Meta-analysis

Statistical methodology used to quantitatively review related studies

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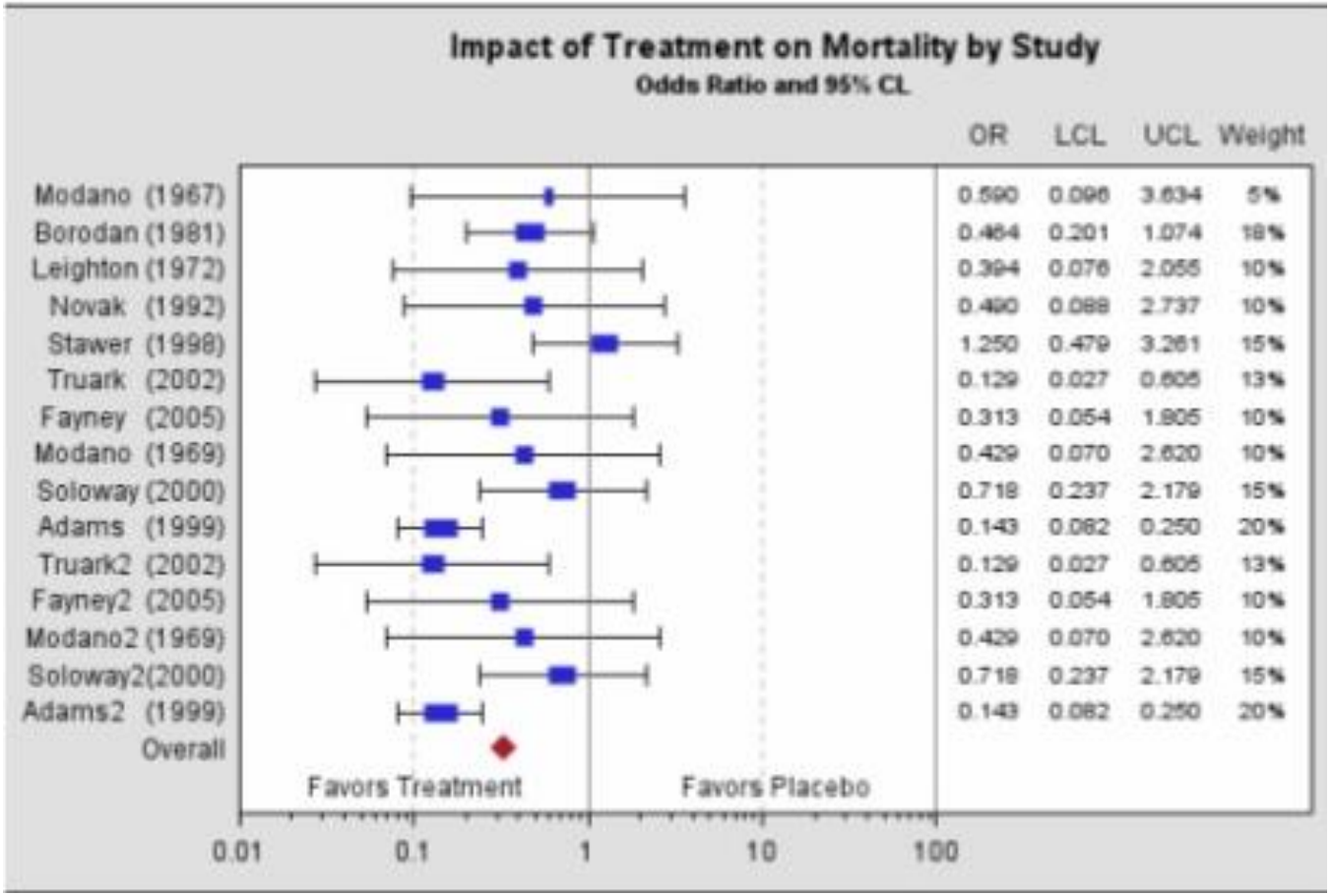
A meta-analysis estimates the overall effect across multiple studies

