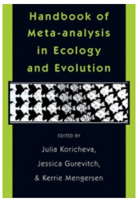

Curtis, P.S., Mengersen, K., Lajeunesse, M.J., Rothstein, H.R. and Stewart, G.B. (2013) Extraction and critical appraisal of data. In J. Koricheva, J. Gurevitch, and K. Mengersen, editors. Handbook of meta-analysis in ecology and evolution (pp. 52−60). Princeton University Press, Princeton, New Jersey, USA.

5

Extraction and Critical Appraisal of Data

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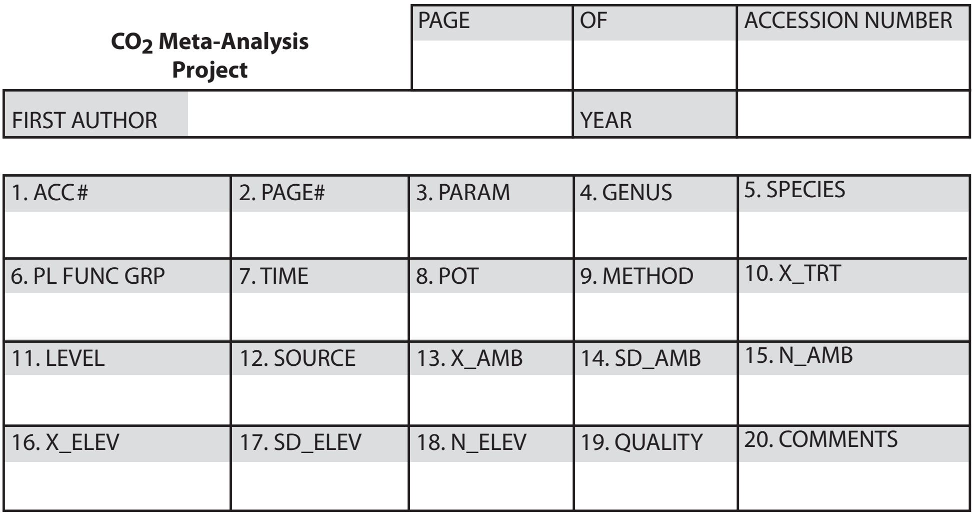
DATA EXTRACTION

The efficient and accurate extraction of data from primary studies is an important component of successful research reviews. It is one of the most time-consuming parts of a research review and should be approached with the goal of repeatability and transparency of results. Careful definition of the research question (Chapter 3) and identification of the effect size metric(s) to be used (Chapters 6 and 7) are prerequisite to efficient data extraction. The components of the data extraction process may be simpler or more complex, depending on the scope of the meta-analysis (e.g., how many studies are to be included, how complex the analysis is likely to be) and the number of people involved in the process (i.e., individual investigator vs. large team effort). For more complex and large group efforts, separate data extraction and database spreadsheets may be used to initially code and then store data from individual sources. For a small, one-person analysis, a simple spreadsheet plus a bibliographic file may be sufficient. Eventually the data will be taken from these files to be analyzed using statistical software.

The data extraction spreadsheet

Although the diversity of ecology and evolutionary biology research resists any general description of the kinds of data that will require extraction, several general principles should be followed in any well-designed data extraction process. First is the development of an appropriate data extraction spreadsheet (Fig. 5.1). This constitutes the link between each primary study and the ultimate research review and as such, informs the meta-analysis model with data for effect size estimation and associated information; it also provides the basis for quality assessment and quality control (QA/QC) and hence the integrity of the review outcomes. Historically, data extraction was carried out exclusively using paper forms, which retain some advantages over the electronic spreadsheets that are now more widely used. For example, when assessments of the data extraction process are conducted by independent observers, it may be easier to compare some data entry fields on paper than on electronic forms. However, most data extraction is now done electronically. Some clear advantages of electronic extraction spreadsheets include the availability of flexible software for interfacing data entry with data management programs, the possibility for some data entry fields to be completed automatically, the reduction in coding errors when transcribing data from paper to computer, and the possibility of incorporating error checking software into the extraction spreadsheet. Furthermore, with the expansion of



CO_2 Meta-Analysis Project	PAGE	OF	ACCESSION NUMBER
FIRST AUTHOR		YEAR	

1. ACC#	2. PAGE#	3. PARAM	4. GENUS	5. SPECIES
6. PL FUNC GRP	7. TIME	8. POT	9. METHOD	10. X_TRT
11. LEVEL	12. SOURCE	13. X_AMB	14. SD_AMB	15. N_AMB
16. X_ELEV	17. SD_ELEV	18. N_ELEV	19. QUALITY	20. COMMENTS

