Dealing with missing data

Types of missing data

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

Dealing with missing data

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

Imputation

- Missing piece of information is filled with a substitute based on available information from other studies
- Usually requires a model for variables with missing values. Predicted values from this model are then substituted for missing values
- It is important that missing values are missing completely at random or missing at random
- Example: estimation of missing standard deviation

$$SD_j = X_j \left(\frac{\sum_i^K SD_i}{\sum_i^K X_i} \right)$$

where X_j is the mean from a given study and X_i and SD_i are means and SD from other studies with complete information

Sample size based weighting

- When the sample variances are missing but sample sizes are available, the weights can be based on inverse effective sample sizes

$$n = \frac{N_T N_C}{N_T + N_C}$$

- Bootstrap can then be used to estimate 95% CI around the mean.

Bootstrap

- Iterative procedure which generates confidence intervals around a given statistic (e.g., mean effect size)
- Randomly choosing (with replacement) *K* effects from available *K* values
- Generating a distribution of possible values for a statistic
- The lowest and highest 2.5% values are chosen as 95% bootstrap confidence limits

Bayesian methods

Andrew L. Rukhin (2017)

Estimation of the common mean from heterogeneous normal observations with unknown variances

Journal of the Royal Statistical Society Series B (Statistical Methodology) 79(5)

DOI: 10.1111/rssb.12227

Criteria of research quality

- Confounding of factors (observational vs. experimental studies)
- Treatments are fully replicated (vs. pseudo-replicated)
- Treatments are randomly assigned to subjects
- Degree of replication

Dealing with variable research quality

- A priori exclusion of flawed research
  - ✓ variation in assessment of study quality
  - ✓ increased likelihood to find methodological flaws in studies that report results that conflict with the reviewer's predisposition

Example:

- Møller & Thornhill (1998) Bilateral symmetry and sexual selection: a meta-analysis

  Excluded studies: N=6 $r = 0.65$

  Included studies: N=140 $r = -0.42$

Dealing with variable research quality

- Coding for quality and a posteriori examination of research differences

Example:

- Gontard-Danek & Møller (1999) The strength of sexual selection: a meta-analysis of bird studies
- r = relationship between the expression of secondary sexual characters and male mating success
- Observational studies: $r = 0.26$ N=45
- Experimental studies: $r = 0.37$ N=34

$Qb = 8.42$, $P<0.001$

Format of meta-analysis report and common mistakes in meta-analyses

Quality of meta-analyses in plant ecology

Criteria	Not relevant	Yes	No	Partial
Reporting full details of bibliographic searches	9%	**32%**	24.5%	34.5%
Reporting inclusion/exclusion criteria	7.5%	60.6%	26.7%	5.2%
Weighting effect sizes by study precision		74.2%	25.8%	
Specifying meta-analytical model		66.5%	33.5%	
Quantifying heterogeneity in effect sizes		52.2%	47.8%	
Exploring causes of heterogeneity		89.1%	10.9%	
Testing for publication bias	8.4%	30.7%	**60.9%**	
Sensitivity analysis		25.2%	**74.8%**	
Controlling for phylogeny	10.5%	10.7%	**78.8%**	
Specifying the software used		76.7%	23.3%	
Providing reference list of primary studies included in the analysis	4.3%	87%	8.7%	
Providing the dataset used for meta-analysis		31.4%	**65.2%**	3.4%

Koricheva & Gurevitch (2014 J Ecol)

Checklist of quality criteria for meta-analysis

1. Has formal meta-analysis been performed, or is it simply a vote-count?
2. Is the search strategy properly reported (keywords, databases, years)?
3. Are inclusion criteria for primary studies listed?
4. Are standard metrics of effect size used? If not, is it explained how variance for non-standard metrics was obtained?
5. If more than one estimate of effect size per study was included in the analysis, is potential non-independence of these estimates taken into account?
6. Are effect sizes weighted by study precision or is the rational for using unweighted approach provided?
7. Are statistical models and the software used described?