- Is does NOT simply average the effects of all studies
  - Effect sizes are weighted, by a degree of sample size
- Meta-analysis is statistically distinct from a primary analysis in that it contains 2 sources of variation
  - Variation within studies
  - Variation between studies

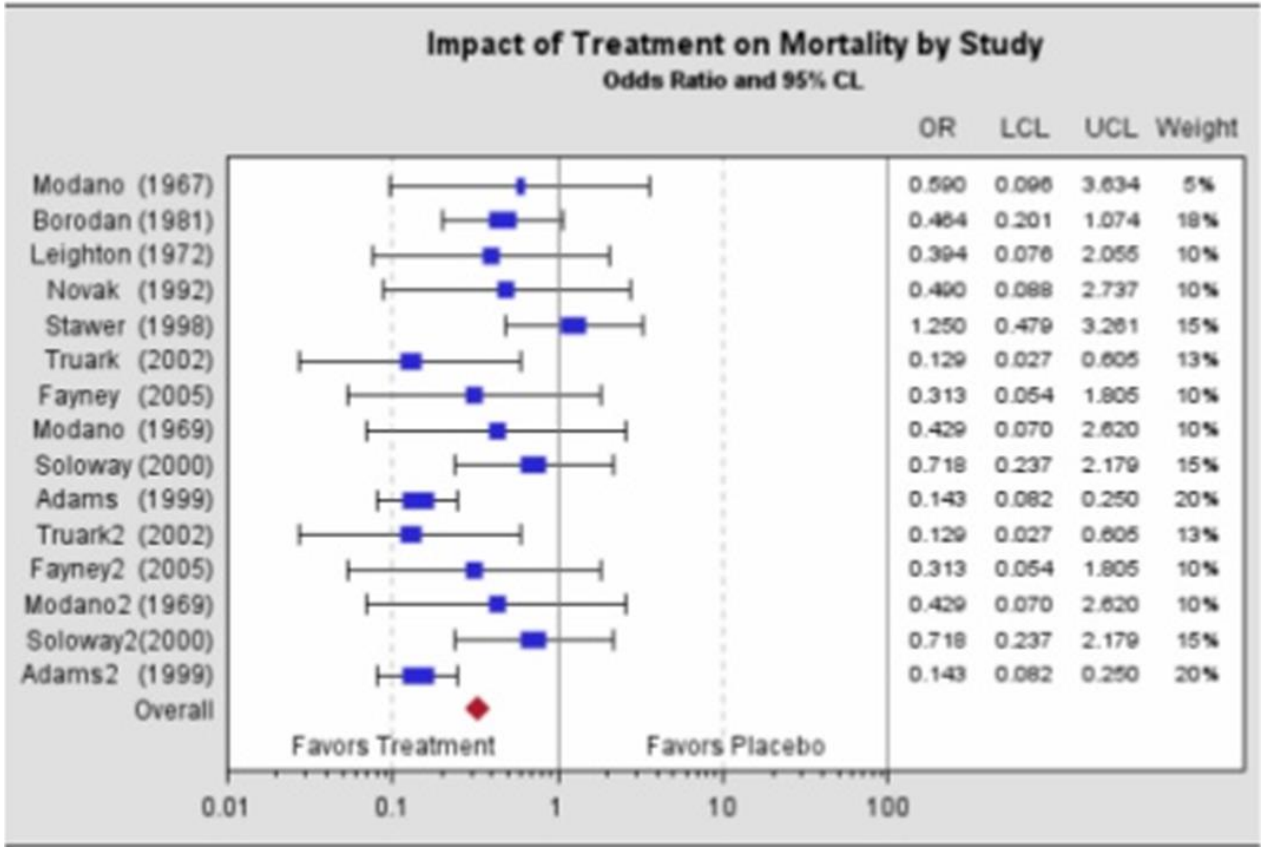
Meta-analysis forest plot



Rizwan et al. 2015

Goals of a meta-analysis

1. Estimate an overall effect
2. Explain heterogeneity between studies



Rizwan et al. 2015

Steps of a meta-analysis

1. Choosing selection parameters, literature search
2. Data extraction
3. **Calculating effect sizes**
4. **Choosing meta-analysis models**
5. **Comparing and contrasting effect sizes (tests for heterogeneity)**

Calculating effect sizes

To allow for comparison of effects between studies we must calculate for each study:

1. standardized effect size
2. standardized variance

The way you calculate standardized effects depends on the type of data you have

Pairs of means

Example question: How is sapling growth rate influenced by living in either a monoculture or a biodiverse area?

