

## Supplementary Material for Field *et al.*, (2024)

### *Appendix I: Description of scoping searches and main literature search*

A scoping study conducted using the database Scopus was used to identify the search terms for use in bibliographic databases and internet searches. This was done by testing search strings in Scopus using the Field Tag (TITLE-ABS-KEY) to search for relevant titles, abstracts and keywords. Search terms were sourced from previous meta-analyses and systematic reviews on themes of mixed forests and/or insect herbivory and forest pathogens, and from the keywords of studies identified *a priori* as highly relevant (see Appendix II). Search results were ordered based on relevance and limited to studies in the 'Agriculture and Biological sciences' and 'Environmental Sciences' topics to remove results from non-relevant subjects. For each search combination, the total number of hits and the number of relevant papers (assessed based on title) in the first 200 hits was recorded. In addition, each search combination was scrutinised for its ability to retrieve a list of **12** studies identified *a priori* as highly relevant to the primary question (test library, see below). These studies were sourced from the personal libraries of the authors and stakeholders. Although all contain information relevant to the primary question, they utilise a range of observational and experimental study systems and the phrasing related to the primary question differs in each case; not all combinations of search terms were able to retrieve all of these papers. The final search terms were able

to retrieve all of these papers, and achieved a good balance between relevant and non-relevant studies in the first 200 results.

The final search terms and their relevance to each of the PECO question elements is summarised in Table S1. Table S2 shows the exact search terms used in each database, the number of hits returned when initially searched, and search date. The large discrepancy in numbers of hits returned from Scopus compared to Web of Science and CABI is likely to be due to the restricted field tag used (TITLE-ABS-KEY) combined with differences in the literature available from Scopus, as without use of this field tag the number of hits returned by this database are typically extremely high (a comparison search using the same search terms without this field tag in Scopus returned over 37,000 hits).

Due to the large number of search results from irrelevant topics, the results of the Scopus search was limited to journals in the “Agricultural and Biological Sciences” and “Environmental Science” categories. In Web of Science, results of searches were limited to the following research areas in order to narrow the search: Agriculture OR Forestry OR Environmental Sciences OR Ecology OR Plant sciences.

PECO question component	Terms	Search terms
Population	Forest	tree* OR forest* OR plantation OR wood* OR orchard OR coppice OR shrub OR abies OR acer OR betula OR eucalyptus OR fagus OR fraxinus OR picea OR pinus OR populus OR quercus
Exposure	Mixed Stands	"mixed species" OR "mixed-species" OR "mixed stand*" OR "tree divers*" OR "tree species divers*" OR "host species divers*" OR "host divers*" OR "community divers*" OR "forest divers*" OR "forest species divers*" OR "divers* stand" OR "divers* plant*" OR "divers* forest" OR "divers* wood*" OR "tree species rich*" OR "host species rich*" OR "forest species rich*" OR polyculture* OR "landscape heterogen*" OR "heterogen* landscape" OR "species mix*" OR "diversity-disease" OR "species composition"

Comparator	Forest	pathogen OR disease OR infection OR
	Pathogen	"root rot" OR "butt rot" OR fung* OR
	Damage	lesion OR canker OR bacteria* OR viral
		OR virus OR Phytophthora OR
		Armillaria OR Heterobasidion

**Table S1:** List of search strings used in bibliographic databases and their relationship to each component of the primary question. Each section was combined using 'AND' (for exact search strings with Boolean operators used in each database, see Table S2).

Database	Search string used	Number of hits	Date
Scopus	( TITLE-ABS-KEY ( ( tree* OR forest* OR plantation OR wood* OR orchard OR coppice OR shrub OR abies OR acer OR betula OR eucalyptus OR fagus OR fraxinus OR picea OR pinus OR populus OR quercus ) AND ( "mixed species" OR "mixed-species" OR "mixed stand*" OR "tree divers*" OR "forest divers*" OR "tree species divers*" OR "host species divers*" OR "host divers*" OR "community divers*" OR	1,744 (limited to Topics: Agricultural/Environmental Science and Biological Sciences)	13 <sup>th</sup> December 2017

