogeneity in the abiotic factor.$I^2_{level\ 3}$ (overall effect size) was 0% and $I^2_{level\ 1}$(individual effects) was 100%, meaning variability in effect size estimates is due to sampling error within studies. (Figure 12).

There is an indication of publication bias because small studies that favours ectomycorrhizal fungi are missing at the lower right hand-side of the plot vice versa (the plot is not symmetrical) or small negative studies at the bottom left do not balance small positive studies at the bottom right. However almost all studies are not significant as only 2 studies were significant.

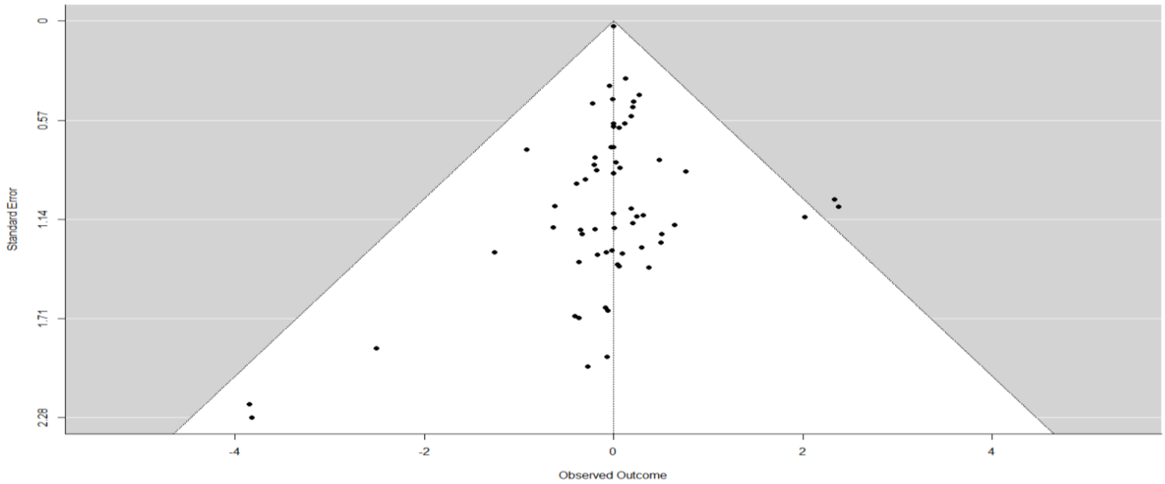


Figure 13: Funnel plot showing publication bias on abiotic stress studies.

Funnel plot showing publication bias of abiotic stress studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome. The outer dashed lines show the 95%Confidence Interval limit. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted funnel.

The pooled estimated effects sizes of the moderators were dispersed around zero meaning ectomycorrhizal fungi did not enhance conifer resistance to abiotic stress (Table 2). They had no significant moderating effect ($P > 0.05$) on the relationship between ectomycorrhizal fungi and conifer resistance to abiotic stress.

Table 2: Overview of estimated pooled effect sizes of abiotic factor moderators using a three level meta-analysis random effects model.

Moderator	**Estimate**	**Standard error**	**T value**	**Degrees of freedom**	**P value**	**Lower confidence interval**	**Higher confidence interval**
ECM	0.001	0.5904	0.0017	56	0.9987	-1.1818	1.1838
Soil type	0.079	0.1356	0.5829	68	0.5619	-0.1915	0.3496
Growth conditions	0.136	0.3183	0.4272	69	0.6705	-0.499	0.7709
Tree age	0.0057	0.0375	0.152	69	0.8796	-0.0691	0.0805
Tree genus	0.0047	0.2939	-0.0159	69	0.9874	-0.5816	0.5909
Stress type	-0.527	0.2597	-0.2029	68	0.8398	-0.5709	0.4655

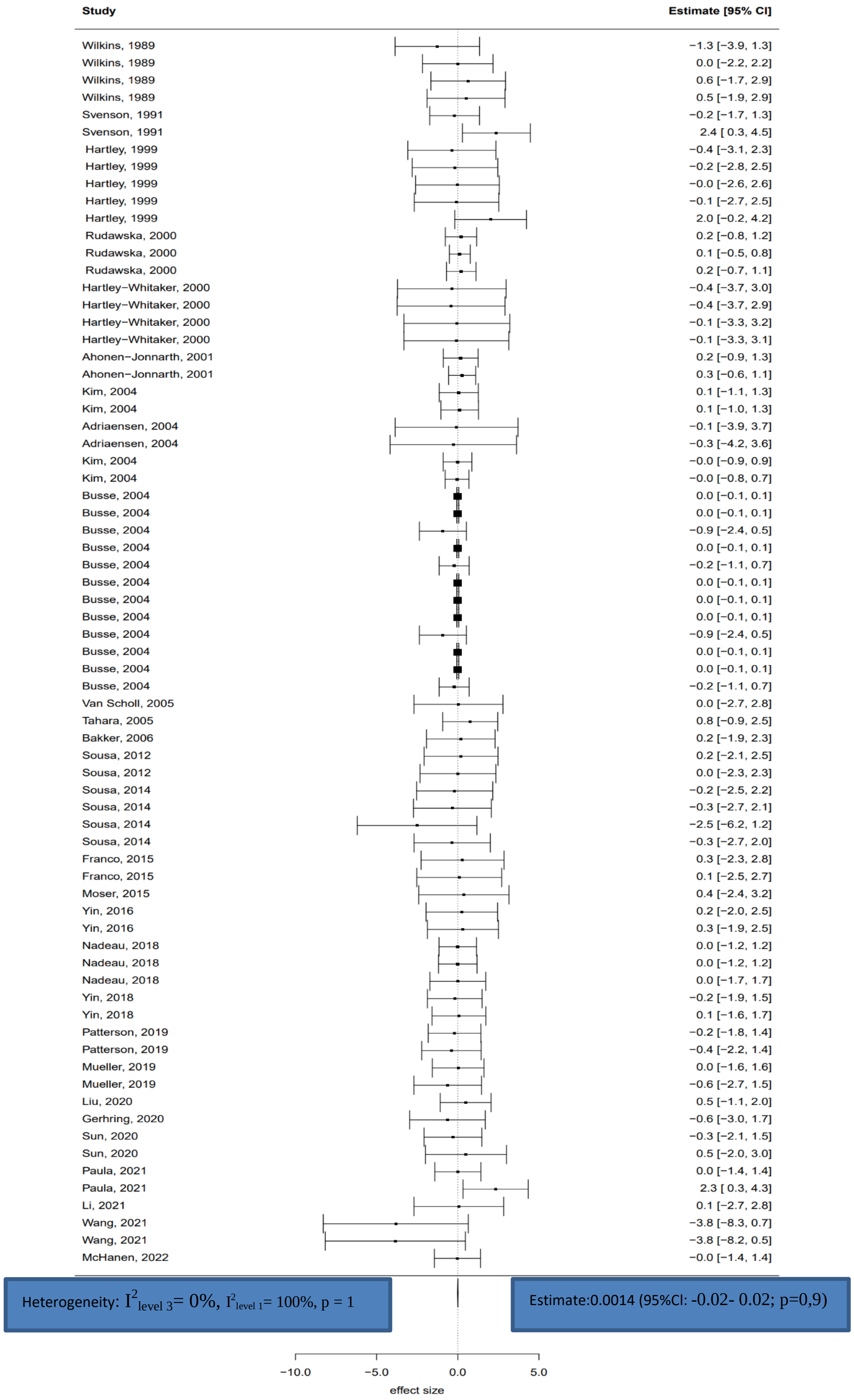

Study
Estimate [95% CI]
Wilkins, 1989 −1.3 [−3.9, 1.3]
Wilkins, 1989 0.0 [−2.2, 2.2]
Wilkins, 1989 0.6 [−1.7, 2.9]
Wilkins, 1989 0.5 [−1.9, 2.9]
Svenson, 1991 −0.2 [−1.7, 1.3]
Svenson, 1991 2.4 [0.3, 4.5]
Hartley, 1999 −0.4 [−3.1, 2.3]
Hartley, 1999 −0.2 [−2.8, 2.5]
Hartley, 1999 −0.0 [−2.6, 2.6]
Hartley, 1999 −0.1 [−2.7, 2.5]
Hartley, 1999 2.0 [−0.2, 4.2]
Rudawska, 2000 0.2 [−0.8, 1.2]
Rudawska, 2000 0.1 [−0.5, 0.8]
Rudawska, 2000 0.2 [−0.7, 1.1]
Hartley−Whitaker, 2000 −0.4 [−3.7, 3.0]
Hartley−Whitaker, 2000 −0.4 [−3.7, 2.9]
Hartley−Whitaker, 2000 −0.1 [−3.3, 3.2]
Hartley−Whitaker, 2000 −0.1 [−3.3, 3.1]
Ahonen−Jonnarth, 2001 0.2 [−0.9, 1.3]
Ahonen−Jonnarth, 2001 0.3 [−0.6, 1.1]
Kim, 2004 0.1 [−1.1, 1.3]
Kim, 2004 0.1 [−1.0, 1.3]
Adriaensen, 2004 −0.1 [−3.9, 3.7]
Adriaensen, 2004 −0.3 [−4.2, 3.6]
Kim, 2004 −0.0 [−0.9, 0.9]
Kim, 2004 −0.0 [−0.8, 0.7]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.9 [−2.4, 0.5]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.2 [−1.1, 0.7]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.9 [−2.4, 0.5]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 0.0 [−0.1, 0.1]
Busse, 2004 −0.2 [−1.1, 0.7]
Van Scholl, 2005 0.0 [−2.7, 2.8]
Tahara, 2005 0.8 [−0.9, 2.5]
Bakker, 2006 0.2 [−1.9, 2.3]
Sousa, 2012 0.2 [−2.1, 2.5]
Sousa, 2012 0.0 [−2.3, 2.3]
Sousa, 2014 −0.2 [−2.5, 2.2]
Sousa, 2014 −0.3 [−2.7, 2.1]
Sousa, 2014 −2.5 [−6.2, 1.2]
Sousa, 2014 −0.3 [−2.7, 2.0]
Franco, 2015 0.3 [−2.3, 2.8]
Franco, 2015 0.1 [−2.5, 2.7]
Moser, 2015 0.4 [−2.4, 3.2]
Yin, 2016 0.2 [−2.0, 2.5]
Yin, 2016 0.3 [−1.9, 2.5]
Nadeau, 2018 0.0 [−1.2, 1.2]
Nadeau, 2018 0.0 [−1.2, 1.2]
Nadeau, 2018 0.0 [−1.7, 1.7]
Yin, 2018 −0.2 [−1.9, 1.5]
Yin, 2018 0.1 [−1.6, 1.7]
Patterson, 2019 −0.2 [−1.8, 1.4]
Patterson, 2019 −0.4 [−2.2, 1.4]
Mueller, 2019 0.0 [−1.6, 1.6]
Mueller, 2019 −0.6 [−2.7, 1.5]
Liu, 2020 0.5 [−1.1, 2.0]
Gerhring, 2020 −0.6 [−3.0, 1.7]
Sun, 2020 −0.3 [−2.1, 1.5]
Sun, 2020 0.5 [−2.0, 3.0]
Paula, 2021 0.0 [−1.4, 1.4]
Paula, 2021 2.3 [0.3, 4.3]
Li, 2021 0.1 [−2.7, 2.8]
Wang, 2021 −3.8 [−8.3, 0.7]
Wang, 2021 −3.8 [−8.2, 0.5]
McHanen, 2022 −0.0 [−1.4, 1.4]
Heterogeneity: I2level 3= 0%, I2level 1= 100%, p = 1
Estimate:0.0014 (95%CI: -0.02- 0.02; p=0,9)
−10.0
−5.0
0.0
5.0
effect size

Figure 14: Forest plot of the overall effects of ECM on conifer resistance to abiotic stress

Forest plot of the overall effects of ectomycorrhizal fungi on *Pinus* or *Picea* to abiotic stress. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall effect of the study.

3.3 Effects of ECM on conifer tree Survival

There are more published articles on *Pinus* compared to *Picea*. Publications for *Picea* were high in 2005 and 2011 followed by a sharp decrease in 2014. There were no *Picea* publications between 2014 to 2020 (Figure 13).

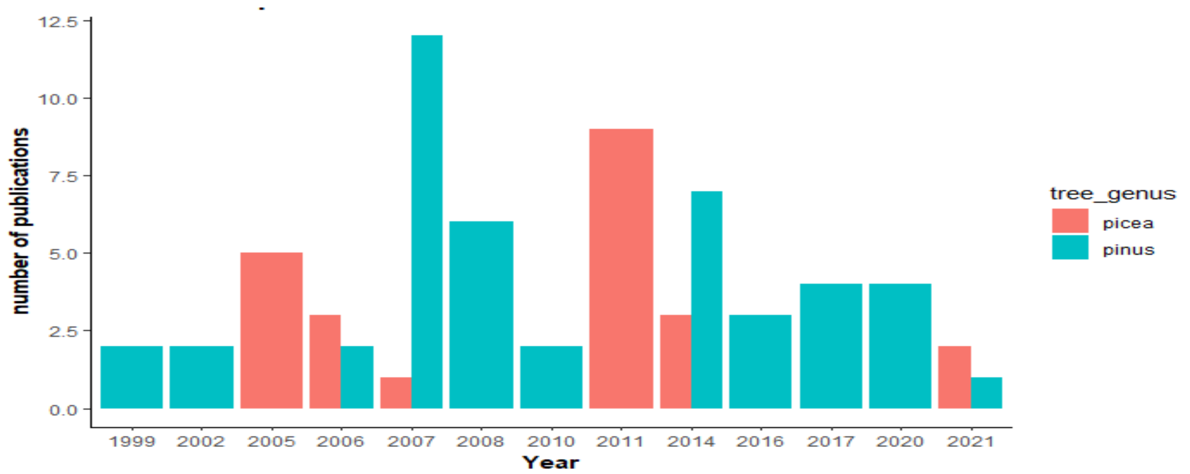


Figure 15: Number of publications on conifer survival.

Publication year of articles included in the meta-analysis of ECM effect on *Pinus* and *Picea* survival.

Most studies were conducted in the field and a significant number of *Picea* species were tested in the field (Figure 14).

Figure 16: Growth conditions under which studies on conifer survival in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on *Pinus* and *Picea* survival were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to "growth facility" and those which were carried out in the field were allocated to "field".

The most common ECM genera used were *Suillus*, *ECM combination* and *Pisolithus*. ECM was mostly tested on *Pinus* species (Figure 15).

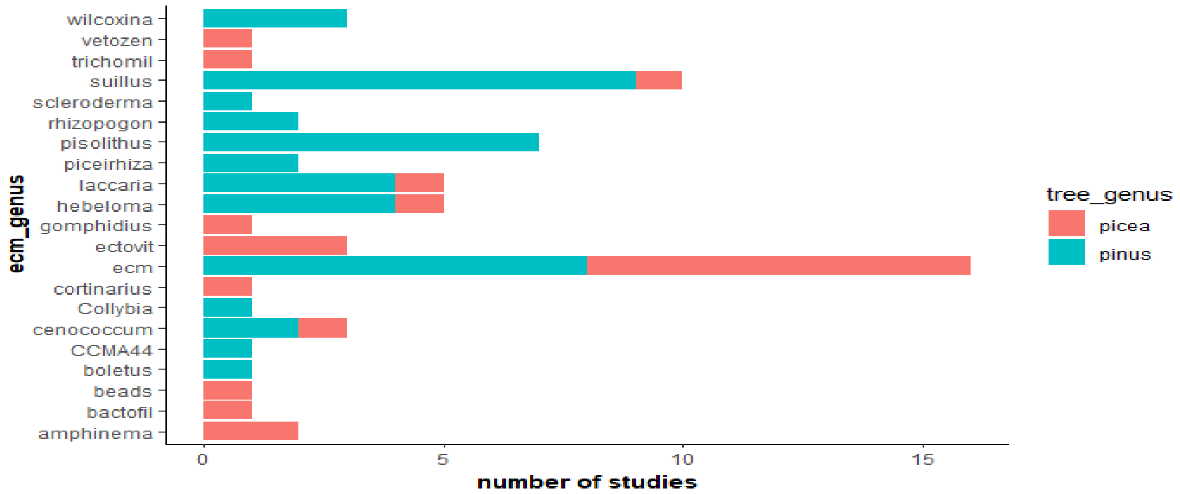


Figure 17: ECM genera which were used for growth studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on survival were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used.

All the four soil types were used on *Pinus* species and three soil types excluding media were used on *Picea* species. The most used soil type on *Pinus* species was the field soil. Both field and composite soil types were mostly used on *Picea* species.