Figure 5.1. Simplified example of a data extraction spreadsheet used in the meta-analysis of elevated CO_2 effects (Curtis and Wang 1998). Each paper is assigned an accession number (ACC#) and multiple entries from the same paper are given separate page numbers (PAGE#). Cells 3–20 contain details of the ecological parameter (outcome variable) being measured (PARAM); the taxa under study (GENUS, SPECIES, PL FUNC GRP); CO_2 exposure time (TIME); growth conditions and other experimental factors (POT, METHOD, X_TRT, LEVEL); the table or figure from which the data were extracted (SOURCE); the means (X_AMB, X_ELEV), standard deviations (SD_AMB, SD_ELEV), and sample sizes (N_AMB, N_ELEV) of the parameter in the ambient and elevated CO_2 treatments; the quality assessment score (QUALITY); and miscellaneous comments (COMMENTS).

electronically available journal holdings it is now possible to largely eliminate paper from the review process.

The specific elements of a data extraction spreadsheet are dictated by the research review questions and anticipated analyses as laid out in the review protocol (see Chapter 3). A common feature of any extraction spreadsheet is a study identifier linking that entry to a specific piece of primary research (e.g., the accession number in Fig. 5.1). It may be desirable to include other study identifiers in the extraction spreadsheet such as lead author or publication date, but typically separate full bibliographic databases also will be maintained (see “The Meta-analysis Database,” below). In determining additional elements of an extraction spreadsheet, a general rule is to include those study characteristics that could affect the study results and help assess their applicability to the research review. Typically, study characteristics form the spreadsheet columns, while individual studies are represented in rows. While the studies being considered for data extraction will all have been previously examined for inclusion criteria, input of data into the spreadsheet provides a final check on suitability as well as allowing evaluation of study quality.

There are a number of other data entry elements that are common across extraction spreadsheets. For experimental studies, these include details of the research methods or experimental conditions that might affect the results (laboratory vs. field-based treatments, size or type of growth containers, etc.), the taxa or system being considered and any pertinent attributes (age, sex, etc.), and details of the experimental treatment (length, intensity, additional factors). For observational studies these might include location, site or population characteristics, and relevant conditions under which observations were made. For both types, an open-ended "Comments" field is useful. If a data entry element is not relevant for a particular study, that cell can simply be left empty or assigned a missing value code. For example, in the elevated CO_2 database, studies with no additional treatment crossed with the CO_2 treatment (X_trt = NONE; see Fig 5.2) would have a missing value designation in the cell coding the crossed treatment level (Level = ".").

The study results themselves, such as sample size, mean, and standard deviation, often represent a comparatively small number of entries in the extraction spreadsheet. To facilitate error checking and other forms of QA/QC it is useful to annotate, either electronically (e.g., by using "Highlight Text Tool" in PDF files) or on hard copy, each manuscript from which data were extracted. The annotated version should specify exactly where information was obtained, such as the specific numbers within a table, points on a graph, or data from the body of the paper. Highlighting descriptive text in the methods, and the extracted data from the reported results, will save considerable time later if questions arise regarding the accuracy of results obtained from a particular study. It is also useful to have a column in the data extraction spreadsheet which specifies the source of the data—for example a particular figure or table from the primary study (Figs. 5.1 and 5.2).