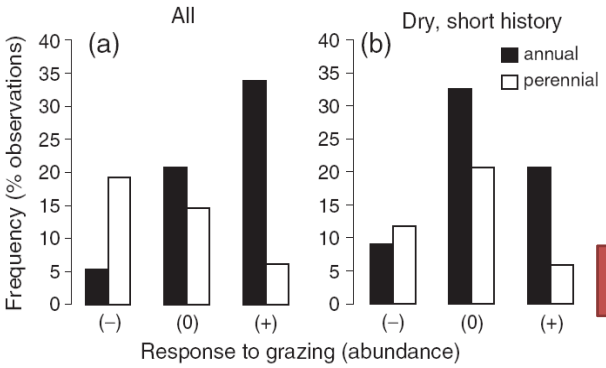
Checklist of quality criteria for meta-analysis (cont.)

8. Is heterogeneity of effect sizes between studies quantified?
9. Are the causes of heterogeneity in effect sizes explored?
10. If effects of multiple moderators are tested, are potential nonindependence of moderators taken into account?
11. If studies conducted on different species are combined, is phylogenetic relatedness of species taken into account?
12. Are tests for publication bias conducted?
13. If meta-analysis combines studies published over considerable time span, have possible temporal changes in effect size been tested?
14. Are sensitivity analysis performed to test the robustness of results?
15. Are full bibliographic details of primary studies provided?
16. Is the dataset used for meta-analysis, including effect sizes and variances/sample sizes from individual primary studies and moderator variables, provided as electronic appendix?

Global Change Biology (2007) **13**, 313–341, doi: 10.1111/j.1365-2486.2006.01288.x

Plant trait responses to grazing – a global synthesis

SANDRA DÍAZ*, SANDRA LAVOREL*†[1], SUE McINTYRE‡, VALERIA FALCZUK*, FERNANDO CASANOVES§, DANIEL G. MILCHUNAS¶, CHRISTINA SKARPE‖, GRACIELA RUSCH‖, MARCELO STERNBERG**, IMANUEL NOY-MEIR††, JILL LANDSBERG‡[2], WEI ZHANG‡‡, HARRY CLARK§§ and BRUCE D. CAMPBELL¶¶



"We conducted a **meta-analysis** of plant trait responses to grazing, based on 197 studies from all major regions of the world"

Not a meta-analysis, a vote-count!

Global Change Biology (2007) **13,** 2582–2591, doi: 10.1111/j.1365-2486.2007.01456.x

Simulated global changes alter phosphorus demand in annual grassland

DUNCAN N. L. MENGE* and CHRISTOPHER B. FIELD†
*Earth Systems Program, Stanford University, Stanford, CA 94305, USA, †Department of Global Ecology, Carnegie Institution of Washington, Stanford, CA 94305, USA

Table 3 Meta-analysis: effects of global change manipulations on P limitation or demand

Effect on P limitation or demand	# Measures of P limitation or demand	# Studies	# Ecosystems
CO_2			
Increase	3†	2†	1
No effect	10	5	2
Decrease	2	0	0
% that increased	20	29	33
N			
Increase	16***	10***	6***
No effect	11	7	5
Decrease	0	0	0
% that increased	59	59	55
Temperature			
Increase	1	0	0
No effect	12	2	3
Decrease	1	0	0
% that increased	7	0	0

'Increase' and 'decrease' indicate significant effects of the relevant variable on a measure of P limitation or demand, as reported in the source. Study effects were deemed significant if a majority of the measures in a study were significant; similarly, ecosystem effects were deemed significant if a majority of the studies in that ecosystem were significant. Ties (an equal number of significant and nonsignificant effects) were split between 'no effect' and 'increase' or 'decrease.' Although some studies manipulated more than one variable, only main effects are shown.

Not a meta-analysis,
a vote-count!

Vote-counting: summary

- Vote-counting ≠ meta-analysis!
- Vote-counting has very poor statistical properties and will often lead to wrong conclusions
- Vote-counting should never be used instead of meta-analysis
- If the studies to be reviewed are too heterogeneous in terms of outcomes or do not report results in the way which allows formal meta-analysis, using flawed method to summarize their outcomes will not help!

Materials and methods

"Based on the "Methods" section in a meta-analysis, a researcher should be able to redo the entire analysis starting from the literature search and database build-up, proceeding with the statistical analysis, and finally coming to the same conclusions. Of course, these criteria are no different than the standards that should be imposed by reviewers on any publishable research."