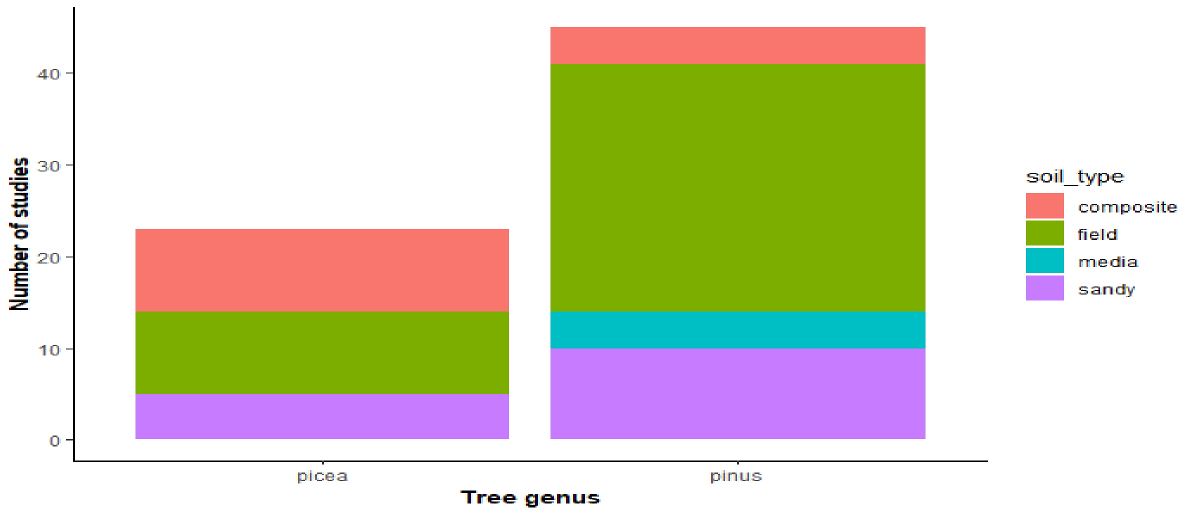


Figure 18: Soil type used on conifer tree survival studies.

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled estimated effect size based on the three-level meta -analysis model was 0.09 (95% CI: 0.25- 0.44; p = 1) meaning that ectomycorrhizal fungi had a negative effect on conifer survival. There is high heterogeneity in the study, $I^2_{level\ 3}$ (overall effect size) was 34.27% and $I^2_{level\ 2}$ (nested effect sizes from individual studies) was 64.61% (Figure 17).

There is an indication of publication bias because the graph is asymmetrical. Small studies that do not favour and that favours ectomycorrhizal fungi are missing at the lower right hand and left hand of the plot. Most studies are not significant, and a few significant studies are outside the triangle.

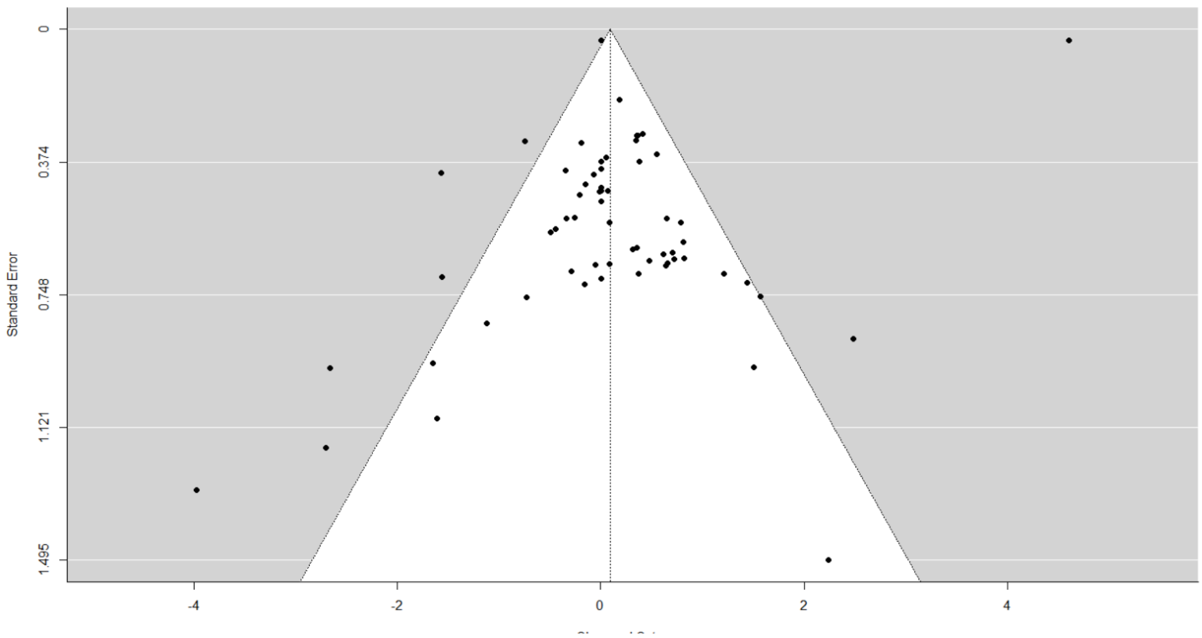


Figure 19: Funnel plot showing publication bias of survival studies.

Funnel plot showing publication bias of studies on survival. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome (effect size). The outer dashed lines show the 95% confidence interval. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted funnel.

The pooled estimated effects sizes of the moderators were dispersed around zero meaning ectomycorrhizal fungi did not enhance and conifer tree survival (Table 3). They had no significant moderating effect (P>0.05) on the relationship between ectomycorrhizal fungi and conifer survival.

Table 3: Overview of estimated pooled effect sizes of survival factor moderators using a three level meta-analysis random effects model.

Moderator	**Estimate**	**Standard error**	**T value**	**Degrees of freedom**	**P value**	**Lower confidence interval**	**Higher confidence interval**
ECM	0.001	0.6831	0.0015	47	0.9988	-1.3732	1.3752
Soil type	-0.0876	0.4044	-0.2165	63	0.8293	-0.8957	0.7206
Growth conditions	0.0654	0.219	-0.2986	66	0.7662	-0.3719	0.5027
Tree age	0.2698	0.3117	0.8657	66	0.3898	-0.3525	0.8921
Tree genus	0.1403	0.3002	0.4672	66	0.6419	-0.4592	0.7397

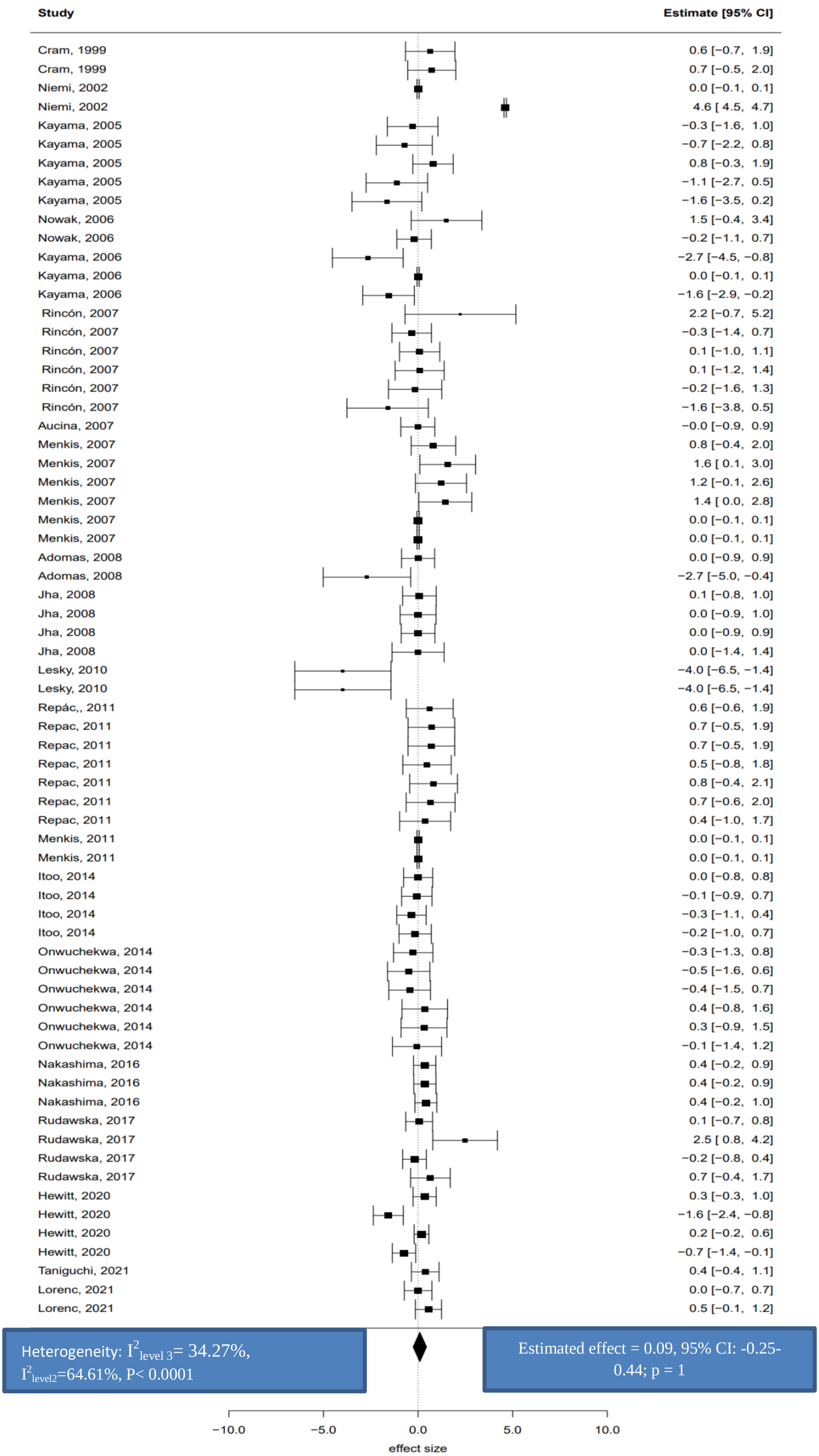

Study
Estimate [95% CI]
Cram, 1999 0.6 [−0.7, 1.9]
Cram, 1999 0.7 [−0.5, 2.0]
Niemi, 2002 0.0 [−0.1, 0.1]
Niemi, 2002 4.6 [4.5, 4.7]
Kayama, 2005 −0.3 [−1.6, 1.0]
Kayama, 2005 −0.7 [−2.2, 0.8]
Kayama, 2005 0.8 [−0.3, 1.9]
Kayama, 2005 −1.1 [−2.7, 0.5]
Kayama, 2005 −1.6 [−3.5, 0.2]
Nowak, 2006 1.5 [−0.4, 3.4]
Nowak, 2006 −0.2 [−1.1, 0.7]
Kayama, 2006 −2.7 [−4.5, −0.8]
Kayama, 2006 0.0 [−0.1, 0.1]
Kayama, 2006 −1.6 [−2.9, −0.2]
Rincón, 2007 2.2 [−0.7, 5.2]
Rincón, 2007 −0.3 [−1.4, 0.7]
Rincón, 2007 0.1 [−1.0, 1.1]
Rincón, 2007 0.1 [−1.2, 1.4]
Rincón, 2007 −0.2 [−1.6, 1.3]
Rincón, 2007 −1.6 [−3.8, 0.5]
Aucina, 2007 −0.0 [−0.9, 0.9]
Menkis, 2007 0.8 [−0.4, 2.0]
Menkis, 2007 1.6 [0.1, 3.0]
Menkis, 2007 1.2 [−0.1, 2.6]
Menkis, 2007 1.4 [0.0, 2.8]
Menkis, 2007 0.0 [−0.1, 0.1]
Menkis, 2007 0.0 [−0.1, 0.1]
Adomas, 2008 0.0 [−0.9, 0.9]
Adomas, 2008 −2.7 [−5.0, −0.4]
Jha, 2008 0.1 [−0.8, 1.0]
Jha, 2008 0.0 [−0.9, 1.0]
Jha, 2008 0.0 [−0.9, 0.9]
Jha, 2008 0.0 [−1.4, 1.4]
Lesky, 2010 −4.0 [−6.5, −1.4]
Lesky, 2010 −4.0 [−6.5, −1.4]
Repác,, 2011 0.6 [−0.6, 1.9]
Repac, 2011 0.7 [−0.5, 1.9]
Repac, 2011 0.7 [−0.5, 1.9]
Repac, 2011 0.5 [−0.8, 1.8]
Repac, 2011 0.8 [−0.4, 2.1]
Repac, 2011 0.7 [−0.6, 2.0]
Repac, 2011 0.4 [−1.0, 1.7]
Menkis, 2011 0.0 [−0.1, 0.1]
Menkis, 2011 0.0 [−0.1, 0.1]
Itoo, 2014 0.0 [−0.8, 0.8]
Itoo, 2014 −0.1 [−0.9, 0.7]
Itoo, 2014 −0.3 [−1.1, 0.4]
Itoo, 2014 −0.2 [−1.0, 0.7]
Onwuchekwa, 2014 −0.3 [−1.3, 0.8]
Onwuchekwa, 2014 −0.5 [−1.6, 0.6]
Onwuchekwa, 2014 −0.4 [−1.5, 0.7]
Onwuchekwa, 2014 0.4 [−0.8, 1.6]
Onwuchekwa, 2014 0.3 [−0.9, 1.5]
Onwuchekwa, 2014 −0.1 [−1.4, 1.2]
Nakashima, 2016 0.4 [−0.2, 0.9]
Nakashima, 2016 0.4 [−0.2, 0.9]
Nakashima, 2016 0.4 [−0.2, 1.0]
Rudawska, 2017 0.1 [−0.7, 0.8]
Rudawska, 2017 2.5 [0.8, 4.2]
Rudawska, 2017 −0.2 [−0.8, 0.4]
Rudawska, 2017 0.7 [−0.4, 1.7]
Hewitt, 2020 0.3 [−0.3, 1.0]
Hewitt, 2020 −1.6 [−2.4, −0.8]
Hewitt, 2020 0.2 [−0.2, 0.6]
Hewitt, 2020 −0.7 [−1.4, −0.1]
Taniguchi, 2021 0.4 [−0.4, 1.1]
Lorenc, 2021 0.0 [−0.7, 0.7]
Lorenc, 2021 0.5 [−0.1, 1.2]
Heterogeneity: I2level 3= 34.27%, I2level2=64.61%, P< 0.0001
Estimated effect = 0.09, 95% CI: -0.25-0.44; p = 1
−10.0
−5.0
0.0
5.0
10.0
effect size

Figure 20: Forest plot of the overall effects of ECM on conifer survival

Forest plot of the overall effects of ectomycorrhizal fungi on *Pinus* or *Picea* survival. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall effect of the study.

3.4 Effects of ECM on conifer resistance to biotic stress

There were very few publications on *Picea* species between 1993 and 2022. Only three articles were published (2010, 2018 and 2021), (Figure 20).

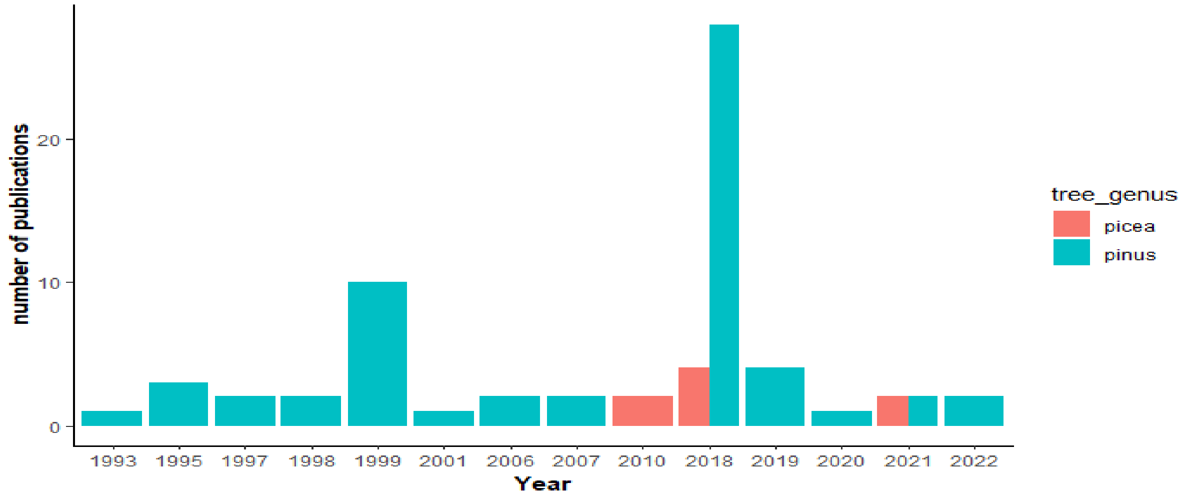


Figure 21: Number of publications on conifer resistance to biotic stress

Publication year of articles included in the meta-analysis of ECM effect on *Pinus* and *Picea* on biotic stress.

Most studies were conducted in a growth facility with *Pinus* accounting to more than half of the studies. Minute studies were conducted in the field on both tree species.