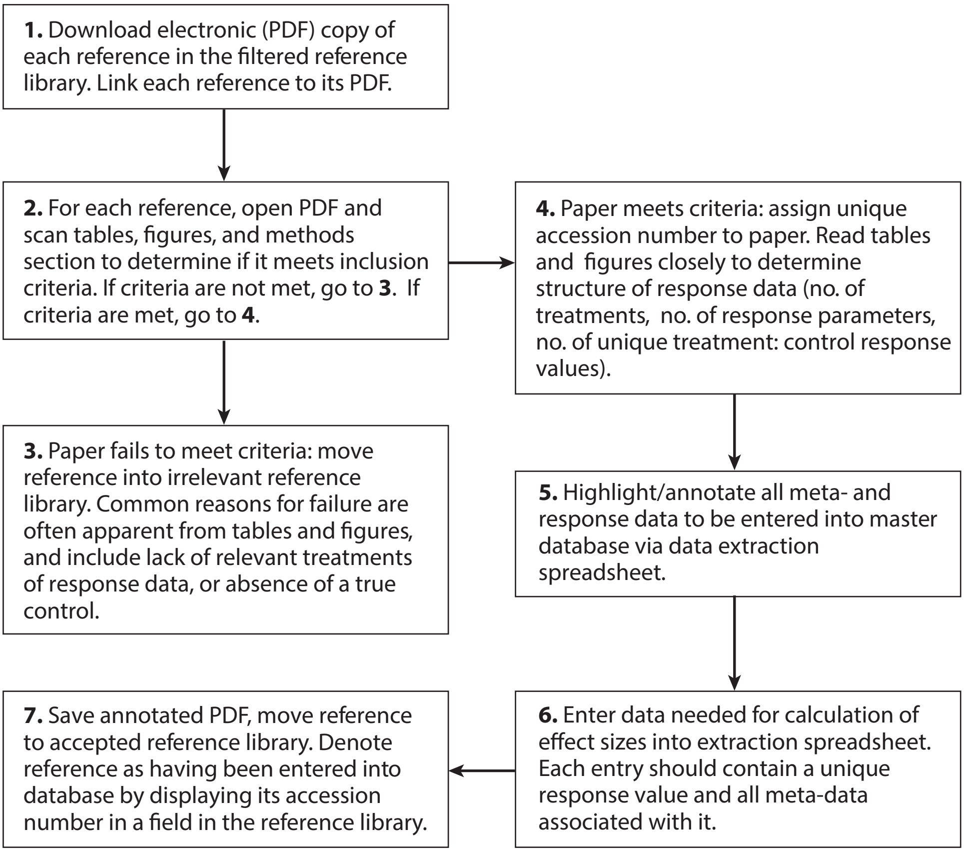
It is important to properly document not only the literature used in the meta-analysis, but all of the literature retrieved in the search process, recording those papers which were examined but not included in the analysis, and organizing the copies of the papers from which data were extracted. Each step in this process is important in establishing the breadth and freedom from bias of a literature search. Prior to the widespread availability of journal articles in electronic format, this part of a large meta-analysis could easily fill numerous filing cabinets. Fortunately for the meta-analysis enterprise, electronic article retrieval coupled with bibliographic software has vastly streamlined this part of the process. Figure 5.3 illustrates a flow chart and decision tree that begins with the filtered reference list (papers judged acceptable based on examination of title and abstract) and results in two bibliographic files (e.g., EndNote libraries). One library file contains citation information and electronic copies of papers (or permanent links to papers) found to not possess the necessary inclusion criteria. The other library file contains citation data and annotated copies of all papers included in the meta-analysis. It is important to maintain both libraries since it may be important to demonstrate why a particular study was not included in the analysis. For papers not included in the meta-analysis, a record should be kept of the reason for rejecting them. One of the most common reasons for rejecting studies in ecological and evolutionary meta-analyses is that essential data are missing (e.g., sample sizes and any measures of variance).

Data to be extracted may reside in any part of a paper, but are most commonly found in the "Materials and methods" section describing details of the experimental conditions, treatments, number of replicates, etc., and in the "Results" section describing the data needed for calculation of treatment effect size. Numerical data cited in the text or contained in tables are easily transferred to the data extraction spreadsheet. Data contained in figures can present a variety of extraction challenges depending on the manner in which they are plotted (e.g., scatterplots, histograms, trend lines, use of multiple or three-dimensional axes, etc.), the size of symbols or lines relative to the axis scale, and the size and printed quality of the figure itself. However, with a good-quality digital image of a data figure, it is relatively simple using graphical data-extraction software (e.g., freeware DataThief, Graphclick, or ImageJ) to obtain accurate numerical information. When symbol or line thickness is large relative to the axis scale it is usual to consider their midpoint as the correct numerical data point to record.