	<p>"forest species divers*" OR "divers* stand" OR "divers* plant*" OR "divers* forest" OR "divers* wood*" OR "tree species rich*" OR "host species rich*" OR "forest species rich*" OR polyculture* OR "landscape heterogen*" OR "heterogen* landscape" OR "species mix*" OR "diversity-disease" OR "species composition" ) AND ( pathogen OR disease OR infection OR "root rot" OR "butt rot" OR fung* OR lesion OR canker OR bacteria* OR viral OR virus OR phytophthora OR armillaria OR heterobasidion))) AND ( LIMIT-TO ( SUBJAREA , "AGRI " ) OR LIMIT-TO ( SUBJAREA , " ENVI " ) )</p>		
<p>Web of Science (All databases: WoS Core</p>	<p>TS = (tree* or forest* or plantation or wood* or orchard or coppice or shrub or abies or acer or betula or eucalyptus or fagus or fraxinus or</p>	<p>5,703 (limited to Research Areas within Science and</p>	<p>13<sup>th</sup> December 2017</p>

Collection 1945-present, BioSIS Citation Index, Current Contents Connect, Data Citation Index, Derwent Innovations Index, Inspec, KCI-Korean Journal Database, MEDLINE, Russian Science Citation Index, SciELO Citation Index,	picea or pinus or populus or quercus) AND TS = ("mixed species" or "mixed-species" or "mixed stand*" or "tree divers*" or "tree species divers*" or "forest divers*" or "host species divers*" or "host divers*" or "community divers*" or "forest species divers*" or "divers* stand" or "divers* plant*" or "divers* forest" or "divers* wood*" or "tree species rich*" or "host species rich*" or "forest species rich*" or polyculture* or "landscape heterogen*" or "heterogen* landscape" or "species mix*" or "diversity-disease" or "species composition") AND TS = (pathogen or disease or infection or "root rot" or "butt rot" or fung* or lesion or canker or bacteria* or viral or virus or Phytophthora or Armillaria or Heterobasidion)	Technology: (Agriculture OR Forestry OR Environmental Sciences OR Ecology OR Plant sciences)	
---	---	---	--

Zoological Record)			
CAB Abstracts (Database: 1910 - 2017)	(tree* or forest* or plantation or wood* or orchard or coppice or shrub or abies or acer or betula or eucalyptus or fagus or fraxinus or picea or pinus or populus or quercus) AND ("mixed species" or "mixed-species" or "mixed stand*" or (mixed adj1 stand) or "tree divers*" or "tree species divers*" or "host species divers*" or "host divers*" or "community divers*" or "forest divers*" or "forest species divers*" or "tree species divers*" or (forest adj1 divers*) or (tree adj1 divers*) or "divers* stand" or "divers* plant*" or "divers* forest" or "divers* wood*" or "tree species rich*" or "host species rich*" or "forest species rich*" or polyculture* or "landscape heterogen*" or "heterogen* landscape" or "species mix*" or "diversity-disease" or	2,756 Searching abstract, title, original title, broad terms, heading words, identifiers, cabicodes	13 <sup>th</sup> December 2017

	"species composition") AND (pathogen or disease or infection or "root rot" or "butt rot" or fung* or lesion or canker or bacteria* or viral or virus or Phytophthora or Armillaria or Heterobasidion)		
--	--	--	--

**Table S2:** List of search strings used in each major database queried during the systematic review, with number of hits returned and date initially searched.

NB: Google Scholar does not permit the use of Boolean operators, so search terms were modified and the first 1000 results downloaded from Google Scholar. We tried several search term combinations in Google Scholar to maximise the number of test library studies found while minimising duplication with the rest of the literature searches. Final search terms used in Google Scholar were: ‘ “mixed stand” forest pathogen ‘ (Search completed on 21<sup>st</sup> February 2018).

*Appendix II: Test Library used in Scoping Searches*

1. Dillen, Mathias, Kris Verheyen, and Christian Smit. 2016. Identity rather than Richness Drives Local Neighbourhood Species Composition Effects on Oak

Sapling Growth in a Young Forest. *Forest Ecology and Management* 380 (November): 274–84. doi:10.1016/j.foreco.2016.09.004.