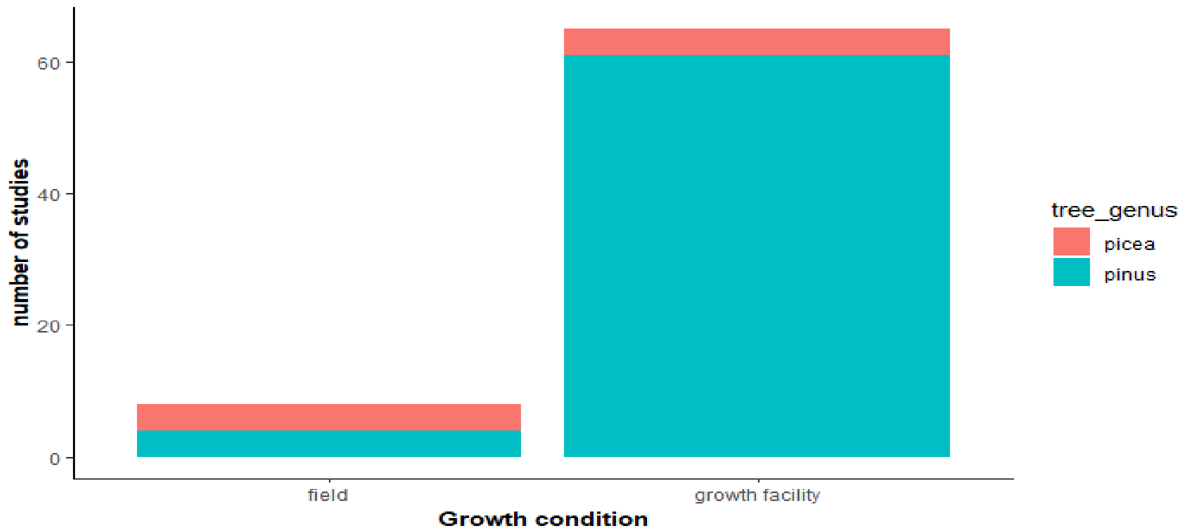


Figure 22: Growth conditions under which studies on conifer biotic stress studies in the meta-analysis were conducted.

Growth condition under which studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on biotic stress were conducted. Studies conducted under controlled environments, greenhouse, glasshouse, lab, or nursery, were allocated to "growth facility" and those which were carried out in the field were allocated to "field". (*Pinus* is represented by blue and *Picea* by pink).

The most used ECM were the *Rhizopogon*, *Lactarius*, *Suillus*, *Paxillus* and ECM combination, but they were only experimented *Pinus*. There were very few studies on Picea species (Figure 20).

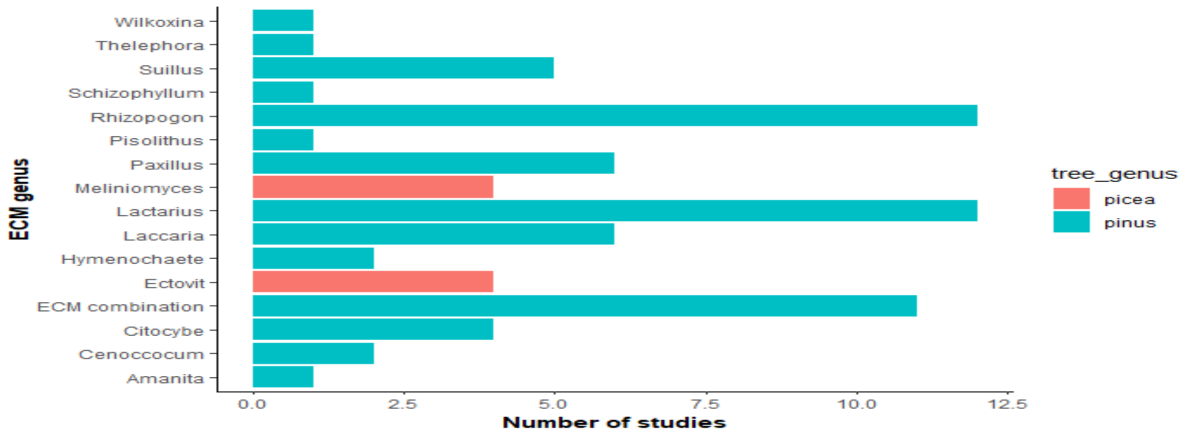


Figure 23: ECM genera which were used for biotic studies in the meta-analysis.

ECM genera used in studies included in meta-analysis of ECM effect on *Pinus* and *Picea* on biotic stress were conducted. ECM denotes ectomycorrhizal fungi where more than one ECM genus was used.

The most common used soil type on *Pinus* species was the composite followed by the field soil type. Both composite and field soil types were equally used on *Picea* species.

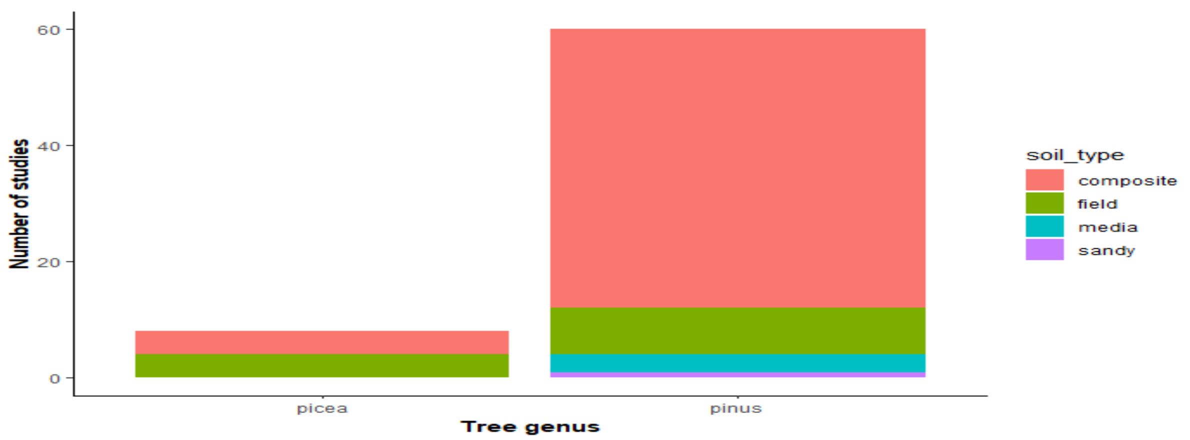


Figure 24: Soil type used on conifer resistance to biotic stress studies

Soil from the forest or field was categorised as field. Nursery soils, i.e., various mixtures of soil substrates such as vermiculite and peat, were categorised as composite soil. Studies using sand as the main substrate were classified as sandy soil. Liquid substrates and agars were classified as media.

The overall pooled estimated effect size based on the level three meta -analysis model was (-0.1), (95% CI: -0.8- 0.69; p = 1) meaning ectomycorrhizal fungi did not improve tree resistance to biotic stress. There is high heterogeneity in the biotic factor study. $I^2_{level\ 3}$ (overall effect size) was 5.5% and $I^2_{level\ 2}$ (nested effect sizes from individual studies) was 90.34% (Figure 22).

The pooled estimated effects sizes of the moderators were below zero indicating a very weak relationship on biotic stress (Table 4). They had no significant moderating effect (P>0.05) on the relationship between ectomycorrhizal fungi and conifer resistance to biotic stress, though growth conditions, tree age and soil type had positive effects.

Table 4: Overview of estimated pooled effect sizes of biotic factor moderators using a three level meta-analysis random effects model.

Moderator	**Estimate**	**Standard error**	**T value**	**Degrees of freedom**	**P value**	**Lower confidence interval**	**Higher confidence interval**
ECM	-2.078	0.6831	0.0015	56	0.4721	-7.6393	3.6873
Soil type	-0.1581	0.4044	-0.2165	63	0.8697	-2.0.762	1.7599
Growth conditions	0.8807	0.219	-0.2986	71	0.3722	-2.8363	1.0749
Tree age	0.9474	0.3117	0.8657	57	0.7386	-4.7106	6.6054
Stress type	7.7104	5.4015	1.4275	37	0.1618	-3.2341	18.6549

There is an indication of publication bias because the graph looks asymmetrical. There is only one small study that does not favour ectomycorrhizal fungi at the lower bottom left of the funnel (missing small studies). Most studies are however not significant.

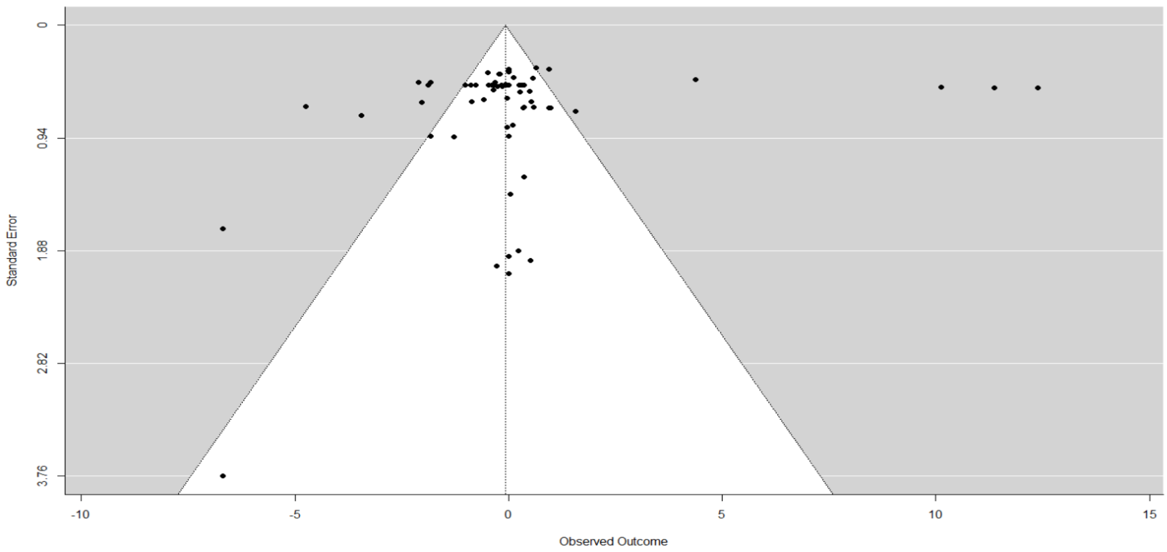


Figure 25: Funnel plot showing publication bias of biotic studies.

Funnel plot showing publication bias of biotic studies. Each dot represents a study (measuring effect of ectomycorrhizal fungi). The y-axis represents the study precision (standard error) and the x-axis shows the study outcome. The outer dashed lines shows the 95% confidence interval limit. The average effect size is shown by the dashed line in the middle. Larger and most powerful studies are placed towards the top. In the absence of a bias the scatter will resemble a symmetrical inverted funnel.

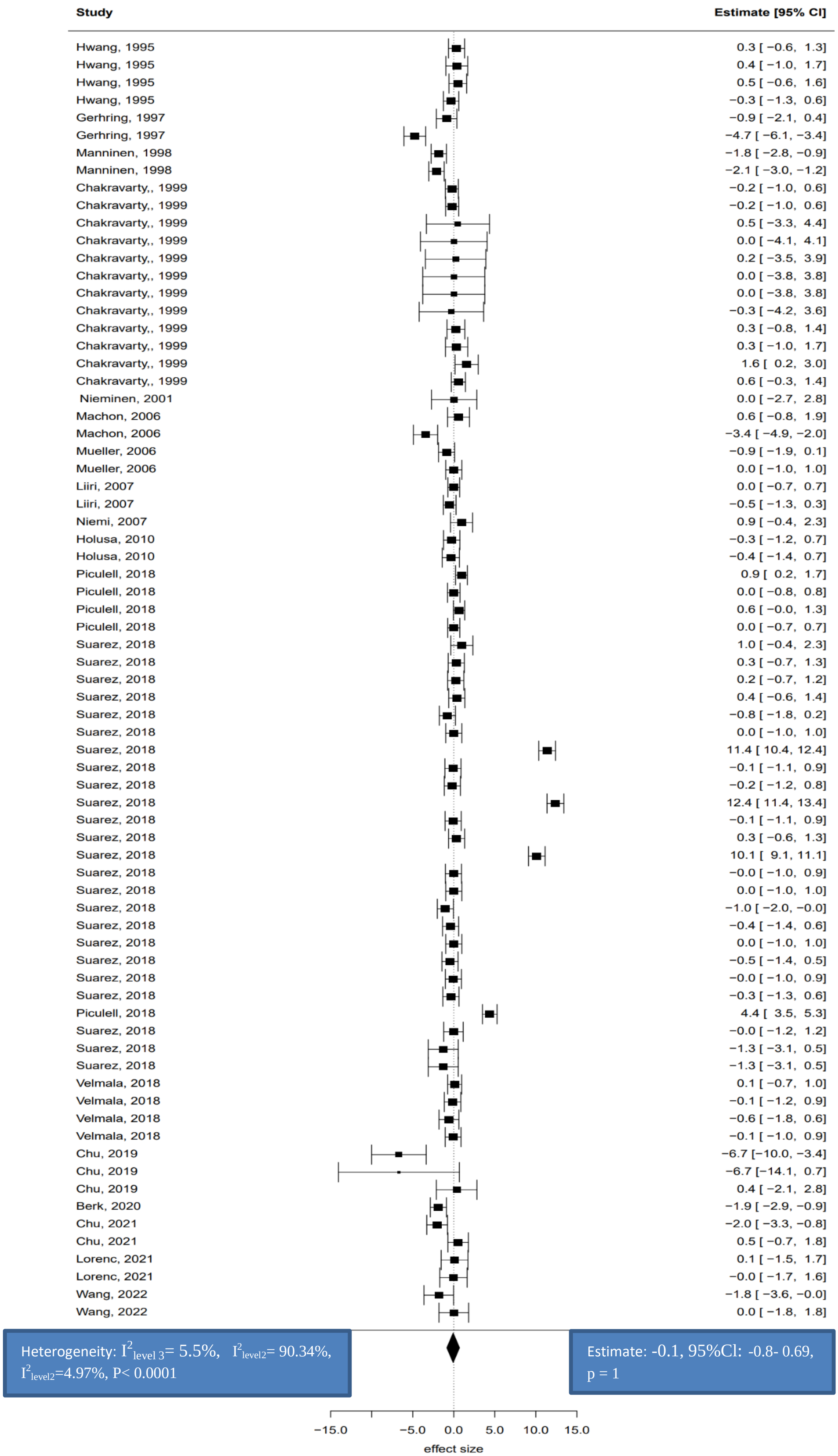

Study
Estimate [95% CI]
Hwang, 1995 0.3 [−0.6, 1.3]
Hwang, 1995 0.4 [−1.0, 1.7]
Hwang, 1995 0.5 [−0.6, 1.6]
Hwang, 1995 −0.3 [−1.3, 0.6]
Gerhring, 1997 −0.9 [−2.1, 0.4]
Gerhring, 1997 −4.7 [−6.1, −3.4]
Manninen, 1998 −1.8 [−2.8, −0.9]
Manninen, 1998 −2.1 [−3.0, −1.2]
Chakravarty,, 1999 −0.2 [−1.0, 0.6]
Chakravarty,, 1999 −0.2 [−1.0, 0.6]
Chakravarty,, 1999 0.5 [−3.3, 4.4]
Chakravarty,, 1999 0.0 [−4.1, 4.1]
Chakravarty,, 1999 0.2 [−3.5, 3.9]
Chakravarty,, 1999 0.0 [−3.8, 3.8]
Chakravarty,, 1999 0.0 [−3.8, 3.8]
Chakravarty,, 1999 −0.3 [−4.2, 3.6]
Chakravarty,, 1999 0.3 [−0.8, 1.4]
Chakravarty,, 1999 0.3 [−1.0, 1.7]
Chakravarty,, 1999 1.6 [0.2, 3.0]
Chakravarty,, 1999 0.6 [−0.3, 1.4]
Nieminen, 2001 0.0 [−2.7, 2.8]
Machon, 2006 0.6 [−0.8, 1.9]
Machon, 2006 −3.4 [−4.9, −2.0]
Mueller, 2006 −0.9 [−1.9, 0.1]
Mueller, 2006 0.0 [−1.0, 1.0]
Liiri, 2007 0.0 [−0.7, 0.7]
Liiri, 2007 −0.5 [−1.3, 0.3]
Niemi, 2007 0.9 [−0.4, 2.3]
Holusa, 2010 −0.3 [−1.2, 0.7]
Holusa, 2010 −0.4 [−1.4, 0.7]
Piculell, 2018 0.9 [0.2, 1.7]
Piculell, 2018 0.0 [−0.8, 0.8]
Piculell, 2018 0.6 [−0.0, 1.3]
Piculell, 2018 0.0 [−0.7, 0.7]
Suarez, 2018 1.0 [−0.4, 2.3]
Suarez, 2018 0.3 [−0.7, 1.3]
Suarez, 2018 0.2 [−0.7, 1.2]
Suarez, 2018 0.4 [−0.6, 1.4]
Suarez, 2018 −0.8 [−1.8, 0.2]
Suarez, 2018 0.0 [−1.0, 1.0]
Suarez, 2018 11.4 [10.4, 12.4]
Suarez, 2018 −0.1 [−1.1, 0.9]
Suarez, 2018 −0.2 [−1.2, 0.8]
Suarez, 2018 12.4 [11.4, 13.4]
Suarez, 2018 −0.1 [−1.1, 0.9]
Suarez, 2018 0.3 [−0.6, 1.3]
Suarez, 2018 10.1 [9.1, 11.1]
Suarez, 2018 −0.0 [−1.0, 0.9]
Suarez, 2018 0.0 [−1.0, 1.0]
Suarez, 2018 −1.0 [−2.0, −0.0]
Suarez, 2018 −0.4 [−1.4, 0.6]
Suarez, 2018 0.0 [−1.0, 1.0]
Suarez, 2018 −0.5 [−1.4, 0.5]
Suarez, 2018 −0.0 [−1.0, 0.9]
Suarez, 2018 −0.3 [−1.3, 0.6]
Piculell, 2018 4.4 [3.5, 5.3]
Suarez, 2018 −0.0 [−1.2, 1.2]
Suarez, 2018 −1.3 [−3.1, 0.5]
Suarez, 2018 −1.3 [−3.1, 0.5]
Velmala, 2018 0.1 [−0.7, 1.0]
Velmala, 2018 −0.1 [−1.2, 0.9]
Velmala, 2018 −0.6 [−1.8, 0.6]
Velmala, 2018 −0.1 [−1.0, 0.9]
Chu, 2019 −6.7 [−10.0, −3.4]
Chu, 2019 −6.7 [−14.1, 0.7]
Chu, 2019 0.4 [−2.1, 2.8]
Berk, 2020 −1.9 [−2.9, −0.9]
Chu, 2021 −2.0 [−3.3, −0.8]
Chu, 2021 0.5 [−0.7, 1.8]
Lorenc, 2021 0.1 [−1.5, 1.7]
Lorenc, 2021 −0.0 [−1.7, 1.6]
Wang, 2022 −1.8 [−3.6, −0.0]
Wang, 2022 0.0 [−1.8, 1.8]
Heterogeneity: $I^2_{level\ 3}$= 5.5%, I^2_{level2}= 90.34%, I^2_{level2}=4.97%, P< 0.0001
Estimate: -0.1, 95%Cl: -0.8- 0.69, p = 1
−15.0
−5.0
0.0
5.0
10.0
15.0
effect size

Figure 17:

Forest plot of the overall effects of ectomycorrhizal fungi on *Pinus* or *Picea* to biotic stress. Error bars represents 95% confidence intervals (CI). The black diamond on the scale is representing the overall pooled effect size of the studies.

