Meta-analysis in biological and environmental sciences

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DFG Deutsche Forschungsgemeinschaft

Day 1	**Introduction to meta-analysis** • What is a meta-analysis? • Examples of meta-analyses • Why performing a meta-analysis? • Procedure of meta-analysis in a nutshell **Searching the literature** **Effect sizes and moderators** **Data extraction/Coding**
Day 2	**Meta-analytic models** • Fixed effects model • Random effects model • Mixed effects/hierarchical model **Quantifying and explaining heterogeneity**
Day 3	**Assumptions, biases and confounding effects** • Variance homogeneity and normality of residuals • Publication bias • Sensitivity analysis **Interpretation and presentation of results** • Format for meta-analysis report • PRISMA flow diagram • Forest plots
Day 4	**Methodological issues, advances, and common mistakes** • Non-independence among effect sizes • Non-independence of moderators • Missing data **Criticism of meta-analysis**

Meta-analysis in biological and environmental sciences

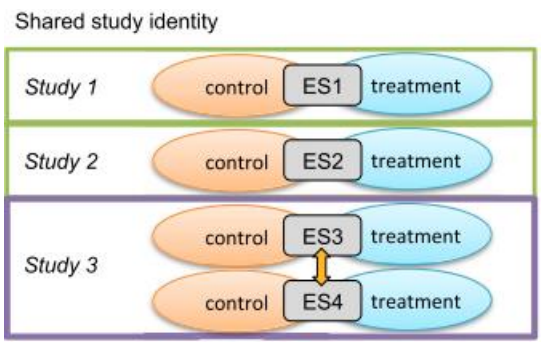
Methodological issues, advances, and common mistakes

Non-independence among effect sizes

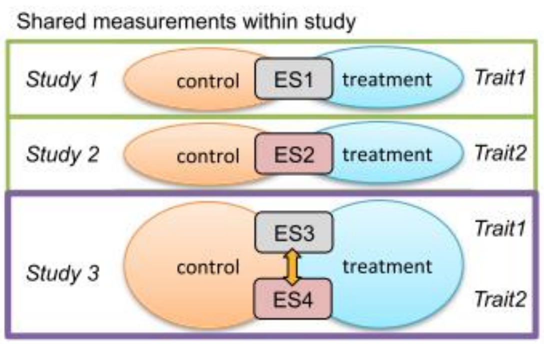
- Within-study non-independence
  - Multiple experiments
  - Multiple treatments with common control
  - Multiple measures of outcome
  - Repeated measures on the same individual
- Between-study non-independence
  - Among study organisms (research bias, phylogenetic relatedness)
  - Among researchers/research groups and labs

Dealing with within-study non-independence

- Multiple experiments
  - Choosing single experiment per study (random draw, largest sample size)
  - Aggregated measure of outcome per study



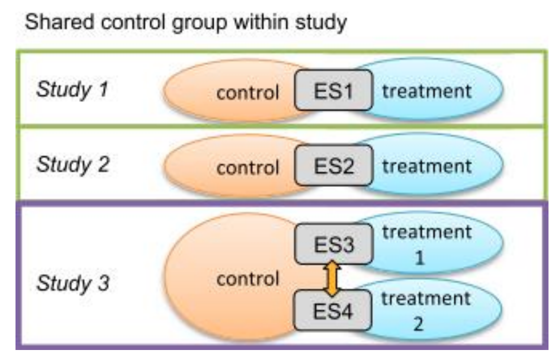
- Multiple measures of outcome
  - Choosing single most important measure (e.g. the one most closely related to fitness)
  - Aggregated measure of outcome per study
  - Multivariate analysis



Nakagawa et al. (2017) BMC Biology

Dealing with within-study non-independence

- Multiple treatments with common control
  - New variances are derived for several common experimental designs, e.g. multiple treatments with common control, repeated measures, multivariate or correlated factorial designs



Nakagawa et al. (2017) BMC Biology

Ecology, 92(11), 2011, pp. 2049–2055

On the meta-analysis of response ratios for studies with correlated and multi-group designs

Marc J. Lajeunesse[1]