2. DeLong RL, Lewis KJ, Simard SW, Gibson S. (2002). Fluorescent pseudomonad population sizes baited from soils under pure birch, pure Douglas-fir, and mixed forest stands and their antagonism toward *Armillaria ostoyae* in vitro. *Can. J. For. Res.* 32:2146–59.
3. Filip, G. M., Bronson, J. J., Chadwick, K. L., Filip, J. B., Frankel, S. J., Goheen, D. J et al (2015). Precommercial Thinning in Mixed-Species Conifer Plantations Affected by *Armillaria* and *Heterobasidion* Root Diseases in West-Central Oregon and Washington: 30-Year Results. *Forest Science*.
4. Gerlach, J P, P B Reich, K Puettmann, and T Baker. 1997. Species, Diversity, and Density Affect Tree Seedling Mortality from *Armillaria* Root Rot. *Canadian Journal of Forest Research* 27 (9): 1509–12. doi:10.1139/x97-098.
5. Haas, Sarah E., Mevin B. Hooten, David M. Rizzo, and Ross K. Meentemeyer. 2011. Forest Species Diversity Reduces Disease Risk in a Generalist Plant Pathogen Invasion. *Ecology Letters* 14 (11): 1108–16. doi:10.1111/j.1461-0248.2011.01679.x.

6. Hantsch, Lydia, Steffen Bien, Stine Radatz, Uwe Braun, Harald Auge, and Helge Bruelheide. 2014. Tree Diversity and the Role of Non-Host Neighbour Tree Species in Reducing Fungal Pathogen Infestation. *Journal of Ecology* 102 (6): 1673–87. doi:10.1111/1365-2745.12317.
7. Hantsch, Lydia, Uwe Braun, Michael Scherer-Lorenzen, and Helge Bruelheide. 2013. Species Richness and Species Identity Effects on Occurrence of Foliar Fungal Pathogens in a Tree Diversity Experiment. *Ecosphere* 4 (7): 1–12.
8. Jules ES, Kauffman MJ, Ritts WD, Carroll AL. (2002). Spread of an Invasive Pathogen over a Variable Landscape: A Nonnative Root Rot on Port Orford Cedar. *Ecology* 83:3167–81.
9. Morrison, D. J., M. G. Cruickshank, and A. Lalumière. 2014. Control of Laminated and Armillaria Root Diseases by Stump Removal and Tree Species Mixtures: Amount and Cause of Mortality and Impact on Yield after 40 Years. *Forest Ecology and Management* 319 (May): 75–98. doi:10.1016/j.foreco.2014.02.007.
10. Nguyen D, Castagneyrol B, Bruelheide H, Bussotti F, Guyot V, Jactel H, et al. (2016). Fungal disease incidence along tree diversity gradients depends on latitude in European forests. *Ecol. Evol.* 2016;n/a-n/a.

11. Lindén, Magnus, and Gudmund Vollbrecht. 2002. Sensitivity of *Picea Abies* to Butt Rot in Pure Stands and in Mixed Stands with *Pinus Sylvestris* in Southern Sweden. *Silva Fennica* 36 (4). doi:10.14214/sf.519.
  
12. Piri T., Korhonen K., Sairanen A., 1990. Occurrence of *Heterobasidion annosum* in pure and mixed spruce stands in Southern Finland. *Scand. J. For. Res.* 5, 113-125

*Appendix III: List of stakeholders consulted during the literature searching stage*

Centre for International Forest Research (CIFOR)

EU COST action on Mixed Forests (EUMIXFOR)

EUFORGEN

European Forest Institute

Food and Agriculture Organisation of the United Nations

Forest Europe

Forest Research (UK)

French National Institute for Agricultural Research (INRA)

International Union of Forestry Research Organisations (IUFRO)