4.0 DISCUSSION

In this study a meta- analysis of the effects of ectomycorrhizal fungi in enhancing conifer (*Pinus* and *Picea*) growth, survival and resistance to biotic and abiotic stress was conducted. I found that there was a large body of literature on this topic (1806 publications). Statistical data was recorded for articles which measured morphological characteristics such as seedling height, root length and stem diameter. This is because plant height is closely related to the life span, seed mass and time to maturity(Moles et al., 2009), and linked to the yield potential(Tilly et al., 2014). Stem diameter has been considered to be the best predictor of field survival and growth (Haase, 2008) and root length very important because it controls water and nutrient uptake. Other parameters recorded were growth rate, survival, mortality and disease incidence. Several articles which were published in the 1980s and 1990s were in accessible, thus were excluded for the meta-analysis. The reason may be because they had not been digitalised during that time.

A meta-analysis outcome can be affected by publication and other forms of selection biases, and funnel plots are usually used to quantify and detect such biases (Tang & Liu, 2000). A symmetrical funnel indicates absence of bias, and an asymmetrical funnel indicates bias(Sterne & Harbord, 2004), (Figure 5). There were huge volume of studies on growth which may have caused the width of the confidence intervals to decrease(Higgins, 2011). There is an indication of publication bias in this study which is indicated by the asymmetry of funnel plots(Sterne & Harbord, 2004). However asymmetrical shape of the funnel plots may also be as a result of other biases such as non- inclusion of articles that were not accessible but relevant, language (only studies written in English was included), method of selection or small study effects. Additional, negative studies have a small chance on publication in English language journals, although the regularity has not always been observed(Thornton & Lee, 2000). The bias can also be as a result of citation as studies with positive results are cited more. As a result, they are easily identified and incorporated in databases (Eyding et al., 2010). Karst et al. (2023) also gave evidence of citation bias on mycorrhizal networks in forests and this has affected a clear understanding of mycorrhizal structure and function.

This analysis is also characterised by high heterogeneity which made it difficult to interpret the results. Higgins and Thompson (2002) argue that heterogeneity is inevitable and any level of heterogeneity is acceptable provided that the studies included were appropriate and the data was handled properly. In this analysis, I used the widely accepted heterogeneity statistic $I^{2.}$ However it should be noted that this statistic may overestimate the heterogeneity when the sample size of the study is small. (von Hippel, 2015). Heterogeneity between studies may also produce asymmetrical funnel plots. The plot assumes that the spread of effect sizes is as a result of heterogeneity, but this does not necessarily indicate that the effects are insignificant. Additional, when dealing with larger studies more investment is needed and there is a chance of the methodology being more rigorous. This can also contribute to asymmetry in the funnel plots (Page et al., 2020). Thus, all conclusions made in this thesis should be considered with these biases in mind.

Lack of correct identification of mycorrhiza may also contribute to inaccurate results in that species may have been incorrectly designated in databases. This is supported by Fruleux et al. (2022) who argues that there may be putative diagnosis errors such as reported ectomycorrhizal fungi which will be otherwise Arbuscular mycorrhizal fungi. Improving sequencing technologies that produce more longer sequence reads and more accurate base calling may help to identify mycorrhiza and resolve these inaccuracies.

In this study, most of the experiments were conducted in growth facilities except for survival studies where field experiments dominated. This limited transfer of methods to the field was highlighted as critical regardless of publication bias by Khokon and Meier (2023). The criticality comes in the sense that the field encompasses the widest ecosystem where mycorrhizal traits could be studied without moderating environmental conditions. Lack of consistency in the results of this study was also as a result of lack of more published articles on the relationship of ECM with *Picea* or *Pinus*. The whole study was also dominated by the use of *Suillus* species as the ectomycorrhizal inoculant. A total of 8.2% of ectomycorrhizal fungi papers in the past 40 years have concerned *Suillus* which is known to exhibit a high degree of specificity to conifers(Dahlberg & Finlay, 1999). Interestingly Zhang et al. (2022) study on host shift speciation of *Suillus* and the Pinaceae did not identify any cospeciation patterns between *Suillus* and the sub genera Pinacea and their history together is seen to be discordant.

The initial research question of this meta-analysis was to know if there is evidence of ectomycorrhizal fungi in enhancing conifer growth and survival and if it improves their resistance to biotic and abiotic stress. Ectomycorrhizal fungi were however found to enhance growth but no significant effect was found on enhancing conifer survival and resistance to biotic and abiotic stress. The evidence of ectomycorrhizal fungi in enhancing growth is supported in a meta-analysis by Alberton et al. (2014) where ECM was found to increase growth of *Pinus species*. However, data from only 6 studies were collected for this meta-analysis. A meta-analysis by Gan et al. (2021) provided some quantitative evidence of the rhizosphere in influencing below ground carbon and nutrient cycling in forest ecosystems which in turn improves growth.

In this study, ectomycorrhizal fungi were however found to have no relationship on tree resistance to abiotic stress. A review by Lehto and Zwiazek (2011) suggested that mycorrhizal structure may impede water movement to the plant due to fine root architecture or the hydrophobicity of the cell wall. This may heavily affect the plant's water absorption efficiency and can get worse during drought stress. Defrenne et al. (2019) research revealed a distinct root structure from seedlings planted in a nursery compared to seedlings regenerated in the field. This architectural difference was thought to lack of ectomycorrhizal partners, which may in turn affect a plant's response to abiotic stress, survival and growth.

Karst et al. (2008) used a meta -analysis to quantitatively evaluate the role of biotic and abiotic factors on host growth and responses to ectomycorrhizal associations on *Pinus* and *Picea*. Overall, in their analysis the host biomass increased in response to ectomycorrhizal inoculation, but the results were distorted by publication bias and methodological issues thus, distorted the spectrum on which they evaluated the host responses to ectomycorrhizal inoculation. This also supports this meta-analysis.

In this study ectomycorrhizal fungi had no effect on survival. This is revealed in Quoreshi et al. (2008), where conifer survival rate of the inoculated seedlings was not significant from the control whose seedlings were naturally colonised by the resident fungi. Nevertheless, ectomycorrhizal fungi helped the conifers to alleviate biotic stress against pathogens and insects. A meta-analysis by Holden and Treseder (2013), showed an increase of fungal abundance following an insect infestation and pathogen induced mortality in a boreal forest.

Howbeit, fungal abundance does not imply the effectiveness of ectomycorrhizal fungi to the host plant (Wagg et al., 2011).

In this study moderators such as soil type, growth condition and tree age were tested to determine their influence on the relationship between conifer growth, survival and resistance to biotic and abiotic stress and ectomycorrhizal fungi. All the moderators They had no significant moderating effect on the relationship between ectomycorrhizal fungi and conifer tree resistance to biotic stress, survival and growth, except for soil type as whole. Therefore, the study cannot determine which soil type contributed the most because they did not have a significant effect when analysed individually but had a significant effect when analysed as a whole.

5.0 CONCLUSION

The interaction between ectomycorrhizal fungi and their conifer host is very complex. Thus it is difficult to capture all the factors that influence the relationship within a study. In this study, publication bias and study heterogeneity made it difficult to interpret the effects of ectomycorrhizal fungi on *Pinus* and *Picea* growth, survival and resistance to biotic and abiotic stress. Therefore, the analysis did not provide concrete conclusions. However, the results of the analysis emphasize the importance of ectomycorrhizal fungi on conifer growth. The majority of the studies were conducted in growth facilities while very few were conducted in the field. There is need to conduct more experiments in the field to better understand the role of ectomycorrhizal fungi in conifer health and success. Also negative results must be published and a platform for this scenario must be created. I also urge researchers to report publication biases in their results. Therefore, there is still too sparse knowledge to provide recommendations on how ectomycorrhizal fungi can be used in forest management.

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APPENDICES

A- Abiotic factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

study_id	year	author	tree_genus	soil_type	ecm_genus	growth_conditions	stress_type	tree_age	tree_category	measured_parameter	n_sample	n_control	treatment_me	Control_mean	data_type	RR	logRR	SElogRR
16	2022	McHanen(2022)	picea	field	thelephora	growth facility	metal	6	seedling	field	7	7	0.92	0.943	percentage	0.97560976	-0.024692613	0.52411006
18	2021	Paula(2021)	pinus	field	commecial in	field	metal	5	seedling	final height	18	18	0.288	0.288	percentage	1	0.001	0.52411006
18	2021	Paula(2021)	pinus	field	commecial in	field	metal	5	seedling	stem diameter	18	18	0.516	0.05	percentage	10.32	2.33408376	1.05245703
22	2021	Li(2021)	pinus	field	suillus	growth facility	drought	12	seedling	seedling height	24	24	0.0213	0.02	percentage	1.065	0.062974799	1.98901522
27	2020	Liu(2021)	pinus	sandy	suillus	growth facility	metal	6	seedling	seedling height	45	45	0.13	0.08	percentage	1.625	0.485507816	0.63582506
29	2020	Gerhring(2020)	pinus	field	ecm	field	drought	6.72	seedling	shoot length	10	5	0.09	0.17	percentage	0.52941176	-0.635988767	1.40981619
51	2016	Yin(2016)	pinus	composite	suillus	growth facility	drought	4	seedling	plant height	10	10	0.127	0.099	percentage	1.28282828	0.249067236	1.26392349
51	2016	Yin(2016)	pinus	composite	suillus	growth facility	drought	4	seedling	plant height	10	10	0.136	0.099	percentage	1.37373737	0.317535036	1.24313922
60	2015	Franco(2015)	pinus	field	pisolithus	growth facility	herbicide	1	seedling	shoot height	10	10	0.076	0.0567	percentage	1.34038801	0.29295913	1.69689655
60	2015	Franco(2015)	pinus	field	suillus	growth facility	herbicide	1	seedling	shoot height	10	10	0.0621	0.0567	percentage	1.0952381	0.090971778	1.78156515
66	2014	Sousa(2015)	pinus	field	suillus	growth facility	metal	6	seedling	shoot height	8	8	0.099	0.12	percentage	0.825	-0.192371893	1.43328048
66	2014	Sousa(2015)	pinus	field	rhizopogon	growth facility	metal	6	seedling	shoot height	8	8	0.086	0.12	percentage	0.71666667	-0.333144447	1.49838414
66	2014	Sousa(2015)	pinus	field	suillus	growth facility	metal	6	seedling	shoot height	8	8	0.0106	0.13	percentage	0.08153846	-2.506680449	3.53609831
66	2014	Sousa(2015)	pinus	field	rhizopogon	growth facility	metal	6	seedling	shoot height	8	8	0.092	0.13	percentage	0.70769231	-0.345745873	1.43883081
91	2012	Sousa(2015)	pinus	field	suillus	growth facility	metal	1.25	seedling	seedling height	10	10	0.11	0.09	percentage	1.22222222	0.200670695	1.34914863
91	2012	Sousa(2015)	pinus	field	rhizopogon	growth facility	metal	1.25	seedling	seedling height	10	10	0.091	0.09	percentage	1.01111111	0.011049836	1.41774899
143	2006	Bakker(2006)	pinus	field	cenococcum	field	drought	20	seedling	root length	4	4	0.297	0.247	percentage	1.20242915	0.184343802	1.16357062
168	2004	Kim(2004)	pinus	composite	paxillus	growth facility	metal	8	seedling	stem length	3	3	0.85	0.8	percentage	1.0625	0.060624622	0.37703695
168	2004	Kim(2004)	pinus	composite	suillus	growth facility	metal	8	seedling	stem length	3	3	0.9	0.8	percentage	1.125	0.117783036	0.34694433
172	2004	Adriaensen(2004)	pinus	sandy	suillus	growth facility	metal	1.5	seedling	Relative growth rate	5	5	0.027	0.029	percentage	0.93103448	-0.071458964	3.7288013
172	2004	Adriaensen(2004)	pinus	sandy	suillus	growth facility	metal	1.5	seedling	Relative growth rate	5	5	0.022	0.029	percentage	0.75862069	-0.276253377	3.94809585
184	2005	Van Scholl(2005)	pinus	sandy	ecm	field	metal	3.5	seedling	root length	8	8	0.0625	0.06	percentage	1.04166667	0.040821995	1.95789002
191	2001	Ahonen-Jonnarth(	pinus	sandy	laccaria	growth facility	metal	3.75	seedling	relative shoot growth	15	15	0.66	0.55	percentage	1.2	0.182321557	0.2981424
191	2001	Ahonen-Jonnarth(	pinus	sandy	laccaria	growth facility	metal	3.75	seedling	relative shoot growth	15	15	0.93	0.71	percentage	1.30985915	0.269919616	0.17957719
197	2000	Rudawska(2000)	pinus	composite	suillus	growth facility	metal	6	seedling	shoot height	23	23	0.66	0.54	percentage	1.22222222	0.200670695	0.2437928
197	2000	Rudawska(2000)	pinus	composite	suillus	growth facility	metal	6	seedling	shoot height	23	23	0.94	0.83	percentage	1.13253012	0.124454174	0.10807587
197	2000	Rudawska(2000)	pinus	composite	suillus	growth facility	metal	6	seedling	shoot height	23	23	0.73	0.59	percentage	1.23728814	0.212921997	0.21516205
203	1999	Hartley(1999	pinus	sandy	ecm	growth facility	metal	10	seedling	root length	12	12	0.0368	0.053	percentage	0.69433962	-0.364794068	1.91576437
203	1999	Hartley(2000	pinus	sandy	ecm	growth facility	metal	10	seedling	root length	12	12	0.0448	0.053	percentage	0.84528302	-0.168083774	1.80714676
203	1999	Hartley(2001	pinus	sandy	ecm	growth facility	metal	10	seedling	root length	12	12	0.052	0.053	percentage	0.98113208	-0.019048195	1.73442339
203	1999	Hartley(2002	pinus	sandy	ecm	growth facility	metal	10	seedling	root length	12	12	0.049	0.053	percentage	0.9245283	-0.078471615	1.76248139
203	1999	Hartley(2003	pinus	sandy	ecm	growth facility	metal	10	seedling	root length	12	12	0.4	0.053	percentage	7.54716981	2.021172634	1.27043052
248	1989	Wilkins(1989)	picea	sandy	paxillus	growth facility	metal	2.5	seedling	shoot height	7	7	0.054	0.19	percentage	0.28421053	-1.258040026	1.76399208
248	1989	Wilkins(1989)	picea	sandy	paxillus	growth facility	metal	2.5	seedling	shoot height	7	7	0.16	0.16	percentage	1	0.001	1.22474487
248	1989	Wilkins(1989)	picea	field	paxillus	growth facility	metal	2.5	seedling	shoot height	7	7	0.19	0.1	percentage	1.9	0.641853886	1.3764944
248	1989	Wilkins(1989)	picea	field	paxillus	growth facility	metal	2.5	seedling	shoot height	7	7	0.15	0.09	percentage	1.66666667	0.510825624	1.50132217
270	2018	Nadeau(2018)	picea	composite	Cadophora	growth facility	metal	8	seedling	root length	3	3	0.8458	0.8458	percentage	1	0.001	0.34862836
270	2018	Nadeau(2018)	picea	composite	tricholoma	growth facility	metal	8	seedling	root length	3	3	0.832	0.832	percentage	1	0.001	0.36689969
270	2018	Nadeau(2018)	picea	composite	hebeloma	growth facility	metal	8	seedling	root length	3	3	0.5301	0.5301	percentage	1	0.001	0.76873772
293	2019	Patterson(2019)	pinus	field	ecm	field	drought	2	seedling	cumulative shoot gr	12	4	0.36	0.44	percentage	0.81818182	-0.200670695	0.68288357
293	2019	Patterson(2019)	pinus	field	ecm	field	drought	2	seedling	cumulative shoot growth	12	4	0.23	0.34	percentage	0.67647059	-0.390866309	0.87423088
294	2005	Tahara(2005)	pinus	composite	pisolithus	growth facility	metal	1	seedling	relative root length	5	3	0.84	0.39	percentage	2.15384615	0.767255153	0.74797243
296	2004	Kim(2004)	pinus	composite	paxillus	growth facility	metal	8	seedling	stem length	9	9	0.84	0.85	percentage	0.98823529	-0.011834458	0.20192044
296	2004	kim(2004)	pinus	composite	suillus	growth facility	metal	8	seedling	stem length	9	9	0.9	0.94	percentage	0.95744681	-0.043485112	0.13941979
311	2015	Moser(2015)	pinus	field	cenococcum	field	drought	6	seedling	cumulative root length	25	25	0.0238	0.0164	percentage	1.45121951	0.372404246	2.00989966
320	2000	Hartley-Whitaker(	pinus	composite	paxillus	growth facility	metal	2	seedling	root length	5	5	0.0381	0.055	percentage	0.69272727	-0.367118903	2.91302377
320	2000	Hartley-Whitaker(	pinus	composite	suillus	growth facility	metal	2	seedling	root length	5	5	0.0385	0.058	percentage	0.6637931	-0.409784769	2.87107664
320	2000	Hartley-Whitaker(	pinus	composite	paxillus	growth facility	metal	2	seedling	root length	5	5	0.0482	0.051	Percentage	0.94509804	-0.056466612	2.76964731
320	2000	Hartley-Whitaker(	pinus	composite	suillus	growth facility	metal	2	seedling	root length	5	5	0.0494	0.0539	Percentage	0.91651206	-0.087180054	2.71277683
322	2018	Yin(2018)	pinus	composite	suillus	growth facility	drought	3	seedling	plant height	30	30	0.1	0.12	Percentage	0.83333333	-0.182321557	0.73786479
322	2018	Yin(2018)	pinus	composite	suillus	growth facility	drought	3	seedling	collar diameter	30	30	0.12	0.112	Percentage	1.07142857	0.068992871	0.71325322
337	2020	Sun(2020)	pinus	composite	suillus	field	metal	24	seedling	plant height	3	3	0.43	0.58	Percentage	0.74137931	-0.299242895	0.82658319
337	2020	Sun(2020)	pinus	composite	suillus	field	metal	24	seedling	ground base diameter	3	3	0.27	0.163	Percentage	1.65644172	0.504671758	1.61644394
43	2021	Wang(2021)	pinus	composite	suillus	growth facility	drought	5	seedling	mortality	3	3	0.0123	0.56	percentage	0.02196429	-3.818337521	5.19892705
43	2021	Wang(2021)	pinus	composite	suillus	growth facility	drought	5	seedling	mortality	3	3	0.0141	0.66	percentage	0.02136364	-3.846065038	4.84551811
288	1991	Svenson(1991)	pinus	composite	pisolithus	growth facility	drought	9.25	seedling	Seedling height	12	12	0.28	0.34	percentage	0.82352941	-0.194156014	0.6132295
288	1991	Svenson(1991)	pinus	composite	pisolithus	growth facility	drought	9.25	seedling	root collar diameter	12	12	0.67	0.062	Percentage	10.8064516	2.380143327	1.14096339
300	2019	Mueller(2019)	pinus	field	tuber	growth facility	drought	72	mature	mortality	7	7	0.4	0.39	Percentage	1.02564103	0.025317808	0.66161087
300	2019	Mueller(2019)	pinus	field	geopora	growth facility	drought	72	mature	mortality	7	7	0.14	0.26	Percentage	0.53846154	-0.619039208	1.13320096
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	1	1	Percentage	1	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	1	1	Percentage	1	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	0.4	1	percentage	0.4	-0.916290732	0.54772256
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	0	1	percentage	0	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	0.8	1	percentage	0.8	-0.223143551	0.2236068
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	0	1	percentage	0	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	1	1	percentage	1	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	1	1	percentage	1	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	0.4	1	percentage	0.4	-0.916290732	0.54772256
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	0	1	percentage	0	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	1	1	percentage	1	0.001	0.001
173	2004	Busse(2004)	pinus	sandy	ecm(unnamec	growth facility	herbicide	4	seedling	survival	5	5	0.8	1	percentage	0.8	-0.223143551	0.2236068