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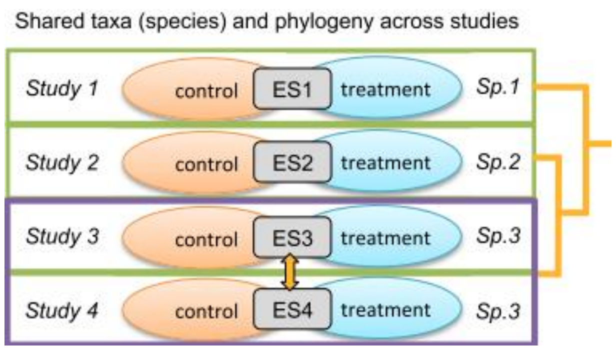
- Repeated measures
  - Use a single time point (e.g. final measure)
  - Use effect metric which assesses change in effect over time (e.g. correlation with time or standardized mean difference between 2 time points) and then combine these in a meta-analysis
  - Treat repeated measures as a multivariate outcome

Dealing with between-study non-independence

- Phylogenetic relatedness
  - Shared origin can lead to under- or overestimation effect sizes
    - Chamberlain et al. (2012). Does phylogeny matter? Assessing the impact of phylogenetic information in ecological meta-analysis. *Ecology Letters*, **15**, 627–636.
- Multiple studies by the same author/lab
  - Sensitivity analyses
  - Including sources of non-independence as moderators in the analysis
  - Using hierarchical models accounting for possible dependencies



Nakagawa et al. (2017) BMC Biology

Missing data

Types of missing data:

- Missing effect sizes or incomplete reporting of data for effect size calculations
- Missing information on study characteristics (moderators)

Dealing with missing data:

- Long-term solution: to raise publication standards (Gerstner et al. 2017 MEE)
- Contacting original investigators
- Consulting external literature or maps (e.g. for information on moderators)
- Algebraic recalculations, conversions and approximations (e.g. calculation of effect sizes from test statistics)
- Imputation methods (Lajeunesse 2013)
- Nonparametric analyses and resampling methods (bootstrapping and randomization tests)
- Unweighted meta-analysis
- Exclusion of incomplete reports from the analysis

Missing statistical information

Usefulness for meta-analysis	Study statistics	What is available?	Adressing what‘s missing
High	Completely reported	Everything	Nothing is missing!
	Selectively reported	Data are available in forms that are not easily accessible (e.g. data in figures or tables, t-tests without reporting means)	Extract data from figure or tables, convert available statistics
	Partially reported	Some information is missing and cannot be estimated directly from what is available (e.g. missing variance estimates)	Recalculation or conversion of available statitsics, or within-study imputation or multiple imputation methods
Low	Unreported	No statitsics or data are available, although may have specified a protocol for the analysis in the Methods section	Exclude from meta-analysis

cf. Koricheva et al. (2013) Box 13.1

Conversions among effect sizes and approximations using test statistics

Hedges d

independent t-test

$$d = t\sqrt{\frac{n_T + n_C}{n_T n_C}} \qquad d = \frac{2t}{\sqrt{n_{total}}} \qquad d = t_R\sqrt{\frac{2(1-r_R)}{n_{total}}}$$

n_{total} assumes that $n_T = n_C$, t_R = t-test from repeated measures, r_R = corr. between measures

correlation (r)

$$d = \frac{r}{\sqrt{1-r^2}}\sqrt{\frac{n(n-1)}{n_T n_C}} \qquad d^* = \frac{2r}{\sqrt{1-r^2}}$$

$n = n_T + n_C$, * indicates Cohen's d

F-ratio from one-way ANOVA

$$|d| = \sqrt{\frac{F(n_T + n_C)}{n_T n_C}} \qquad |d| = 2\sqrt{\frac{F}{n_{total}}}$$

n_{total} assumes that $n_T = n_C$

Z-score

$$d = \sqrt{\frac{Z\sqrt{n}}{1-\sqrt{Z^2 n^{-1}}}}$$

$n = n_T + n_C$

Chi-square (2 x 2 χ^2)

$$d = \sqrt{\frac{\chi^2(n_T + n_C)}{n_T n_C}}$$

Koricheva et al. Box 13.2.

Conversions among effect sizes and approximations using test statistics

Pearson's r

linear regression

$$r = \beta\left(\frac{SD_x}{SD_y}\right) \quad \text{if } y = \alpha + \beta x$$