Hillebrand & Cardinale 2010 Ecology 91: 2545-2549

Reporting of search strategy

Bad examples:

"The literature and our own unpublished reports were searched for relevant data"

"Studies were derived from an extensive literature search and through communications with scientists practicing in the field"

Good example:

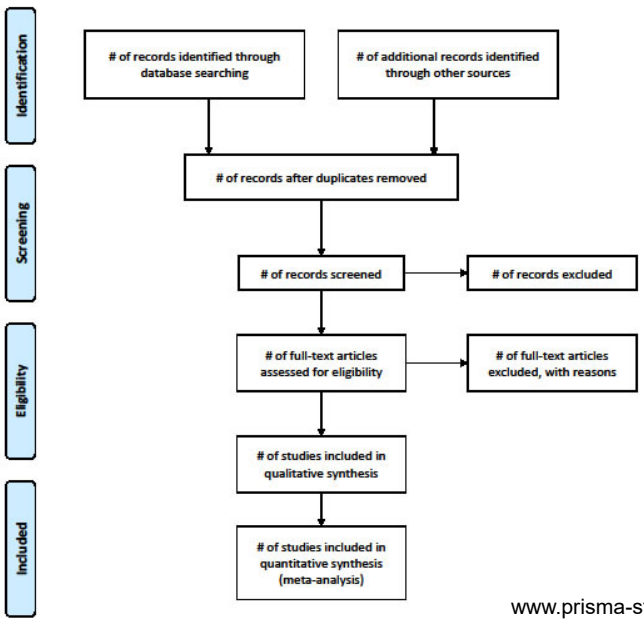
We searched the literature with Web of Science. Our searches included all records through August 2010. We used a combination of the following keywords: "disturb∗ OR fragment∗ OR degrad∗ OR hunt∗" AND "seed_dispersal OR seed_removal OR frugivor∗."

Inclusion criteria: good example

The articles included in the meta-analysis had to fulfil the following requirements:

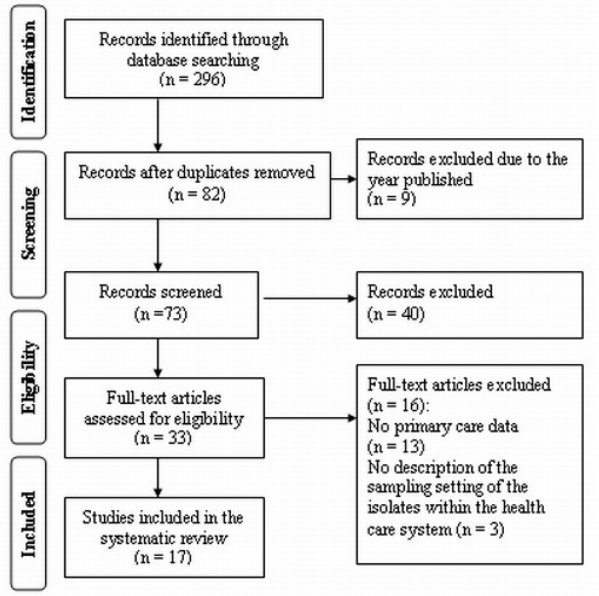
1. at least one of the predators in the studied system had to be a bird species;
2. the experiment had to contrast two groups, one of which contained a substantially lower level of bird predation than the other;
3. there had to be at least one measured response from the plants, e.g. the extent of leaf damage, or changes in biomass, growth or mortality;
4. sample sizes, means, and standard deviations had to be reported for both experimental and control groups.

PRISMA diagram



www.prisma-statement.org

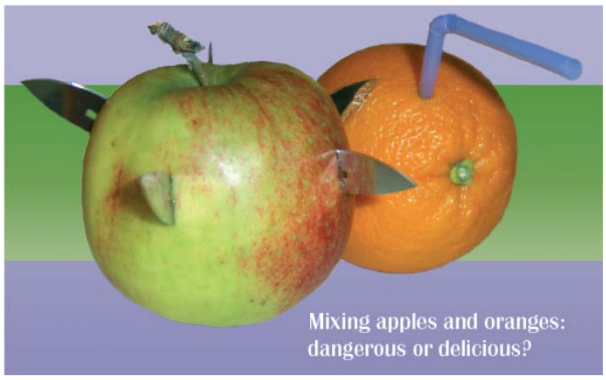
PRISMA diagram



Hoffmann et al. BMC Infectious Diseases 2011 11:330 doi:10.1186/1471-2334-11-330

Database

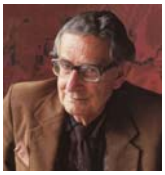
- Should include effects sizes and their variances/sample sizes from individual primary studies as well as moderators
- Could be included as a table in the paper itself if the number of studies is small
- Otherwise provide a table as an electronic appendix
- ~~"Available upon request from the authors"~~



Criticisms of meta-analysis

Grounds of criticism

1. Mixing dissimilar studies ("apples and oranges")



Hans Eysenck

"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."