B- Growth factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

study_id	year	author	tree_genus	soil_type	ecm_genus	growth_condition	tree_age	tree_category	Measured parameter	data_type	effect_size	var_d	source
4	2022	Tapwal	pinus	field	scleroderma	field	21	seedling	shoot height	mean	3.38806394	0.66303858	hedges_d
4	2022	Tapwal	pinus	field	scleroderma	field	21	seedling	root length	mean	17.9258364	1.81897308	hedges_d
6	2022	Fahey	pinus	composite	ecm group	growth facility	7	seedling	basal diameter	mean	0	4.90577891	hedges_d
6	2022	Fahey	pinus	composite	ecm group	growth facility	7	seedling	basal diameter	mean	0	4.90577891	hedges_d
6	2022	Fahey	pinus	composite	ecm group	growth facility	7	seedling	basal diameter	mean	0	4.90577891	hedges_d
8	2022	Huang	pinus	media	tuber	growth facility	5	seedling	stem diameter	mean	3.68550399	1.0399382	hedges_d
8	2022	Huang	pinus	media	tuber	growth facility	5	seedling	stem diameter	mean	2.24149681	1.25782598	hedges_d
11	2022	Repac	picea	composite	ectovit	growth facility	36	sapling	stem height	mean	0	4.90577891	hedges_d
23	2021	Peng	pinus	field	suillus	field	54	sapling	seedling height	mean	604.778303	8.27496737	hedges_d
23	2021	Peng	pinus	field	suillus	field	54	sapling	seedling height	mean	680.615556	8.34826893	hedges_d
23	2021	Peng	pinus	field	suillus	field	54	sapling	seedling height	mean	495.411954	8.18358342	hedges_d
23	2021	Peng	pinus	field	suillus	field	54	sapling	seedling height	mean	297.050298	8.06263673	hedges_d
25	2021	Lorenc	picea	sandy	ectovit	field	36	sapling	seedling height	mean	-7.98913065	13.6069853	hedges_d
25	2021	Lorenc	picea	sandy	ectovit	field	36	sapling	seedling height	mean	6.18273874	12.761251	hedges_d
30	2020	verma	pinus	sandy	suillus	field	9	seedling	shoot length	mean	40.4227467	2.6330341	hedges_d
30	2020	verma	pinus	sandy	suillus	field	9	seedling	shoot length	mean	27.3060644	2.42994941	hedges_d
31	2020	zhang	pinus	sandy	tuber	growth facility	8	seedling	plant height	mean	146.490187	12.0049424	hedges_d
31	2020	Zhang	pinus	sandy	tuber	growth facility	8	seedling	plant height	mean	-39.2951055	12.0043023	hedges_d
31	2020	zhang	pinus	sandy	tuber	growth facility	8	seedling	root length	mean	-195.508095	12.0054811	hedges_d
31	2020	Zhang	pinus	sandy	tuber	growth facility	8	seedling	root length	mean	-499.399903	12.0122655	hedges_d
37	2020	Li	pinus	sandy	tuber	growth facility	8	seedling	plant height	mean	-247.277512	5.33962002	hedges_d
37	2020	Li	pinus	sandy	tuber	growth facility	6	seedling	plant height	mean	-195.4605	4.77244191	hedges_d
40	2017	zhang	pinus	composite	handkea	growth facility	6	seedling	root length	mean	84.4937786	3.64755096	hedges_d
40	2017	zhang	pinus	composite	suillus	growth facility	3	seedling	root length	mean	30.1529756	2.46859955	hedges_d
40	2017	zhang	pinus	composite	suillus	growth facility	3	seedling	root length	mean	56.6184389	2.95836221	hedges_d
44	2017	rudawska	pinus	field	suillus	field	24	sapling	seedling height	mean	107.315624	5.95587064	hedges_d
44	2017	rudawska	pinus	field	wilcoxina	field	24	sapling	seedling height	mean	29.9766491	5.92794916	hedges_d
44	2017	rudawska	pinus	field	wilcoxina	field	24	sapling	seedling height	mean	-142.398829	5.97881005	hedges_d
44	2017	rudawska	pinus	field	cenococcum	field	24	sapling	seedling height	mean	135.069978	5.97349327	hedges_d
45	2018	Gallart	pinus	composite	tylospora	growth facility	7	seedling	tree height	mean	6.37186006	3.33542119	hedges_d
45	2018	Gallart	pinus	composite	tylospora	growth facility	7	seedling	tree height	mean	-1.11702215	3.33339752	hedges_d
48	2017	Hazard	pinus	composite	laccaria	growth facility	2	seedling	shoot height	mean	1750.10691	29.2154997	hedges_d
48	2017	Hazard	pinus	composite	laccaria	growth facility	2	seedling	shoot height	mean	2474.20512	29.2157309	hedges_d
48	2017	Hazard	pinus	composite	laccaria	growth facility	2	seedling	root length	mean	-509.304726	29.2152879	hedges_d
48	2017	Hazard	pinus	composite	laccaria	growth facility	2	seedling	root length	mean	70.2247853	29.2152687	hedges_d
51	2016	yin	picea	composite	suillus	growth facility	4	seedling	plant height	mean	-73.7293623	3.81890098	hedges_d
51	2016	yin	picea	composite	suillus	growth facility	4	seedling	plant height	mean	-298.146124	5.95380364	hedges_d
51	2016	yin	pinus	composite	suillus	growth facility	4	seedling	plant height	mean	42.1842529	3.69727978	hedges_d
51	2016	yin	pinus	composite	suillus	growth facility	4	seedling	plant height	mean	51.5035655	3.72668141	hedges_d
52	2016	Barroetaveña	pinus	sandy	suillus	field	54	sapling	stem height	mean	11.0567223	3.64081897	hedges_d
52	2016	Barroetaveña	pinus	sandy	rhizopogon	field	54	sapling	stem height	mean	23.0299468	3.65480432	hedges_d
52	2016	Barroetaveña	pinus	sandy	hebeloma	field	54	sapling	stem height	mean	-5.98784466	3.6378515	hedges_d
52	2016	Barroetaveña	pinus	sandy	suillus	field	54	sapling	stem height	mean	4.90995289	3.63744786	hedges_d
52	2016	Barroetaveña	pinus	sandy	rhizopogon	field	54	sapling	stem height	mean	5.0481131	3.63749514	hedges_d
54	2016	Barroetaveña	pinus	sandy	hebeloma	field	54	sapling	stem height	mean	-1.57666328	3.63670475	hedges_d
59	2015	vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	6.26883073	3.00839469	hedges_d
59	2015	Vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	7.84776961	3.01020299	hedges_d
59	2015	vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	3.0927723	3.00598079	hedges_d
59	2015	vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	11.0376474	3.01508493	hedges_d
59	2015	vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	9.63897674	3.0127423	hedges_d
59	2015	vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	-1.49498508	3.00538538	hedges_d
59	2015	vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	0	3.00520382	hedges_d
59	2015	vaario	pinus	composite	tricholoma	growth facility	2	seedling	shoot height	mean	17.5483064	3.03011762	hedges_d
64	2015	Repac	picea	composite	thelephora	growth facility	24	seedling	stem height	mean	-11.9399617	34.7062341	hedges_d
64	2015	Repac	picea	composite	ectovit	growth facility	24	seedling	stem height	mean	2019.58	34.7063274	hedges_d
67	2014	Itoo	pinus	field	hebeloma	growth facility	5.8	seedling	seedling height	mean	103.887067	8.93579366	hedges_d
67	2014	Itoo	pinus	field	boletus	growth facility	5.8	seedling	seedling height	mean	63.5850613	8.93431828	hedges_d
67	2014	Itoo	pinus	field	scleroderma	growth facility	5.8	seedling	seedling height	mean	83.537197	8.93495997	hedges_d
67	2014	Itoo	pinus	field	suillus	growth facility	5.8	seedling	seedling height	mean	51.787504	8.93402073	hedges_d
72	2013	Dominguez-N	pinus	composite	rhizopogon	field	5	seedling	seedling height	mean	-15.2150103	3.3452204	hedges_d
74	2013	Sanchez-Zaba	pinus	composite	lactarius	field	9	seedling	seedling height	mean	56.8137841	3.49543137	hedges_d
74	2013	Sanchez-Zaba	pinus	composite	lactarius	field	9	seedling	seedling height	mean	58.9066289	3.50729159	hedges_d
74	2013	Sanchez-Zaba	pinus	composite	pisolithus	field	9	seedling	seedling height	mean	29.5819983	3.37804857	hedges_d
74	2013	Sanchez-Zaba	pinus	composite	suillus	field	9	seedling	seedling height	mean	-54.5502199	3.4830437	hedges_d
79	2012	Lazarević	pinus	composite	suillus	field	11	seedling	seedling height	mean	2.25378578	7.27582008	hedges_d
79	2012	Lazarevic	pinus	composite	suillus	field	11	seedling	seedling height	mean	-47.171341	7.27755735	hedges_d
81	2012	Ragonezi	pinus	media	pisolithus	growth facility	1	seedling	root length	mean	15.6685336	4.44074812	hedges_d
84	2012	Sousa	pinus	composite	suillus	growth facility	6	seedling	shoot height	mean	63.0732891	3.53205194	hedges_d
84	2012	Sousa	pinus	composite	pisolithus	growth facility	6	seedling	shoot height	mean	231.31477	5.42774344	hedges_d
84	2012	Sousa	pinus	composite	rhizopogon	growth facility	6	seedling	shoot height	mean	171.207244	4.6003489	hedges_d
84	2012	Sousa	pinus	composite	suillus	growth facility	6	seedling	root length	mean	26.4570343	3.36914786	hedges_d
84	2012	Sousa	pinus	composite	pisolithus	growth facility	6	seedling	root length	mean	65.9454468	3.54999575	hedges_d
84	2012	Sousa	pinus	composite	rhizopogon	growth facility	6	seedling	root length	mean	56.7580503	3.49512085	hedges_d
85	2012	Otgonsuren	pinus	composite	Phialocephala	growth facility	6	seedling	seedling height	mean	-4.94281178	1.28760829	hedges_d
86	2012	Otgonsuren	pinus	composite	Phialocephala	growth facility	6	seedling	root length	mean	3.77969663	1.27212621	hedges_d
86	2012	Dominguez	pinus	composite	tuber	growth facility	1	seedling	seedling height	mean	48.5176226	4.22627432	hedges_d
86	2012	Dominguez-N	pinus	composite	tuber	growth facility	1	seedling	seedling height	mean	-15.5973602	4.18999162	hedges_d
87	2012	Oliveira	pinus	composite	thelephora	growth facility	6	seedling	shoot height	mean	-9.70134724	3.63985289	hedges_d
87	2012	Oliveira	pinus	composite	rhizopogon	growth facility	6	seedling	shoot height	mean	34.9672064	3.67840677	hedges_d
87	2012	Oliveira	pinus	composite	ecm group	growth facility	6	seedling	shoot height	mean	37.5525293	3.68477246	hedges_d
87	2012	Oliveira	pinus	composite	ecm group	growth facility	6	seedling	shoot height	mean	47.2538765	3.71257757	hedges_d
93	2011	Buscardo	pinus	composite	ecm group	field	54	sapling	sapling height	mean	0	0.35355339	hedges_d
96	2011	Wagg	pinus	composite	ecm strain	field	6	seedling	growth rate	mean	121.728445	5.7178305	hedges_d
96	2011	wagg	picea	composite	ecm strain	field	6	seedling	growth rate	mean	62.854965	7.96871021	hedges_d
97	2011	Koele	picea	composite	ecm group	growth facility	4	seedling	shoot weight	mean	88.4022821	5.9461515	hedges_d
97	2011	Koele	picea	composite	ecm group	growth facility	4	seedling	root weight	mean	74.0361124	5.94001617	hedges_d
98	2011	Repác,	picea	composite	Cortinarius	growth facility	5	seedling	shoot length	mean	53.2	4.92709997	hedges_d
98	2011	Repac	picea	composite	gomphidius	growth facility	5	seedling	shoot length	mean	0	4.90577891	hedges_d
98	2011	Repac	picea	composite	Cortinarius	growth facility	5	seedling	root length	mean	-49.6833691	4.92437954	hedges_d
98	2011	Repac	picea	composite	gomphidius	growth facility	5	seedling	root length	mean	-4.92255085	4.90596184	hedges_d