SD = standard deviation, α = intercept, β = slope

biserial r (r_b)

$$r \approx r_b$$

point-biserial r (r_{pb})

$$r_b = \frac{r_{pb}\sqrt{n_T n_C}}{u(n_T + n_C)}$$

u = ordinate of unit normal distribution (see Terrell 1982)

independent t-test

$$r_{pb} = \sqrt{\frac{t^2}{t^2 + n_T + n_C - 2}} \qquad r_{pb} = \sqrt{\frac{t^2}{t^2 + df}} \qquad |r_{pb}| = \frac{P}{\sqrt{P^2 + 4}}$$

df = degrees of freedom, P = P-value

Hedges' d

$$r = \sqrt{\frac{d^2 n_T n_C}{d^2 n_T n_C + n(n-1)}}$$

$n = n_T + n_C$

F-ratio of one-way ANOVA

$$|r_{pb}| = \sqrt{\frac{F}{F + n_T + n_C - 2}}$$

F-ratio of ANOVA > 2 groups

$$|r_{pb}| = \sqrt{\frac{SS_{\text{between}}}{SS_{\text{between}} + SS_{\text{within}}}}$$

SS = sums of squares

Chi-square

$$|r| = \sqrt{\frac{\chi^2}{n}}$$

$n = n_T + n_C$

Z-score

$$r = \frac{Z}{\sqrt{n}}$$

$n = n_T + n_C$

odds-ratio

$$r = \frac{n_T^A n_C^B - n_C^A n_T^B}{\sqrt{(n_T^A + n_C^A)(n_C^B + n_T^B)(n_T^A + n_T^B)(n_C^A + n_C^B)}}$$

see Box 13.4

coefficient of determination (R^2)

$$|r| = \sqrt{R^2} \qquad r = \frac{\beta\sqrt{R^2}}{|\beta|}$$

β = regression slope

Spearman's rho rank corr. (ρ)

$$r = 2\sin\left(\frac{\pi\rho}{6}\right),\ \text{if } n < 90;\quad r = \rho,\ \text{if } n \geq 90$$

Mann-Whitney U

$$|r_{pb}| = \frac{1 - 2U}{n_T n_C}$$

Kendall's tau rank corr. (τ)

$$r = \sin\left(\frac{\pi\tau}{2}\right)$$

Koricheva et al. Box 13.3.

Conversions among effect sizes and approximations using test statistics

Fisher's z

Hedges' d

$$Z = \frac{d}{\sqrt{n(d^2+4)}}$$

$n = n_T + n_C$

Correlation coefficient (r)

$$Z = \frac{1}{2}\exp\left(\frac{1+r}{1-r}\right)$$

t-test

$$Z = \frac{t\sqrt{n}}{t+\sqrt{n-1}}$$

$n = n_T + n_C$

Mann-Whitney U

$$Z = \frac{U - 0.5(n_T n_C)}{\sqrt{\frac{n_T n_C (n+1)}{12}}}$$

$n = n_T + n_C$

Kendall's tau rank corr. (τ)

$$Z = \frac{\tau}{\sqrt{\frac{2(2n+5)}{9n(n-1)}}}$$

$n = n_T + n_C$

Koricheva et al. Box 13.5.

Imputation of missing data

- Missing data is filled with a substitute based on available information from other studies
- Available imputation methods:
  - randomly sample from all available data
  - take the mean of available data
  - fit a model and use model predictions
- Multiple-imputation methods repeatedly fill the data gaps
  - avoid treating imputed values as true observation
  - account for the variability associated with imputing data

Methods in Ecology and Evolution 2015, **6**, 153–163 doi: 10.1111/2041-210X.12322

Using multiple imputation to estimate missing data in meta-regression

E. Hance Ellington[1]*, Guillaume Bastille-Rousseau[1], Cayla Austin[1], Kristen N. Landolt[1], Bruce A. Pond[2], Erin E. Rees[3], Nicholas Robar[1] and Dennis L. Murray[4]

Example 4.1

1. Conversion among effect sizes
2. Temporal effects
3. Phylogenetic relatedness

Exercise 4.1

Data

Stewart, G.B. A database on windfarm impacts on birds.

1. Convert among effect sizes.
2. Study temporal effects using cumulative meta-analysis.
3. Control for shared phylogeny of species.

Meta-analysis in biological and environmental sciences

Criticism of meta-analysis

Mixing dissimilar studies ("apples and oranges")

"Meta-analysis is only properly applicable if the data summarized are homogenous – that is, treatment, patients, and end points must be similar or at least comparable."

Hans Eysenck

"Of course it [meta-analysis] mixes apples and oranges; in the study of fruit nothing else is sensible; comparing apples and oranges is the only endeavor worthy of true scientists; comparing apples to apples is trivial."

Gene Glass

Mixing dissimilar studies (“apples and oranges”)

“In many areas of ecology, sampling system and design properties are virtually unique from study to study. We should be wary of trying to crunch chalk and cheese data together, and we should be circumspect in regard to the use of meta-analysis in ecology.”