Effect size measure: Cohen's d, Hedge's g (or Hedge's d)

- Used to compare two estimated means (M_E and M_C) within a study

$$d = \frac{M_E - M_C}{\text{Sample } SD \text{ pooled}} \times \left(\frac{N-3}{N-2.25}\right) \times \sqrt{\frac{N-2}{N}}$$

correction factor for small samples <50

Correlation data

Example question: How does latitude influence sapling growth rate?

Effect size measure: Pearson's correlation coefficient

- Measures the association between two continuous variables
- Often transformed by Fishers Z to avoid skew at large values
- Can be calculated directly from a test statistic (i.e. t, z, X^2), and the sample size used in a linear regression

Two x two contingency data

Example question: Does whether a seedling grows near or far from the parent's location influence the seedling's survival?

Effect size measure: Odds-ratio effect / rate of difference

	Survived	Died
Close to parent	37	56
Far from parent	48	39

$$\text{Rate of difference} = \frac{\text{Close}_{\text{survived}}}{(Close_{died} + Close_{survived})} - \frac{Far_{survived}}{(Far_{died} + Far_{survived})}$$

- Uses binomial count data to measure the likelihood of outcome A relative to outcome B
- Used most widely in medicine

Choosing your effect size metric

The type of effect size used will depend on

1. the type of effect been measured (continuous vs. categorical)
2. the availability of data in the published materials

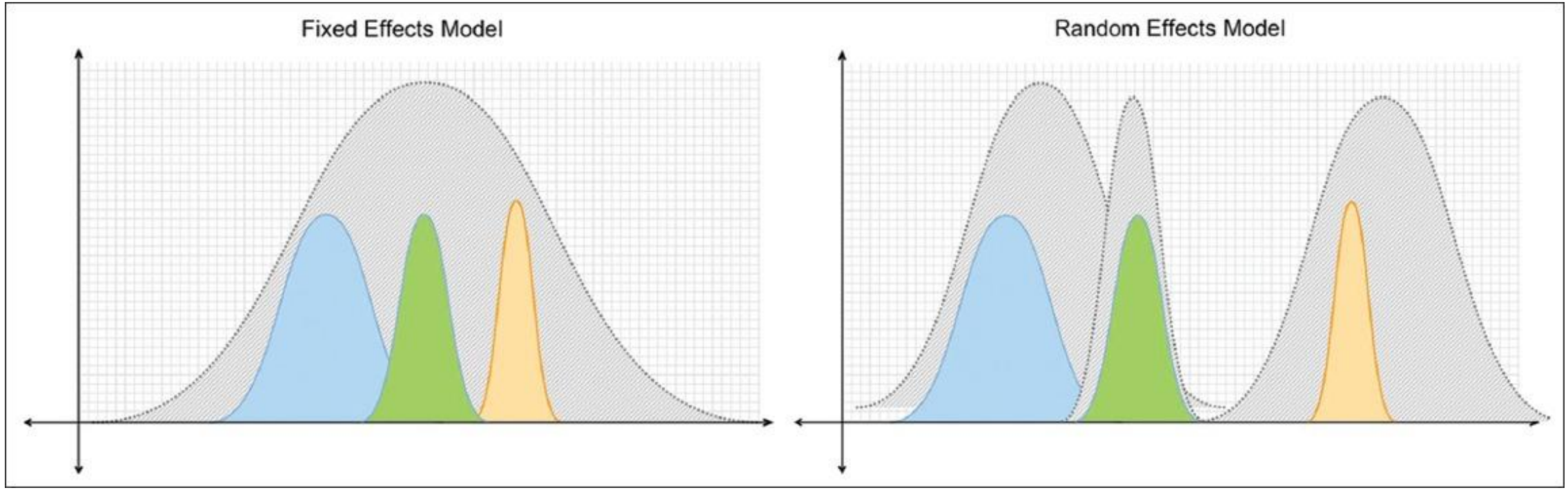
There are other effect size options if the most common ones don’t fit your data!