United States Department of Agriculture

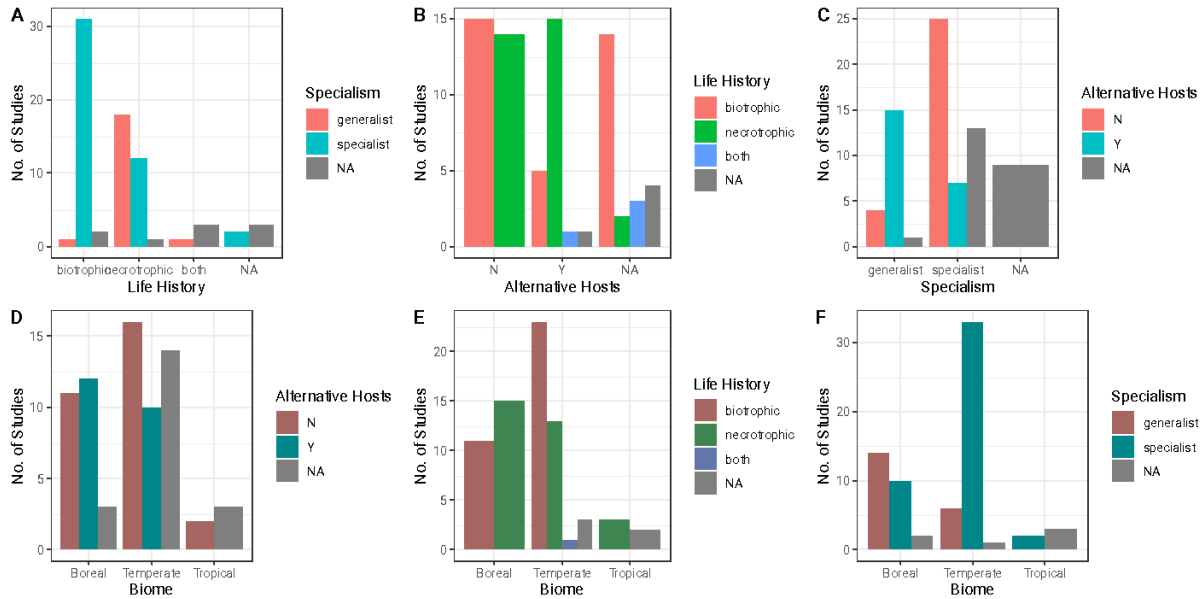
World Agroforestry Centre

*Appendix IV: Metadata Form sent to stakeholders from TreeDivNet contributing unpublished data sets*

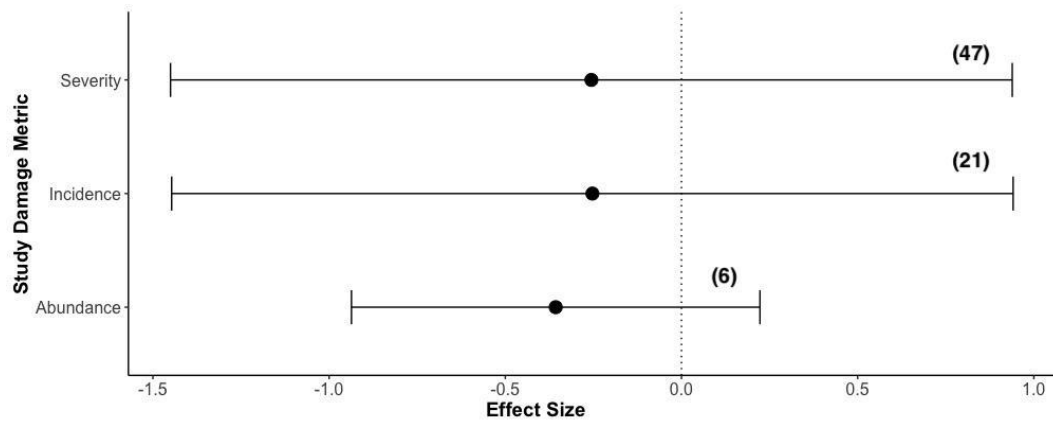
TreeDivNet Pathogen Data for Systematic Synthesis	
Name:	Institution:
Position:	Contact email:
Contact address:	Experiment name:
Location of experiment (latitude and longitude):	Dates of data collection:
Year planted:	
Who collected the data?	Contact email of the person who collected the data (if different from above):
Tree species planted in experiment:	Tree species sampled for pathogens:
Please provide a brief description of sampling protocol, including the number of plots sampled and treatment levels, number of trees sampled per plot, number of leaves/shoots sampled per tree.	
How were pathogens identified (e.g. by eye in the field, microscopically from sampled leaves, molecular methods)?	
What is the metric of pathogen damage recorded? (e.g. % damage per leaf, number of stem lesions, etc).	