Robert J Whittaker

“In my view, ecology is a highly idiographic science best served by amassing a catalogue of case studies.”

Dan Simberloff

Varying study quality ("garbage in, garbage out")

Meta-analysis mixes good and bad studies

"Rather than thinking of meta-analysis as a process of garbage in, garbage out we can think of it as a process of waste management"

Borenstein et al. 2009 John Wiley & Sons

- A priori inclusion criteria
- Incorporation of study quality into meta-regression analysis

The role of meta-analyses in ecology: Practical meaning of mean effect sizes

"Determining a mean effect size is unlikely to be very useful for invasion policies or management. Knowing that the mean effect size is, say, 0.93 is not very useful to conservation biologists."

Dan Simberloff

Meta-analysis does not simply report the summary effect, it allows to test for degree of heterogeneity in effects between studies and to explore it causes

The role of meta-analyses in ecology: See the forest for the trees

"Meta-analyses are the remote-sensing tools of ecology. They allow us to step back from small-scale contingencies and see a broader, albeit less detailed, overview of how a system operate. The goal of meta-analyses is to reveal pattern and process of the whole forest, not to show what's happening on the individual trees."

Hillebrand & Cardinale (2010) Ecology

The role of meta-analyses in ecology: Evidence-based decision making

Collaboration for Environmental Evidence

http://www.environmentalevidence.org/

ELSEVIER Opinion TRENDS in Ecology and Evolution Vol.19 No.6 June 2004
Full text provided by www.sciencedirect.com SCIENCE DIRECT

The need for evidence-based conservation

William J. Sutherland[1], Andrew S. Pullin[2], Paul M. Dolman[3] and Teri M. Knight[4]

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"Support for decision making in conservation could benefit from following the medical model through the production of systematic reviews of evidence on the effectiveness of interventions in achieving stated objectives"

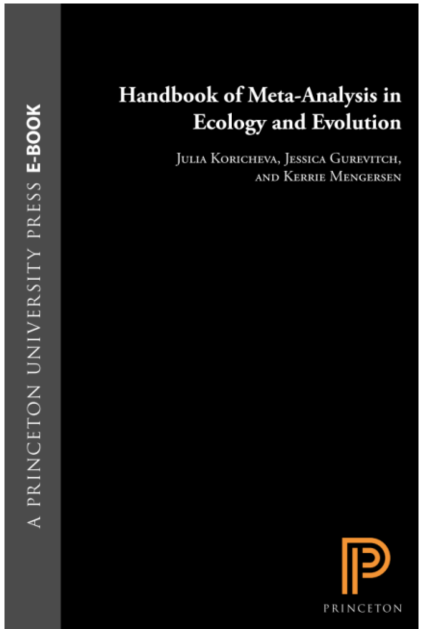
Sutherland et al. (2004) TREE

Other grounds of criticism

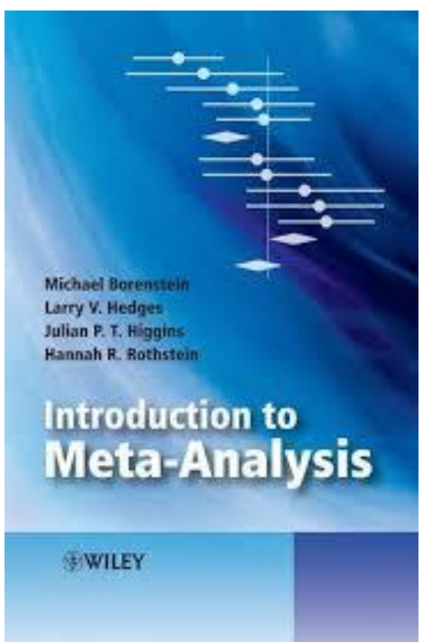
- Non-representative sample of all research on the subject (publication bias)
- Research bias
- Non-independence among comparisons
- Results of different meta-analyses on the same topic sometimes disagree

> "Doing a meta-analysis is easy. Doing one well is hard."
> Ingram Olkin

References



Koricheva, J., Gurevitch, J. & Mengersen, K.L. (2013) *Handbook of Meta-analysis in Ecology and Evolution*. Princeton University Press, Princeton.



Borenstein, M., Hedges, L.V., Higgins, J.P.T. & Rothstein, H.R. (2011) *Introduction to Meta-Analysis*. John Wiley & Sons.

Your turn

- Questions?
- Feedback?
- Own experiences?