The next step: model selection

- A meta-analysis will quantitatively aggregate standardized effect sizes into a ‘meta-analytic mean’
- The calculation of the meta-analytic mean relies on the
  - Weighting of each study
  - Variation within studies (similar to a primary analysis)
  - Variation between studies (unique feature of meta-analysis)
- Two base models to choose from:
  - Fixed-effects model
  - Random-effects model

Fixed effects model: assumes no difference between the true effects between studies

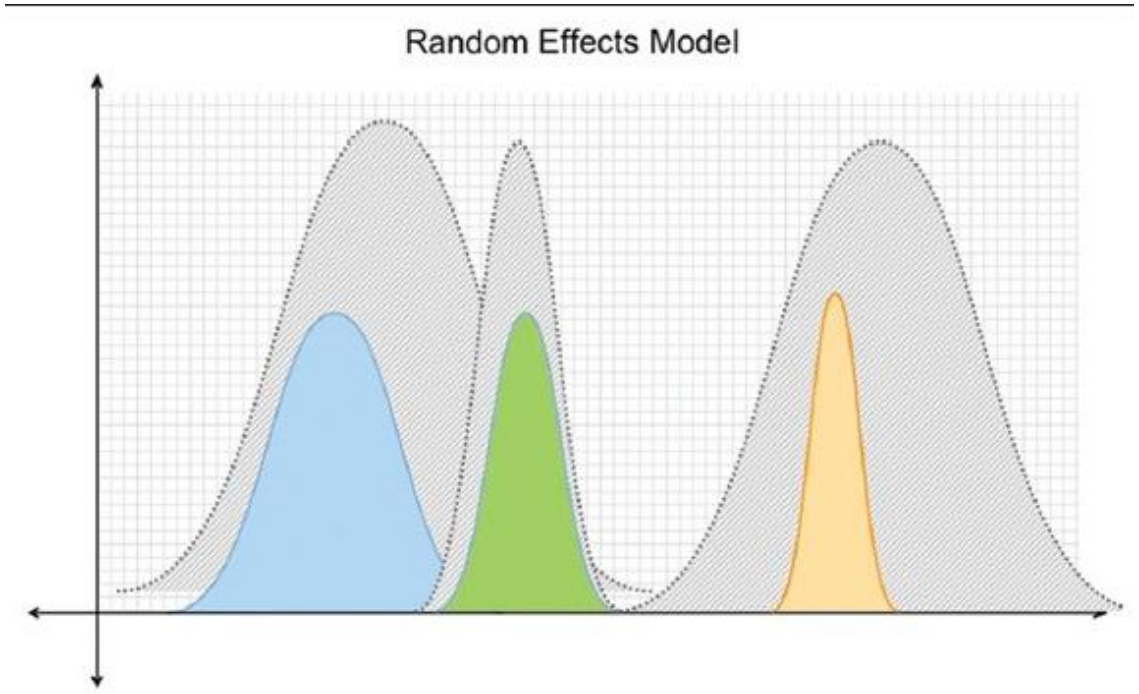
Random effects model: allows for the true effects to differ between studies



Each color represents the sampled distribution of one study. The grey outlines represents how the meta-analysis model estimates the true distributions of each study.

Last step: Testing for heterogeneity

- We can use statistics to test how different the estimated effects are between studies
- This step only applies to random-effects models
- Two commonly used tests of heterogeneity….