Further comments

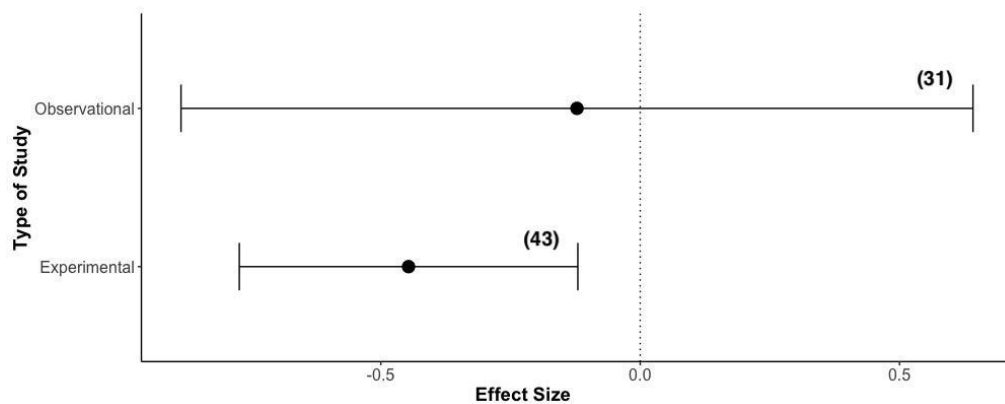
### Appendix V: Supplementary Figures



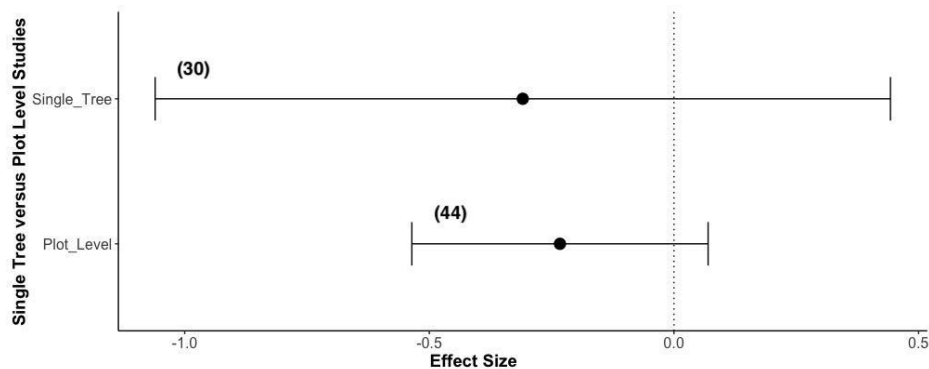
**Figure S1.** Bar charts showing categorical moderators used in mixed effects meta-analysis models, plotted against number of studies. Shown in each plot are the numbers of studies in each category, for two categorical moderators. Several moderators are well confounded (A, C, E, F). We therefore chose to analyse moderators separately rather than including them in the same models. Total no. of studies ( $k$ ) = 74.



**Figure S2:** Effect of diversity metric used in studies on effect size (Hedges'  $d$ ). Shown is the mean effect size  $\pm$  95% confidence intervals for each group. Metrics of pathogen damage fell into two main categories: pathogen incidence ( $k = 21$  studies) and pathogen severity ( $k = 47$  studies), with a smaller number ( $k = 6$  studies) that assessed pathogen abundance. Diversity metric was a non-significant predictor of effect size  $Q_M = 0.11$ ,  $p = 0.95$ ,  $df = 2$ ). In brackets is the number of studies in each group (total  $k = 72$  studies).