Gene Glass

"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."

Grounds of criticism

1a. Meta-analysis might be ok in other disciplines, but not in ecology where studies are just too dissimilar

Robert J Whittaker

"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."

Dan Simberloff

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

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

Helmut Hillebrand

Bradley J Cardinale

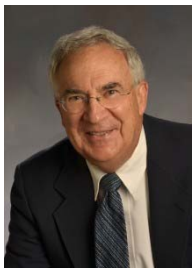
"Meta-analyses are the remote-sensing tools of ecology. They allow us to step back from small-scale contingencies and see a broader, albeit less detailed, overview of how a system operate.

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 91: 2545-2549

Grounds of criticism

2. Summarizing a research domain by a single value (overemphasis on mean effect size)



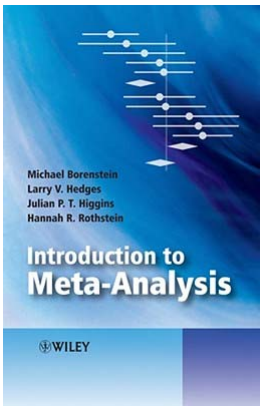
Dan Simberloff

"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".

- 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

Grounds of criticism

3. Meta-analysis mixes good and bad studies ("garbage in, garbage out")



"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"*

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

Grounds of criticism

4. Results of different meta-analyses on the same topic sometimes disagree

Robert J Whittaker

Ecology, 91(9), 2010, pp. 2522–2533

"None of the meta-analyses agree with one another on how to classify a large proportion of the data sets in their analyses, raising immediate concerns over the approach and doubts as to whether they constitute repeatable science"

- As long as inclusion criteria and methods of meta-analysis are reported in sufficient detail and the original datasets used are available, differences in results between meta-analyses can be reconciled

Grounds of criticism

5. Publication bias invalidates meta-analysis

- Publication bias may affect results of any research synthesis, including narrative review
- Unlike other methods of research synthesis, meta-analysis allows one to test for publication bias and adjust for it

Papers published on meta-analysis and publication bias (ISI Web of Science)

Years	"Meta-analy*"	"Publication bias"
1970-1975	1	0
1976-1980	30	0
1981-1985	226	2
1986-1990	377	19
1991-1995	2421	207
1996-2000	5738	397
2001-2006	12770	1005

EDITORIAL

Data Sharing

The NEW ENGLAND JOURNAL of MEDICINE

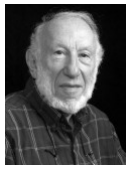
Dan L. Longo, M.D., and Jeffrey M. Drazen, M.D.

N Engl J Med 2016; 374:276-277 | January 21, 2016

"A concern held by some is that a new class of research person will emerge — people who had nothing to do with the design and execution of the study but use another group's data for their own ends, possibly stealing from the research productivity planned by the data gatherers, or even use the data to try to disprove what the original investigators had posited. There is concern among some front-line researchers that the system will be taken over by what some researchers have characterized as "research parasites."

Other grounds of criticism

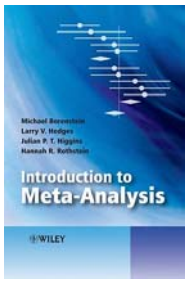
- Non-representative sample of all research on the subject (publication bias)
- Non-independence among comparisons
- Research bias
- Correlational nature of review-generated evidence



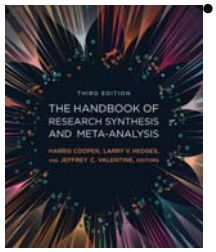
Ingram Olkin

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

General textbooks on meta-analysis and research synthesis



- Borenstein M, Hedges LV, Higgins JPT, Rothstein HR. 2009. Introduction to meta-analysis. Wiley & Sons



- Cooper H, Hedges LV, Valentine JC (eds). 2019. The handbook of research synthesis and meta-analysis. 3rd edition. Russell Sage Foundation, New York.

For ecologists and evolutionary biologists

- Harrison F. 2011. Getting started with meta-analysis. Methods in Ecology and Evolution 2: 1-10

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