Heterogeneity test: Q statistic

- Tests the null hypothesis that all the studies are a homogenous sample from a population of studies with a true effect μ

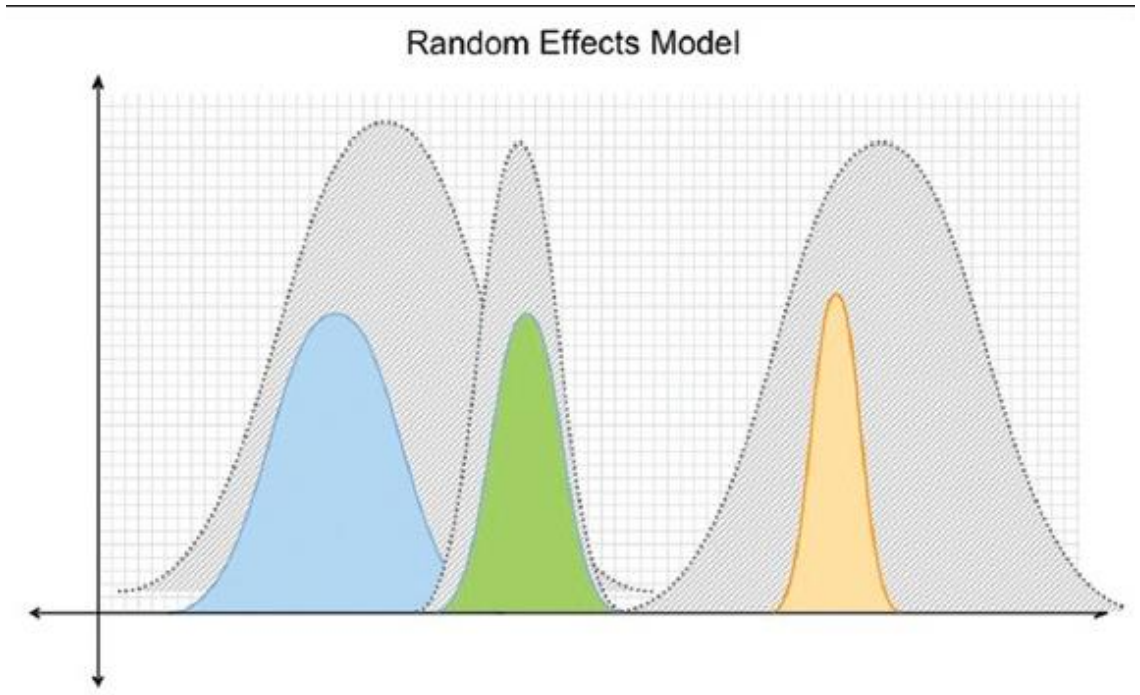
$$Q_t = \sum_{k=1}^{k} w_k(\theta_k - \mu)^2$$

- Test is performed by comparing Q_t to a X^2 distribution with K-1 degrees of freedom
- A significant value indicates that the estimated effect sizes are more heterogeneous than would be expected by chance
- Spurious results in the sample size is too small OR too large

Heterogeneity test: I^2 statistic

$$I^2 = \frac{variation\ between\ studies}{variation\ between\ studies + variation\ within\ studies} \text{ x } 100$$

- A proportion of the two types of variances
- Comparable between studies
- May be unable to detect heterogeneity if
  - Number of studies are small
  - Within study variation is relatively large



So, you've determined there is heterogeneity in the data – what now?

We can expand our meta-analysis model into a **meta-regression** to test the influence of specific **moderator factors** in explaining heterogeneity

Some potentially appropriate moderators:

- Year of study
- Location of study
- Specific aspects of the experimental design
- Lab group
- Species of study

Moderator terms can be continuous or categorical

Metafor

- One (of many) software tools available to conduct meta-analyses
- Other R packages which may be useful for conducting meta-analysis: https://cran.r-project.org/web/views/MetaAnalysis.html
- **Pros:** one of the most widely used packages
- **Limitation:** no Bayesian inference (e.g. phylogenetic analysis)