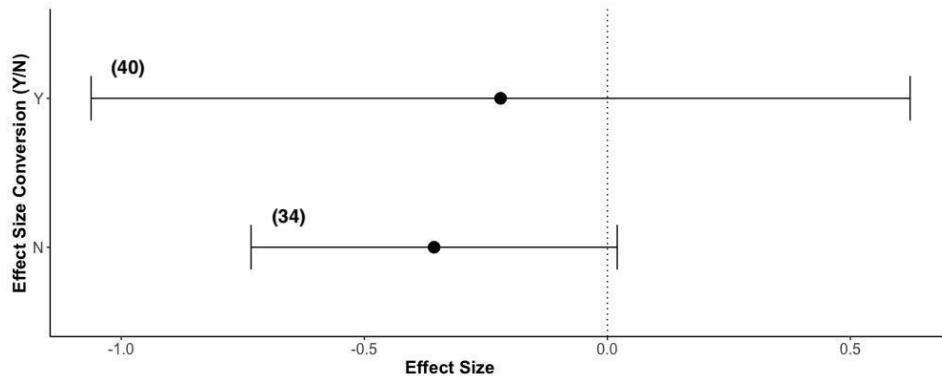


**Figure S3:** Effect of study type (experimental versus observational) on effect size (Hedges'  $d$ ). Shown is the mean effect size  $\pm$  95% confidence intervals for each group. Study type was a non-significant predictor of effect size  $Q_M = 2.12, p = 0.14, df = 1$ ). Damage in experimental studies was significantly lower in mixed forests compared to monocultures, but the effect was not significantly different from observational studies (Fig. 6). In brackets is the number of studies in each group (total  $k = 72$  studies).

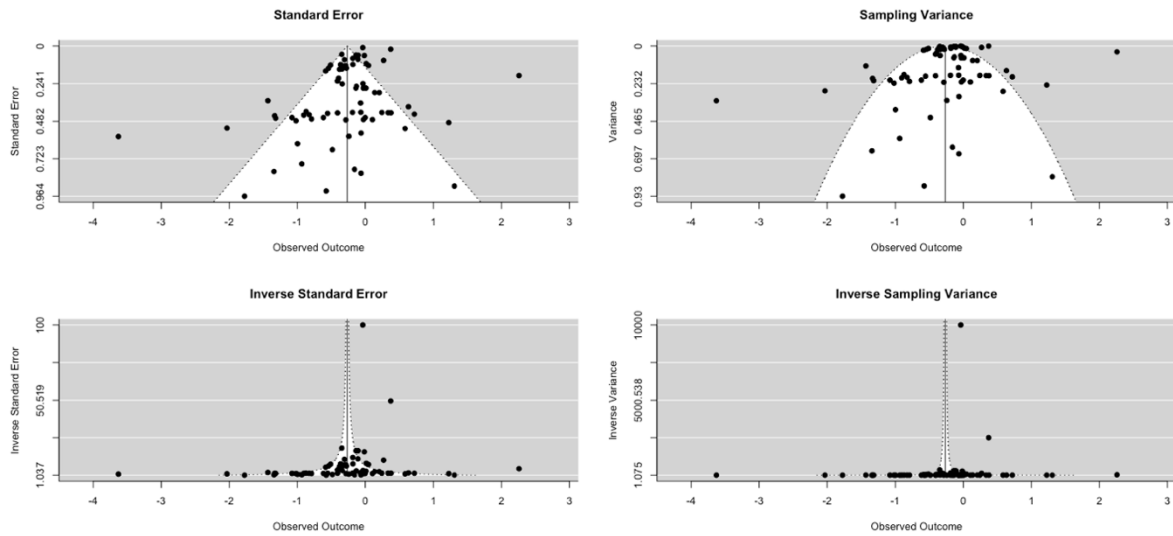


**Figure S4:** Effect of study level (single tree level versus plot level estimates) on effect size (Hedges'  $d$ ). Shown is the mean effect size  $\pm$  95% confidence intervals for each

group. Study type was a non-significant predictor of effect size  $Q_M = 0.11, p = 0.74, df = 1$ . In brackets is the number of studies in each group (total  $k = 72$  studies).



**Figure S5:** Comparison of directly calculated effect sizes and those converted from other metrics of effect size. Conversions were mostly from correlation coefficients, in some cases  $p$ -values and  $\chi^2$  statistics. Shown is the mean effect size  $\pm$  95% confidence intervals for each group. Effect size conversion was a non-significant predictor of effect size  $Q_M = 0.33, p = 0.57, df = 1$ . In brackets is the number of studies in each group (total  $k = 72$  studies).



**Figure S6.** Funnel plots showing observed outcome (study effect sizes) against study standard error, variance, and inverse standard error/inverse variance. Plotted are the effect sizes. The black vertical line indicates the overall effect size, with the white region showing the boundaries within which studies would lie given perfect symmetry.