(Growth)

101	2010	Sarjala	pinus	media	pisolithus	growth facility	0.5	seedling	root length	mean	9.68403911	4.90648687	hedges_d
101	2010	Sarjala	pinus	media	paxillus	growth facility	0.5	seedling	root length	mean	206.159221	5.21679357	hedges_d
103	2010	Vaario	pinus	media	tricholoma	growth facility	8	seedling	shoot height	mean	-2.64723476	2.64671641	hedges_d
103	2010	vaario	pinus	media	tricholoma	growth facility	8	seedling	shoot height	mean	-2.86544682	2.64688204	hedges_d
103	2010	Vaario	picea	media	tricholoma	growth facility	8	seedling	shoot height	mean	-11.7432913	2.66467892	hedges_d
103	2010	Vaario	picea	media	tricholoma	growth facility	8	seedling	shoot height	mean	-0.27298422	2.64576158	hedges_d
104	2010	Lesky	pinus	composite	suillus	growth facility	24	sapling	plant height	mean	-0.86513995	6.80000088	hedges_d
104	2010	Lesky	pinus	composite	wilcoxina	growth facility	24	sapling	plant height	mean	0	6.8	hedges_d
125	2008	Zhu	pinus	sand	boletus	growth facility	6	seedling	shoot height	mean	14.375	1.53937973	hedges_d
125	2008	zhu	pinus	sand	lactarius	growth facility	6	seedling	shoot height	mean	0.70554065	1.25077755	hedges_d
125	2008	Zhu	pinus	sand	ecm group	growth facility	6	seedling	shoot height	mean	12.1474679	1.4625013	hedges_d
125	2008	Zhu	pinus	sand	pisolithus	growth facility	6	seedling	root length	mean	11.4258657	1.43960499	hedges_d
125	2008	Zhu	pinus	sand	boletus	growth facility	6	seedling	root length	mean	13.7348427	1.51637662	hedges_d
125	2008	Zhu	pinus	sand	ecm group	growth facility	6	seedling	root length	mean	4.17534722	1.27694937	hedges_d
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	seedling height	mean	-4.44813191	1.79988104	hedges_d
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	seedling height	mean	6.2730707	1.81071887	hedges_d
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	seedling height	mean	5.77968994	1.80743178	hedges_d
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	seedling height	mean	9.57932943	1.83943663	hedges_d
131	2007	Rincón	pinus	field	amanita	field	43.2	sapling	seedling height	mean	8.1450147	1.82556362	hedges_d
133	2007	Aučina	pinus	field	ecm group	field	24	sapling	seedling height	mean	28.2161172	6.80093658	hedges_d
134	2007	Kozdrój	pinus	sand	amanita	growth facility	3	seedling	shoot length	mean	2.32550423	0.61919878	hedges_d
134	2007	Kozdrój	pinus	sand	hebeloma	growth facility	3	seedling	shoot length	mean	2.25306987	0.61671414	hedges_d
134	2007	Kozdrój	pinus	sand	amanita	growth facility	3	seedling	root length	mean	10.9557894	1.20196337	hedges_d
134	2007	Kozdrój	pinus	sand	hebeloma	growth facility	3	seedling	root length	mean	10.6517744	1.17638924	hedges_d
136	2013	Dominguez-N	pinus	sand	pisolithus	growth facility	3	seedling	seedling height	mean	22.5997443	3.35950367	hedges_d
136	2013	Dominguez-N	pinus	sand	pisolithus	growth facility	3	seedling	stem basal diameter	mean	12.8169226	3.34177293	hedges_d
143	2006	Bakker	pinus	sand	cenococcum	field	54	sapling	root length	mean	2.27156856	1.2580367	hedges_d
145	2001	Probanza	pinus	sand	pisolithus	growth facility	4.8	seedling	root length	mean	-2.41522512	3.33363339	hedges_d
145	2001	Probanza	pinus	sand	pisolithus	growth facility	4.8	seedling	root length	mean	33.2482081	3.38972077	hedges_d
145	2001	Probanza	pinus	sand	pisolithus	growth facility	4.8	seedling	root length	mean	12.224736	3.34101195	hedges_d
155	2005	Choi	pinus	composite	pisolithus	growth facility	4.5	seedling	stem diameter	mean	13.0523654	5.12601436	hedges_d
156	2005	Rincón	pinus	composite	suillus	growth facility	4.5	seedling	tap root length	mean	-71.9519303	6.80608796	hedges_d
156	2005	Rincón	pinus	composite	suillus	growth facility	4.5	seedling	tap root length	mean	12.0208153	6.80017	hedges_d
160	2003	Boukcim	picea	composite	paxillus	growth facility	4	seedling	tap root length	mean	21.4881778	4.90926367	hedges_d
160	2003	Boukcim	picea	composite	paxillus	growth facility	4	seedling	tap root length	mean	-12.0129897	4.90686829	hedges_d
166	2004	Hilszczańska	pinus	sand	thelephora	field	3	seedling	shoot height	mean	-27.6184218	3.6627441	hedges_d
166	2004	Hilszczańska	pinus	sand	thelephora	field	3	seedling	shoot height	mean	-3.63661931	3.63707386	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	growth facility	5	seedling	seed height	mean	17.7322305	6.80036991	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	growth facility	5	seedling	seedling height	mean	61.5643073	6.80445756	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	growth facility	5	seedling	seedling height	mean	16.0030766	6.80030129	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	growth facility	5	seedling	stem diameter	mean	0	6.8	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	growth facility	5	seedling	stem diameter	mean	45.6157867	6.80244756	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	growth facility	5	seedling	stem diameter	mean	53.7244681	6.80339482	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	field	5	seedling	seed height	mean	2.33238076	6.8000064	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	field	5	seedling	seedling height	mean	12.7760107	6.80019203	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	field	5	seedling	seedling height	mean	15.8732255	6.80029642	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	field	5	seedling	stem diameter	mean	11.814925	6.80016422	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	field	5	seedling	stem diameter	mean	5.21536192	6.800032	hedges_d
174	2004	Duñabeitia	pinus	composite	rhizopogon	field	5	seedling	stem diameter	mean	17.1174163	6.8003447	hedges_d
189	2003	Guerin-Laguet	pinus	composite	lactarius	field	5	seedling	shoot height	mean	14.7526513	1.6209365	hedges_d
189	2003	Guerin-Laguet	pinus	field	lactarius	field	5	seedling	shoot height	mean	13.3364862	1.58996478	hedges_d
189	2003	Guerin-Laguet	pinus	field	lactarius	field	5	seedling	shoot height	mean	5.02728578	1.46509977	hedges_d
189	2003	Guerin-Laguet	pinus	field	lactarius	field	5	seedling	shoot height	mean	11.4863728	1.55343981	hedges_d
232	1995	Shaw	pinus	composite	ecm group	growth facility	4	seedling	growth rate	mean	-1.49383981	2.24594067	hedges_d
282	2018	Jenkins	pinus	sand	suillus	growth facility	6	seedling	seedling height	mean	7.31095974	4.75214867	hedges_d
282	2018	Jenkins	pinus	sand	suillus	growth facility	6	seedling	stem diameter	mean	-1.7104491	4.75167205	hedges_d
288	1991	Svenson	pinus	composite	pisolithus	growth facility	9.25	seedling	seedling height	mean	-10.0375567	4.18753027	hedges_d
288	1991	Svenson	pinus	composite	pisolithus	growth facility	9.25	seedling	root collar diameter	mean	0.1549103	4.18578987	hedges_d
340	2003	Mari	picea	composite	laccaria	growth facility	4.5	seedling	plant height	mean	0	1.25	hedges_d
308	2008	Dominguez Nu	pinus	composite	tuber	field	7	seedling	shoot height	mean	56.1582585	4.23994163	hedges_d
308	2008	Dominguez Nu	pinus	composite	tuber	field	7	seedling	stem basal diameter	mean	37.5625133	4.21010246	hedges_d
321	2002	Niemi	pinus	media	pisolithus	growth facility	2	seedling	root length	mean	-0.86671906	0.38532462	hedges_d
321	2002	Niemi	pinus	media	pisolithus	growth facility	2	seedling	root length	mean	-0.93334561	0.39015758	hedges_d
321	2002	Niemi	pinus	media	pisolithus	growth facility	6.25	seedling	root length	mean	-1.70108597	0.46414213	hedges_d
321	2002	Niemi	pinus	media	pisolithus	growth facility	5.5	seedling	root length	mean	0.3933128	0.36032516	hedges_d
11	2022	Repac	picea	composite	ectovit	growth facility	36	seedling	stem height	mean	0	4.90577891	hedges_d
342	1995	Shaw	pinus	media	ecm group	growth facility	3	seedling	growth rate	mean	0.11026495	2.24536873	hedges_d
346	2022	Wang	pinus	composite	hymenochaet	growth facility	16	seedling	shoot length	mean	74.1714286	3.76866046	hedges_d
346	2022	Wang	pinus	composite	hymenochaet	growth facility	16	seedling	stem diameter	mean	12.6490783	1.87616587	hedges_d
346	2022	Wang	pinus	composite	hymenochaet	growth facility	16	seedling	shoot length	mean	61.9762749	3.29880544	hedges_d
346	2022	Wang	pinus	composite	hymenochaet	growth facility	16	seedling	stem diameter	mean	26.1992092	2.13840995	hedges_d
347	2007	Niemi	pinus	media	suillus	growth facility	0.5	seedling	root length	mean	186.278321	5.16110534	hedges_d
347	2007	Niemi	pinus	media	suillus	growth facility	0.5	seedling	root length	mean	276.403104	5.45213975	hedges_d
335	2002	Niemi	pinus	media	pisolithus	growth facility	2	seedling	root length	mean	-0.56288575	4.9057813	hedges_d
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	-0.17079	0.27247906	logRR
213	1998	Scagel,	Picea	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	0.001	0.27247906	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	-0.37688177	0.38422426	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	0.04155723	0.27771915	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	0.12107793	0.25837182	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	1.13435591	0.61410965	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	-0.06774599	0.83902976	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	0.14600782	0.78360686	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	-0.77028291	1.0863137	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	-0.14041718	0.8597638	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	-0.47087737	0.96746159	logRR
213	1998	Scagel,	picea	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	-0.03689272	0.34767659	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	-0.36685027	0.42982908	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	0.06552229	0.32399528	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	-0.11150358	0.36542667	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	0.01251973	0.33615668	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	0.10599024	0.31483865	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	height relative growth rate	percentage	-1.77451766	0.89421943	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	-1.3834	0.72316127	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	0.28768207	0.23156681	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	0.001	0.2529331	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	-1.23338669	0.66516161	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	0.001	0.84859963	logRR
213	1998	Scagel,	pinus	composite	laccaria	growth facility	4	seedling	diameter relative growth rate	percentage	0.001	0.32688002	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	height relative growth rate	percentage	0.43655203	0.31178172	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	height relative growth rate	percentage	0.28653772	0.32934334	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	height relative growth rate	percentage	-0.17641867	0.39503613	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	height relative growth rate	percentage	0.18317336	0.3424448	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	height relative growth rate	percentage	-0.1147937	0.3852001	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	height relative growth rate	percentage	0.25562014	0.38691144	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	diameter relative growth rate	percentage	0.2925247	0.38218869	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	diameter relative growth rate	percentage	0.19118186	0.39544041	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	diameter relative growth rate	percentage	0.68876868	0.33831757	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	diameter relative growth rate	percentage	0.55693073	0.35159644	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	diameter relative growth rate	percentage	0.23203594	0.38999089	logRR
344	1998	Scagel,	pinus	composite	laccaria	field	6	seedling	diameter relative growth rate	percentage	-0.15591825	0.53928685	logRR
315	2006	van Hees	pinus	field	hebeloma	growth facility	18.5	seedling	root relative growth rate	percentage	-0.05913763	0.54358205	logRR
315	2006	van Hees	pinus	field	hebeloma	growth facility	18.5	seedling	shoot relative growth rate	percentage	0.91689115	0.42851324	logRR
348	2007	Niemi	pinus	media	pisolithus	growth facility	4.5	seedling	embryo growth	percentage	1.01296498	0.41768365	logRR
348	2007	Niemi	pinus	media	pisolithus	growth facility	4.5	seedling	embryo growth	percentage	1.01296498	0.41768365	logRR

C- Survival factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

study_id	year	author	tree_genus	soil_type	ecm_genus	growth_conditions	tree_age	tree_category	measured parameter	treatment_n	control_n	treatment_mean	control_mean	data_type	RR	logRR	SElogRR
3	2021	Taniguchi	pinus	sandy	suillus	field	36	sapling	survival	10	10	0.6458	0.4427	percentage	1.458775695	0.37759752	0.13847701
25	2021	Lorenc	picea	sandy	ectovit	field	36	sapling	survival	100	100	0.35	0.943	percentage	0.371155885	0.001	0.13847701
25	2021	Lorenc	picea	sand	ectovit	field	36	sapling	survival	100	100	0.77	0.4445	percentage	1.732283465	0.54944046	0.12443553
33	2020	Hewitt	pinus	field	ecm	field	24	sapling	survival	192	192	0.63	0.4445	percentage	1.417322835	0.34876976	0.09781521
33	2020	Hewitt	pinus	field	ecm	field	24	sapling	survival	192	192	0.17	0.819	percentage	0.207570208	-1.57228565	0.16303365
33	2020	Hewitt	pinus	field	ecm	field	24	sapling	survival	192	192	0.96	0.8	percentage	1.2	0.18232156	0.0389756
33	2020	Hewitt	pinus	field	ecm	field	24	sapling	survival	192	192	0.38	0.8	percentage	0.475	-0.74444047	0.0989944
44	2017	Rudawska	pinus	field	suillus	field	24	sapling	survival	20	20	0.8791	0.83	percentage	1.059156627	0.05747296	0.13083316
44	2017	Rudawska	pinus	field	wilcoxina	field	24	sapling	survival	20	20	0.9613	0.08	percentage	12.01625	2.4862599	0.75961365
44	2017	Rudawska	pinus	field	wilcoxina	field	24	sapling	survival	20	20	0.8274	1	percentage	0.8274	-0.18946702	0.10212866
44	2017	Rudawska	pinus	field	cenococcum	field	24	sapling	survival	20	20	0.8062	0.42	percentage	1.91952381	0.65207714	0.28472262
50	2016	Nakashima	pinus	field	ecm	field	24	sapling	survival	150	150	0.753	0.53	percentage	1.420754717	0.35118822	0.0899931
50	2016	Nakashima	pinus	field	ecm	field	24	sapling	survival	150	150	0.76	0.53	percentage	1.433962264	0.36044143	0.08953889
50	2016	Nakashima	pinus	field	ecm	field	24	sapling	survival	150	150	0.8	0.53	percentage	1.509433962	0.41173472	0.08705525
67	2014	Itoo	pinus	field	hebeloma	growth facility	5.8	seedling	survival	40	40	0.68	0.6769	percentage	1.004579702	0.00456925	0.15394084
67	2014	Itoo	pinus	field	boletus	growth facility	5.8	seedling	survival	40	40	0.62	0.6628	percentage	0.935425468	-0.06675381	0.16745552
67	2014	Itoo	pinus	field	scleroderma	growth facility	5.8	seedling	survival	40	40	0.57	0.8086	percentage	0.704922088	-0.349668	0.15740802
67	2014	Itoo	pinus	field	suillus	growth facility	5.8	seedling	survival	40	40	0.54	0.6299	percentage	0.857278933	-0.15399194	0.18969748
68	2014	Onwuchekwa	pinus	sandy	suillus	field	12	seedling	survival	20	20	0.495	0.64	percentage	0.7734375	-0.25691041	0.28130962
68	2014	Onwuchekwa	pinus	sandy	laccaria	field	12	seedling	survival	20	20	0.39	0.64	percentage	0.609375	-0.49532144	0.32608301
68	2014	Onwuchekwa	pinus	sandy	hebeloma	field	12	seedling	survival	20	20	0.41	0.64	percentage	0.640625	-0.44531102	0.31634826
68	2014	Onwuchekwa	picea	sandy	hebeloma	field	12	seedling	survival	20	20	0.4993	0.35	percentage	1.426571429	0.35527396	0.37814989
68	2014	Onwuchekwa	picea	sandy	suillus	field	12	seedling	survival	20	20	0.4797	0.35	percentage	1.370571429	0.31522775	0.38352178
68	2014	Onwuchekwa	picea	sandy	laccaria	field	12	seedling	survival	20	20	0.3315	0.35	percentage	0.947142857	-0.05430534	0.44009852
98	2011	Repác,	picea	composite	ectovit	growth facility	6	seedling	survival	15	15	0.6481	0.35	percentage	1.851714286	0.61611185	0.40000955
98	2011	Repac	picea	composite	trichomil	growth facility	6	seedling	survival	15	15	0.696	0.3434	percentage	2.026790914	0.70645371	0.39571349
98	2011	Repac	picea	composite	cortinarius	growth facility	6	seedling	survival	15	15	0.6941	0.3434	percentage	2.021258008	0.70372009	0.39604465
98	2011	Repac	picea	composite	gomphidius	growth facility	6	seedling	survival	15	15	0.5521	0.3434	percentage	1.607746069	0.47483324	0.42609248
98	2011	Repac	picea	composite	vetozen	growth facility	6	seedling	survival	15	15	0.712	0.314	percentage	2.267515924	0.81868493	0.41546823
98	2011	Repac	picea	composite	bactofil	growth facility	6	seedling	survival	15	15	0.608	0.314	percentage	1.936305732	0.6607819	0.43431557
98	2011	Repac	picea	composite	beads	growth facility	6	seedling	survival	15	15	0.4561	0.314	percentage	1.452547771	0.3733191	0.47449728
104	2010	Lesky	pinus	composite	suillus	growth facility	24	sapling	survival	25	25	0.014	0.744	percentage	0.018817204	-3.97298371	1.68252973
104	2010	Lesky	pinus	composite	wilcoxina	growth facility	24	sapling	survival	25	25	0.014	0.744	percentage	0.018817204	-3.97298371	1.68252973
123	2008	Adomas	pinus	media	laccaria	growth facility	0.9	seedling	survival	10	10	0.95	0.744	percentage	1.27688172	0.001	0.19917771
123	2008	Adomas	pinus	media	laccaria	growth facility	0.9	seedling	mortality	10	10	0.05	0.744	percentage	0.067204301	-2.70001803	1.39083018
127	2008	Jha	pinus	sandy	*Collybia*	growth facility	0.9	seedling	survival	14	14	0.8	0.744	percentage	1.075268817	0.07257069	0.20599688
127	2008	Jha	pinus	sandy	pisolithus	growth facility	0.9	seedling	survival	14	14	0.7	0.744	percentage	0.940860215	0.001	0.23492513
127	2008	Jha	pinus	sandy	rhizopogon	growth facility	0.9	seedling	survival	14	14	0.8	0.744	percentage	1.075268817	0.001	0.20599688
127	2008	Jha	pinus	sandy	laccaria	growth facility	0.9	seedling	survival	14	14	0.7	0.251	percentage	2.788844622	0.001	0.49372022
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	survival	5	5	0.3846	0.041	Percentage		2.23863177	2.23563628
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	survival	5	5	0.7133	1	Percentage	9.380487805	-0.33785319	0.2835259
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	survival	5	5	0.6964	1	Percentage	0.7133	0.08380367	0.29528168
131	2007	Rincón	pinus	field	suillus	field	43.2	sapling	survival	5	5	0.70682	0.65	Percentage	1.087415385	0.08380367	0.43663461
131	2007	Rincón	pinus	field	CCMA44	field	43.2	sapling	survival	5	5	0.5565	0.65	Percentage	0.856153846	-0.15530519	0.51679914
131	2007	Rincón	pinus	field	rhizopogon	field	43.2	sapling	survival	5	5	0.13	0.65	Percentage	0.2	-1.60943791	1.20256137
133	2007	Aučina	pinus	field	ecm	field	24	sapling	survival	25	25	0.64	0.65	percentage	0.984615385	-0.01550419	0.20985343
154	2005	Kayama	picea	field	ecm	field	48	small tree	survival	16	16	0.32	0.4266	Percentage	0.750117206	-0.28752581	0.46563909
154	2005	Kayama	picea	field	ecm	field	48	small tree	survival	16	16	0.206	0.4266	Percentage	0.482887951	-0.72797064	0.57000467
154	2005	Kayama	picea	field	ecm	field	48	small tree	survival	16	16	0.94	0.4266	Percentage	2.203469292	0.79003307	0.29664226
154	2005	Kayama	picea	field	ecm	field	48	small tree	survival	16	16	0.139	0.4266	Percentage	0.325832161	-1.12137287	0.68640189
154	2005	Kayama	picea	field	ecm	field	48	small tree	survival	16	16	0.082	0.4266	Percentage	0.192217534	-1.64912756	0.88526967
208	1999	Cram	pinus	sandy	pisolithus	field	60	small tree	survival	8	8	0.81	0.4266	percentage	1.898734177	0.64118744	0.44422463
208	1999	Cram	pinus	sandy	pisolithus	field	60	small tree	survival	8	8	0.9	0.436	percentage	2.064220183	0.72475252	0.41902999
271	2006	Nowak	pinus	composite	pisolithus	field	5	seedling	survival	5	5	0.9	0.2	percentage	4.5	1.5040774	0.9067647
271	2006	Nowak	pinus	composite	pisolithus	field	5	seedling	survival	5	5	0.81	1	percentage	0.81	-0.21072103	0.21659543
279	2007	Menkis	pinus	field	cenococcum	field	36	sapling	survival	20	20	0.71	0.315	percentage	2.253968254	0.81269233	0.3593782
279	2007	Menkis	pinus	field	piceirhiza	field	36	sapling	survival	20	20	0.6915	0.144	percentage	4.802083333	1.56904985	0.56526879
279	2007	Menkis	pinus	field	hebeloma	field	36	sapling	survival	20	20	0.6717	0.2	percentage	3.3585	1.21149445	0.47374887
279	2007	Menkis	picea	field	cenococcum	field	36	sapling	survival	20	20	0.7242	0.172	percentage	4.210465116	1.43757312	0.50964632
279	2007	Menkis	pinus	field	piceirhiza	field	36	sapling	survival	20	20	0.6628	0.38	percentage	1.744210526	0.001	0.001
279	2007	Menkis	pinus	field	hebeloma	field	36	sapling	survival	20	20	0.571	1	percentage	0.571	0.001	0.001
285	2006	Kayama	picea	field	ecm	field	36	sapling	survival	16	16	0.07	1	percentage	0.07	-2.65926004	0.91123934
285	2006	Kayama	picea	field	ecm	field	36	sapling	survival	16	16	0.05	1	percentage	0.05	0.001	0.001
285	2006	Kayama	picea	field	ecm	field	36	sapling	survival	16	16	0.21	1	percentage	0.21	-1.56064775	0.48489076
298	2011	Menkis	picea	composite	amphinema	field	24	sapling	survival	10	10	0.882	1	percentage	0.882	0.001	0.001
298	2011	Menkis	picea	composite	amphinema	field	24	sapling	survival	10	10	0.817	1	percentage	0.817	0.001	0.001
321	2002	Niemi	pinus	media	pisolithus	growth facility	6.25	seedling	survival	2	2	100	1	percentage	100	0.001	0.001
321	2002	Niemi	pinus	media	pisolithus	growth facility	5.5	seedling	survival	2	2	100	1	percentage	100	4.60517019	0.001

D-Biotic factor variables

The table shows variables used in the meta-analysis, data type and the calculated effect sizes

study_id	year	author	tree_genus	soil_type	ecm_genus	growth_conditions	stress_type	tree_age	tree_category	measured_parameter	data_type	effect_size	var_d	source
20	2021	Chu	pinus	composite	amanita	growth facility	insect	9	seedling	disease incidence	mean	-2.02780972	0.41398961	Hedges_d
20	2021	Chu	pinus	composite	suillus	growth facility	insect	9	seedling	disease incidence	mean	0.53158842	0.40463384	Hedges_d
211	1998	Manninen	pinus	media	cenoccocum	growth facility	Insect	2.75	seedling	root length	mean	-1.82440703	0.22571024	Hedges_d
211	1998	Manninen	pinus	media	cenoccocum	growth facility	Insect	3.25	seedling	root length	mean	-2.10582351	0.22887826	Hedges_d
218	1997	Gerhring	pinus	field	ecm	field	Insect	96	seedling	mortality	mean	-0.87014149	0.40580496	Hedges_d
218	1997	Gerhring	pinus	field	ecm	field	Insect	96	seedling	mortality	mean	-4.74396802	0.45626071	Hedges_d
277	2018	Piculell	pinus	field	ecm	growth facility	pathogen	5.5	seedling	relative growth rate	mean	0.93802036	0.13500372	Hedges_d
277	2018	Piculell	pinus	field	ecm	growth facility	pathogen	5.5	seedling	relative growth rate	mean	0	0.15123825	Hedges_d
277	2018	Piculell	pinus	field	ecm	growth facility	pathogen	5.5	seedling	relative growth rate	mean	0.64744052	0.12515279	Hedges_d
277	2018	Piculell	pinus	field	ecm	growth facility	pathogen	5.5	seedling	relative growth rate	mean	0	0.14031362	Hedges_d
323	2007	Liiri	pinus	composite	ecm	growth facility	insect	6.5	seedling	root length	mean	0	0.13371318	Hedges_d
323	2007	Liiri	pinus	composite	ecm	growth facility	insect	6.5	seedling	root length	mean	-0.49529781	0.15470792	Hedges_d
324	2007	Niemi	pinus	media	pisolithus	growth facility	pathogen	0.5	seedling	cell masses with developing embryo	mean	0.94742786	0.47079149	Hedges_d
325	2006	Machon	pinus	composite	laccaria	greenhouse	pathogen	3.25	seedling	pre-emergence damping off	mean	0.58304539	0.46527513	Hedges_d
325	2006	Machon	pinus	composite	laccaria	greenhouse	pathogen	3.25	seedling	pre-emergence damping off	mean	-3.44056987	0.56827811	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	shoot height	mean	0.98923827	0.47158708	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	diameter	mean	0.3092284	0.25123464	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	root length	mean	0.24324324	0.25122926	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	shoot height	mean	0.36978551	0.2512407	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	diameter	mean	-0.77815449	0.2513098	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	root length	mean	0	0.25122054	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	shoot height	mean	11.3762552	0.26962635	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	diameter	mean	-0.09760033	0.25122195	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	root length	mean	-0.17199895	0.2512249	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	shoot height	mean	12.3934138	0.27292727	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	diameter	mean	-0.07358928	0.25122134	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	root length	mean	0.34399789	0.25123799	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	shoot height	mean	10.1199055	0.26589071	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	diameter	mean	-0.03771614	0.25122075	Hedges_d
326	2018	Suarez	pinus	composite	lactarius	growth facility	pathogen	5	seedling	root length	mean	0	0.25122054	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	shoot height	mean	-1.02333836	0.25137488	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	diameter	mean	-0.38828141	0.25124277	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	root length	mean	0	0.25122054	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	shoot height	mean	-0.46028913	0.25125177	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	diameter	mean	-0.04689805	0.25122087	Hedges_d
326	2018	Suarez	pinus	composite	rhizopogon	growth facility	pathogen	5	seedling	root length	mean	-0.34399789	0.25123799	Hedges_d
327	2020	Berk	pinus	field	wilkoxina	growth facility	pathogen	2.7	seedling	seedling height	mean	-1.87664869	0.25173922	Hedges_d
329	2006	Mueller	pinus	composite	ecm	field	pathogen	96	mature tree	shoot growth	mean	-0.87347081	0.251333	Hedges_d
329	2006	Mueller	pinus	composite	ecm	field	pathogen	96	mature tree	mortality	mean	0	0.25122054	Hedges_d
334	1995	Hwang	pinus	composite	paxillus	growth facility	pathogen	2.5	seedling	seedling mortality	mean	0.3355963	0.25123714	Hedges_d
334	1995	Hwang	pinus	composite	paxillus	growth facility	pathogen	2.5	seedling	seedling mortality	mean	0.36323253	0.4632008	Hedges_d
334	1995	Hwang	pinus	composite	suillus	growth facility	pathogen	2.5	seedling	seedling mortality	mean	0.4912867	0.30296563	Hedges_d
204	1999	Chakravarty,	pinus	composite	paxillus	growth facility	pathogen	2	seedling	survival	mean	-0.23141273	0.16487542	Hedges_d
204	1999	Chakravarty,	pinus	composite	laccaria	growth facility	pathogen	2	seedling	survival	mean	-0.19568249	0.16487517	Hedges_d
9	2022	Wang	pinus	thunbergia	hymenochaete	growthfacility	pathogen	5	seedling	Infection rate	percentage	-1.82939167	0.85279501	logRR
9	2022	Wang	pinus	thurnbergia	hymenochaete	growth facility	pathogen	5	seedling	Infection rate	percentage	0.001	0.85279501	logRR
25	2021	Lorenc	picea	abies	ectovit	field	pathogen	na	na	Infection rate	percentage	0.09703581	0.69456387	logRR
25	2021	Lorenc	picea	abies	ectovit	field	pathogen	na	na	Infection rate	percentage	-0.03783997	0.72120705	logRR
108	2010	Holusa	picea	abies	ectovit	field	pathogen	72	mature tree	seedling height	percentage	-0.25297888	0.2575645	logRR
108	2010	Holusa	picea	abies	ectovit	field	pathogen	72	mature tree	root length	percentage	-0.36050732	0.28872018	logRR
268	2019	Chu	pinus	tabulaeformis	suillus	growth facility	pathogen	0.9	seedling	cumulative mortality	percentage	-6.68461173	2.88602957	logRR
268	2019	Chu	pinus	tabulaeformis	suillus	growth facility	pathogen	0.9	seedling	cumulative mortality	percentage	-6.68461173	14.1368313	logRR
268	2019	Chu	pinus	tabulaeformis	schizophyllum	growth facility	pathogen	0.9	seedling	cumulative mortality	percentage	0.35468679	1.59326795	logRR
272	2001	Nieminen	pinus	sylvestris	ecm	growth facility	insect	8.25	seedling	stem length	percentage	0.04481933	1.98817723	logRR
277	2018	Piculell	pinus	Taeda	thelephora	growth facility	pathogen	5.5	seedling	relative growth rate	percentage	4.38507808	0.20500389	logRR
326	2018	Suarez	pinus	sylvestris	lactarius	growth facility	pathogen	5	seedling	diameter	percentage	-0.03886452	0.36890751	logRR
326	2018	Suarez	pinus	sylvestris	lactarius	growth facility	pathogen	5	seedling	root length	percentage	-1.28519824	0.87050223	logRR
326	2018	Suarez	pinus	sylvestris	lactarius	growth facility	pathogen	5	seedling	shoot height	percentage	-1.28519824	0.87050223	logRR
334	1995	Hwang	pinus	banksiana	suillus	growth facility	pathogen	2.5	seedling	seedling mortality	percentage	-0.32016753	0.22882448	logRR
336	2018	Velmala	picea	abies	meliniomyces	growth facility	pathogen	12	seedling	shoot length	percentage	0.11341758	0.18859114	logRR
336	2018	Velmala	picea	abies	meliniomyces	growth facility	pathogen	12	seedling	shoot length	percentage	-0.14939123	0.26261032	logRR
336	2018	Velmala	picea	abies	meliniomyces	growth facility	pathogen	12	seedling	damaged needles	percentage	-0.58530065	0.38460264	logRR
336	2018	Velmala	picea	abies	meliniomyces	growth facility	pathogen	12	seedling	damaged needles	percentage	-0.07855036	0.24306634	logRR
204	1999	Chakravarty,	pinus	sylvestris	citocybe	growth facility	pathogen	2	seedling	survival	percentage	0.51082562	3.84177814	logRR
204	1999	Chakravarty,	pinus	sylvestris	paxillus	growth facility	pathogen	2	seedling	survival	percentage	0.001	4.29685501	logRR
204	1999	Chakravarty,	pinus	sylvestris	laccaria	growth facility	pathogen	2	seedling	survival	percentage	0.22314355	3.52766841	logRR
204	1999	Chakravarty,	pinus	sylvestris	citocybe	growth facility	pathogen	2	seedling	survival	percentage	0.001	3.71931893	logRR
204	1999	Chakravarty,	pinus	sylvestris	paxillus	growth facility	pathogen	2	seedling	survival	percentage	0.001	3.71931893	logRR
204	1999	Chakravarty,	pinus	sylvestris	laccaria	growth facility	pathogen	2	seedling	survival	percentage	-0.28768207	4.01847585	logRR
204	1999	Chakravarty,	pinus	sylvestris	Citocybe	growth facility	pathogen	2	seedling	survival	percentage	0.26436485	0.30795331	logRR
204	1999	Chakravarty,	pinus	sylvestris	paxillus	growth facility	pathogen	2	seedling	survival	percentage	0.34281346	0.4782272	logRR
204	1999	Chakravarty,	pinus	sylvestris	laccaria	growth facility	pathogen	2	seedling	survival	percentage	1.57242928	0.51657261	logRR
204	1999	Chakravarty,	pinus	sylvestris	Citocybe	growth facility	pathogen	2	seedling	survival	percentage	0.56426201	0.19232944	logRR

E -Included articles.

Author name	**Year of publication**	**Title**
Tapwal, A.	2022	Growth enhancement in containerized *Pinus gerardiana* seedlings inoculated with ectomycorrhizal fungi
McMahen, K.	2022	Soil microbial legacies influence plant survival and growth in mine reclamation
Fahey, C	2022	Effects of dual mycorrhizal inoculation on *Pinus strobus* seedlings are influenced by soil resource availability
Huang, L.-L.	2022	Ectomycorrhizal synthesis between two *Tuber* species and six tree species: are different host-fungus combinations having dissimilar impacts on host plant growth?
Wang, Y.	2022	Improvement of *Sphaeropsis* Shoot Blight Disease Resistance by Applying the Ectomycorrhizal Fungus *Hymenochaete* sp. Rl and Mycorrhizal Helper Bacterium *Bacillus pumilus* HR10 to *Pinus thunbergii*
Chen, H.	2022	Effects of *Suillus luteus* and *S. bovinus* on the physiological response and nutrient absorption of *Pinus massoniana* seedlings under phosphorus deficiency
Repac, I.	2022	Ectomycorrhiza-hydrogel additive enhanced growth of Norway spruce seedlings in a nutrient-poorpeat substrate
Wang, J.	2021	Effects of ectomycorrhizal fungi (*Suillus variegatus*) on the growth, hydraulic function, and non-structural carbohydrates of *Pinus tabulaeformis* under drought stress
Castro, D.	2021	Effects of early, small-scale nitrogen addition on germination and early growth of scots pine (*Pinus sylvestris*) seedlings and on the recruitment of the root-associated fungal community
Madejon, P.	2021	Plant response to mycorrhizal inoculation and amendments on a contaminated soil
Chu, H.	2021	Inoculation With Ectomycorrhizal Fungi and Dark Septate Endophytes Contributes to the Resistance of *Pinus* spp. to Pine Wilt Disease
Taniguchi,	2021	Plantation soil inoculation combined with straw checkerboard barriers enhances ectomycorrhizal colonization and subsequent growth of nursery grown *Pinus tabulaeformis* seedlings in a dryland
Li, M.	2021	Role of *Suillus placidus* in improving the drought tolerance of masson pine (*Pinus massoniana* lamb.) seedlings
Peng, L.	2021	Soil phosphorus mobilization and utilization by *Suillus* isolates and *Suillus*-mycorrhized pine plants
Lorenc,	2021	Influence of mycorrhizal preparation on seedling growth and *Armillaria* infestation
Liu, H.	2020	Identification of candidate genes conferring tolerance to aluminum stress in *Pinus massoniana* inoculated with ectomycorrhizal fungus
Gehring, C.	2020	Ectomycorrhizal and Dark Septate Fungal Associations of Pinyon Pine Are Differentially Affected by Experimental Drought and Warming
Verma, B.	2020	Biochar augmentation improves ectomycorrhizal colonisation, plant growth and soil fertility
Zhang, X.	2020	Colonization by *Tuber melanosporum* and *Tuber indicum* affects the growth of *Pinus armandii* and phoD alkaline phosphatase encoding bacterial community in the rhizosphere
Hewitt, R.E.	2020	Limited overall impacts of ectomycorrhizal inoculation on recruitment of boreal trees into Arctic tundra following wildfire belie species-specific responses
Li, X.	2020	Root-tip cutting and uniconazole treatment improve the colonization rate of *Tuber indicum* on *Pinus armandii* seedlings in the greenhouse
Gallart, M	2018	Host Genotype and Nitrogen Form Shape the Root Microbiome of *Pinus radiata*
Zhang, H.	2017	Prior contact of *Pinus tabulaeformis* with ectomycorrhizal fungi increases plant growth and survival from damping-off
Hazard, C.	2017	Strain identity of the ectomycorrhizal fungus *Laccaria bicolor* is more important than richness in regulating plant and fungal performance under nutrient rich conditions
Rudawska, M	2017	Forest litter amendment during nursery stage influence field performance and ectomycorrhizal community of Scots pine (*Pinus sylvestris* L.) seedlings outplanted on four different sites
Hazard, C.	2017	Contrasting effects of intra- and interspecific identity and richness of ectomycorrhizal fungi on host plants, nutrient retention and multifunctionality
Nakashima, H.	2016	Effect of ectomycorrhizal composition on survival and growth of *Pinus thunbergii* seedlings varying in resistance to the pine wilt nematode
Yin, D.	2016	Synergistic effects between *Suilllus luteus* and *Trichoderma virens* on growth of Korean spruce seedlings and drought resistance of Scotch pine seedlings
BarroetaveÃa, C	2016	Field performance of *Pinus ponderosa* seedlings inoculated with ectomycorrhizal fungi planted in steppe-grasslands of andean patagonia, Argentina

Vaario, L.-M.	2015	Variation among matsutake ectomycorrhizae in four clones of *Pinus sylvestris*
Franco, A.R.	2015	Effect of benfluralin on *Pinus pinea* seedlings mycorrhized with *Pisolithus tinctorius* and *Suillus bellinii* - Study of plant antioxidant response
Klavina, D.	2015	Seed provenance impacts growth and ectomycorrhizal colonisation of *Picea abies* seedlings
Repac • , I.	2015	Effects of substrate and ectomycorrhizal inoculation on the development of two-years-old container-grown Norway spruce (*Picea abies* Karst.) seedlings
Sousa, N.R.	2014	A genotype dependent-response to cadmium contamination in soil is displayed by *Pinus pinaster* in symbiosis with different mycorrhizal fungi
Itoo, Z.A.	2014	Influence of ectomycorrhizal inoculation on *Pinus wallichiana* and *Cedrus deodara* seedlings under nursery conditions
Onwuchekwa, N.E.	2014	Growth of mycorrhizal jack pine (*Pinus banksiana*) and white spruce (*Picea glauca*) seedlings planted in oil sands reclaimed areas
Dominguez, J.A.	2013	Short communication. Physiological effects of *Rhizopogon roseolus* on *Pinus halepensis* seedlings
Sanchez-Zabala, J.	2013	Physiological aspects underlying the improved outplanting performance of *Pinus pinaster* Ait. seedlings associated with ectomycorrhizal inoculation
Lazarevia, J..	2012	Mycorrhization of containerized *Pinus nigra* seedlings with *Suillus granulatus* under open field conditions
Ragonezi, C.	2012	*Pisolithus Arhizus* (Scop.) rauschert improves growth of adventitious roots and acclimatization of In vitro regenerated plantlets of *Pinus pinea* L.
Sousa, N.R.	2012	Mycorrhizal symbiosis affected by different genotypes of *Pinus pinaster*
Otgonsuren, B.	2012	*Pinus sylvestris* can form ectomycorrhiza with *Phialocephala fortinii*
Dominguez, J.A.	2012	The combined effects of *Pseudomonas fluorescens* and *Tuber melanosporum* on the quality of *Pinus halepensis* seedlings
Oliveira, R.S.	2012	Combined use of *Pinus pinaster* plus and inoculation with selected ectomycorrhizal fungi as an ecotechnology to improve plant performance
Sousa, N.R.	2012	Ectomycorrhizal fungi as an alternative to the use of chemical fertilisers in nursery production of Pinus pinaster
Sousa, N.R.	2012	The effect of ectomycorrhizal fungi forming symbiosis with *Pinus pinaster* seedlings exposed to cadmium
Sousa, N.R.	2011	Reforestation of burned stands: The effect of ectomycorrhizal fungi on *Pinus pinaster* establishment
Buscardo, E.	2011	Common environmental factors explain both ectomycorrhizal species diversity and pine regeneration variability in a post-fire Mediterranean forest
Wagg, C.	2011	Soil microbial communities from an elevational cline differ in their effect on conifer seedling growth
Koele, N.	2011	Differences in growth and nutrient uptake from a coarse-soil substrate by ectomycorrhizal- and fungicide-treated *Picea abies* seedlings
Repac, I.	2011	Testing of microbial additives in the rooting of Norway spruce (*Picea abies* [L.] Karst.) stem cuttings
Sarjala, T.	2010	Mycorrhiza formation is not needed for early growth induction and growth-related changes in polyamines in Scots pine seedlings in vitro
Vaario, L.-M	2010	Ectomycorrhization of *Tricholoma matsutake* and two major conifers in Finland-an assessment of in vitro mycorrhiza formation
Leski, T.	2010	Ectomycorrhizal community structure of different genotypes of Scots pine under forest nursery conditions
Holusa, J.	2009	Impact of mycorrhizal inoculation on spruce seedling: Comparisons of a 5-year experiment in forests infested by honey fungus
Karst, J.	2009	Ectomycorrhizal colonization and intraspecific variation in growth responses of lodgepole pine
CorrÃ, A.	2008	Response of plants to ectomycorrhizae in N-limited conditions: Which factors determine its variation?
Zhu, J.-J	2008	The role of ectomycorrhizal fungi in alleviating pine decline in semiarid sandy soil of northern China: An experimental approach
Jha, B.N.	2008	Effect of ectomycorrhizal development on growth in pine seedlings
Repac • , I.	2007	Ectomycorrhiza formation and growth of *Picea abies* seedlings inoculated with alginate-bead fungal inoculum in peat and bark compost substrates
Rincoln, A.	2007	Inoculation of *Pinus halepensis* Mill. with selected ectomycorrhizal fungi improves seedling establishment 2 years after planting in a degraded gypsum soil
KozdrÃj, J.	2007	Mycorrhizal fungi and ectomycorrhiza associated bacteria isolated from an industrial desert soil protect pine seedlings against Cd(II) impact
Dominguez-Nunez, JA	2013	Effects of *Pseudomonas fluorescens* on the Water Parameters of Mycorrhizal and Non-Mycorrhizal Seedlings of *Pinus halepensis*

Probanza, A	2001	Effects of inoculation with PGPR *Bacillus* and *Pisolithus tinctorius* on *Pinus pinea* L. growth, bacterial rhizosphere colonization, and mycorrhizal infection
Rincon, A.	2005	Effects of ectomycorrhizal inoculation and the type of substrate on mycorrhization, growth and nutrition of containerised *Pinus pinea* L. seedlings produced in a commercial nursery
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Dunabeitia, M.K.	2004	Differential responses of three fungal species to environmental factors and their role in the mycorrhization of *Pinus radiata* D. Don
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Hartley, J.	1999	The effects of multiple metal contamination on ectomycorrhizal Scots pine (*Pinus sylvestris*) seedlings
Chakravarty, P.	1999	Integrated control of *Fusarium* damping-off in conifer seedlings
Hartley, J.	1999	Cross-colonization of scots pine (*Pinus sylvestris*) seedlings by the ectomycorrhizal fungus *Paxillus involutus* in the presence of inhibitory levels of Cd and Zn
Cram, M.M.	1999	Successful reforestation of south carolina sandhills is not influenced by seedling inoculation with *Pisolithus tinctorius* in the nursery
Manninen, A.-M.	1998	Susceptibility of ectomycorrhizal and nonmycorrhizal Scots pine (*Pinus sylvestris*) seedlings to a generalist insect herbivore**, Lygus rugulipennis**, at two nitrogen availability levels
Scagel, C.F.	1998	Relationships between differential in vitro Indole-Acetic Acid or ethylene production capacity by ectomycorrhizal fungi and conifer seedling responses in symbiosis
Scagel, C.F.	1998	Influence of ectomycorrhizal fungal inoculation on growth and root IAA concentrations of transplanted conifers
Gehring, C.A.	1997	Three-way interactions among ectomycorrhizal mutualists, scale insects, and resistant and susceptible pinyon pines
Shaw, T.M.	1995	Interactions between ectomycorrhizal and saprotrophic fungi on agar and in association with seedlings of lodgepole pine (*Pinus contorta*)
BONELLO, P.	1993	Ozone effects on root • disease susceptibility and defence responses in mycorrhizal and non • mycorrhizal seedlings of Scots pine (*Pinus sylvestris* L.)
WILKINS, D.A.	1989	The effects of aluminium and *Paxillus involutus* Fr. on the growth of Norway spruce [*Picea abies* (L.) Karst.]
Berry, C.R.	1977	Growth of loblolly pine seedlings in strip mined kaolin spoil as influenced by sewage sludge
Chu, H.L.	2019	The Dark Septate Endophytes and Ectomycorrhizal Fungi Effect on *Pinus tabulaeformis* Carr. Seedling Growth and their Potential Effects to Pine Wilt Disease Resistance
Nadeau, M.B.	2018	Mycorrhizae and Rhizobacteria on Precambrian Rocky Gold Mine Tailings: I. Mine-Adapted Symbionts Promote White Spruce Health and Growth
Nowak, J.	2006	Loblolly pine and slash pine responses to acute aluminum and acid exposures
Nieminen, J.K.	2001	Influence of carbon and nutrient additions on a decomposer food chain and the growth of pine seedlings in microcosms
Piculell, B.J.	2018	Genetically determined fungal pathogen tolerance and soil variation influence ectomycorrhizal traits of loblolly pine

Menkis, A.	2007	Afforestation of abandoned farmland with conifer seedlings inoculated with three ectomycorrhizal fungi-impact on plant performance and ectomycorrhizal community
Jenkins, M.L.	2018	Scorched Earth: *Suillus* colonization of *Pinus albicaulis* seedlings planted in wildfire-impacted soil affects seedling biomass, foliar nutrient content, and isotope signatures
Kayama, M .	2006	Comparison of growth characteristics and tolerance to serpentine soil of three ectomycorrhizal spruce seedlings in northern Japan
SVENSON, S.E.	1991	Ectomycorrhizae and drought acclimation influence water relations and growth of loblolly-pine
Wen, Z.G.	2019	Distributions and Compositions of Brominated Diphenyl Ethers-209 in Pine Seedlings Inoculated with Ectomycorrhizal Fungi
Sun, Y.J .	2020	Effects of slippery jack (*Suillus luteus*) on the heavy metal accumulation and soil properties of masson's pine (*Pinus massoniana* lamb) in a mining area of china
Velmala, S.M.	2018	Ectomycorrhizal fungi increase the vitality of Norway spruce seedlings under the pressure of *Heterobasidion* root rot in vitro but may increase susceptibility to foliar necrotrophs
Niemi, K.	2007	Spermidine and the ectomycorrhizal fungus *Pisolithus tinctorius* synergistically induce maturation of Scots pine embryogenic cultures
Hwang, S.F.	1995	The effect of two ectomycorrhizal fungi, *Paxillus involutus* and *Suillus tomentosus*, and of *Bacillus subtilis* on *Fusarium* damping-off in jack pine seedlings
Wang, Y.H.	2022	Mycorrhiza helper bacterium *Bacillus pumilus* HR10 improves growth and nutritional status of *Pinus thunbergii* by promoting mycorrhizal proliferation
Mueller, R.C.	2006	Interactions between an above-ground plant parasite and below-ground ectomycorrhizal fungal communities on pinyon pine
Beck, J.L.	2020	Changes in soil fungal communities following anthropogenic disturbance are linked to decreased lodgepole pine seedling performance
Suarez, J.O.	2018	Effects of *Lactarius deliciosus* and *Rhizopogon roseolus* ectomycorrhyzal fungi on seeds and seedlings of Scots and stone pines inoculated with *Fusarium oxysporum* and Fusarium verticillioides
Machon, P.	2006	Influence of the ectomycorrhizal fungus *Laccaria laccata* on pre-emergence, post-emergence and late damping-off by *Fusarium moniliforme* and F-oxysporum on Scots pine seedlings
Niemi, K	2007	*Suillus variegatus* causes significant changes in the content of individual polyamines and flavonoids in Scots pine seedlings during mycorrhiza formation in vitro
Liiri, M	2007	Variable impacts of enchytraeid worms and ectomycorrhizal fungi on plant growth in raw humus soil treated with wood ash
Yin, DC	2018	Ectomycorrhizal fungus enhances drought tolerance of *Pinus sylvestris* var. mongolica seedlings and improves soil condition
Niemi, K .	2002	*Pisolithus tinctorius* promotes germination and forms mycorrhizal structures in Scots pine somatic embryos in vitro
Hartley-Whitaker, J.	2000	Sensitivity to Cd or Zn of host and symbiont of ectomycorrhizal *Pinus sylvestris* L. (Scots pine) seedlings
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Kipfer, T.	2015	Drought resistance of *Pinus sylvestris* seedlings conferred by plastic root architecture rather than ectomycorrhizal colonisation
Dominguez Nunez, J.A.	2008	The effect of Tuber melanosporum Vitt. mycorrhization on growth, nutrition, and water relations of *Quercus petraea Liebl.*, *Quercus faginea* Lamk., and *Pinus halepensis* Mill. seedlings
Nadeau, M.B.	2018	Mycorrhizae and Rhizobacteria on Precambrian Rocky Gold Mine Tailings: II. Mine-Adapted Symbionts Alleviate Soil Element Imbalance for a Better Nutritional Status of White Spruce Seedlings
Franco, A.R.	2015	Inoculation of *Pinus pinea* seedlings with *Pisolithus tinctorius* and *Suillus bellinii* promotes plant growth in benfluralin contaminated soil
Mueller, R.C.	2019	Legacy effects of tree mortality mediated by ectomycorrhizal fungal communities
Menkis, A.	2011	Mycorrhization, Establishment and Growth of Outplanted *Picea abies* Seedlings Produced under Different Cultivation Systems

Kim, C.G.	2004	Effects of host plant exposure to cadmium on mycorrhizal infection and soluble carbohydrate levels of *Pinus sylvestris* seedlings
Tahara, C.	2005	Ectomycorrhizal association enhances Al tolerance by inducing citrate secretion in *Pinus densiflora*
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