ACC	PG#	Param	Genus	Species	Pl Func Grp	Time	Pot	Method	X_trt	Level	Source	X_A	SD_A	N_A	X_E	SD_E	N_E	Quality
44	1	PN	ALNUS	RUBRA	N2FIX	46	0.5	GC	FERT	HI	T3	11.8	1.43	5	23.2	10.31	5	3
44	2	PN	ALNUS	RUBRA	N2FIX	46	0.5	GC	FERT	CTRL	T3	11.7	2.59	5	25.9	3.31	5	3
44	3	TOTWT	ALNUS	RUBRA	N2FIX	47	0.5	GC	FERT	HI	T1	3945.0	1115.80	5	6816.9	1769.98	3	3
44	4	TOTWT	ALNUS	RUBRA	N2FIX	47	0.5	GC	FERT	CTRL	T1	2251.2	327.58	5	2596.1	667.47	5	3
121	1	PN	QUERCUS	PRINUS	ANGIO	76	2.6	GH	NONE	.	T2	2.6	1.05	6	5.4	1.42	6	3
121	2	TOTWT	QUERCUS	PRINUS	ANGIO	70	2.6	GH	NONE	.	T4	6.6	1.63	5	5.9	1.74	5	3
121	3	PN	MALUS	DOMESTICA	ANGIO	77	2.6	GH	NONE	.	T3a	8.2	1.13	6	12.1	1.59	6	3
121	4	TOTWT	MALUS	DOMESTICA	ANGIO	64	2.6	GH	NONE	.	T4	4.1	1.26	4	4.6	1.41	4	3
121	5	PN	ACER	SACCHARINUM	ANGIO	61	2.6	GH	NONE	.	T2	9.2	1.51	7	15.8	1.85	7	3
121	6	TOTWT	ACER	SACCHARINUM	ANGIO	50	2.6	GH	NONE	.	F2	6.4	2.03	3	10.8	1.16	5	3
159	1	TOTWT	CASTANEA	SATIVA	ANGIO	730	GRND	GC	NONE	.	T1	127.3	47.46	3	153.5	27.19	3	3
209	1	TOTWT	CASTANEA	SATIVA	ANGIO	365	24	GH	FERT	HI	F1	144.1	25.70	20	183.6	39.06	20	3
209	2	TOTWT	CASTANEA	SATIVA	ANGIO	365	24	GH	FERT	CTRL	F1	59.9	14.28	16	71.7	14.30	16	3
468	1	PN	CASTANEA	SATIVA	ANGIO	1095	24	OTC	NONE	.	T3	8.3	1.30	4	9.5	1.50	4	3
468	2	TOTWT	CASTANEA	SATIVA	ANGIO	1095	24	OTC	NONE	.	T2	136.0	35.00	5	146.0	10.00	5	3
502	1	PN	LIRIODENDRON	TULIPIFERA	ANGIO	840	GRND	OTC	NONE	.	T1	7.4	1.34	5	12.3	1.79	5	3
505	1	PN	QUERCUS	ALBA	ANGIO	168	2.6	GH	FERT	CTRL	F4a	6.8	2.75	5	11.2	3.60	5	3
505	2	TOTWT	QUERCUS	ALBA	ANGIO	168	2.6	GH	FERT	HI	T2	14.6	2.29	5	17.9	10.19	5	3
505	3	TOTWT	QUERCUS	ALBA	ANGIO	168	2.6	GH	FERT	CTRL	T2	11.2	5.75	5	14.7	5.01	5	3

ACC#	Authors & year	Title/Journal/Pages
44	Arnone, J.A., III, & J.C. Gordon. 1990.	Effect of Nodulation, Nitrogen Fixation and CO2 Enrichment on the Physiology, Growth and Dry Mass Allocation of Seedlings of Alnus rubra Bong. New Phytologist 116:55–66.
121	Bunce, J.A. 1992.	Stomatal Conductance, Photosynthesis and Respiration of Temperate Deciduous Tree Seedlings Grown Outdoors at an Elevated Concentration of Carbon Dioxide. Plant, Cell & Environment 15:541–549.
159	Couteaux, M.M., P. Bottner, H. Rouhier, & G. Billes. 1992.	Atmospheric CO2 Increase and Plant Material Quality: Production, Nitrogen Allocation and Litter Decomposition of Sweet Chestnut. In Responses of Forest Ecosystems to Environmental Changes (A. Teller, P. Mathy, and J.N.R. Jeffers, eds.), Elsevier, London.
209	El Kohen, A., H. Rouhier, & M. Mousseau. 1992.	Changes in Dry Weight and Nitrogen Partitioning Induced by Elevated CO2 Depends on Soil Nutrient Availability in Sweet Chestnut (Castanea sativa Mill.). Annales des Sciences Forestieres 49:83–90.
468	Mousseau, M. 1993.	Effects of Elevated CO2 on Growth, Photosynthesis and Respiration of Sweet Chestnut (Castanea sativa Mill.). Vegetatio 104/105:413–419.
502	Norby, R.J., C.A. Gunderson, S.D. Wullschleger, E.G. O'Neill, & M.K. McCracken. 1992.	Productivity and Compensatory Responses of Yellow-poplar Trees in Elevated CO2. Nature 357:322–324.
505	Norby, R.J., & E.G. O'Neill. 1989.	Growth Dynamics and Water Use of Seedlings of Quercus alba L. in CO2-enriched Atmospheres. New Phytologist 111:491–500.

Figure 5.2. Two linked database spreadsheets from the meta-analysis of elevated CO_2 effects (Curtis and Wang 1998). *Top panel*: main database that receives information from the extraction spreadsheet (Fig. 5.1). Each row corresponds to a unique set of response statistics, with the seven papers listed contributing from one to six independent sets of data. *Bottom panel*: reference spreadsheet containing citation information for each paper. Column headings are as described in Figure 5.1. In this example, the parameters, or outcome variables, in column 3 are photosynthetic rate (PN) and total plant weight (TOTWT).



1. Download electronic (PDF) copy of each reference in the filtered reference library. Link each reference to its PDF.

2. For each reference, open PDF and scan tables, figures, and methods section to determine if it meets inclusion criteria. If criteria are not met, go to **3**. If criteria are met, go to **4**.

3. Paper fails to meet criteria: move reference into irrelevant reference library. Common reasons for failure are often apparent from tables and figures, and include lack of relevant treatments of response data, or absence of a true control.

4. Paper meets criteria: assign unique accession number to paper. Read tables and figures closely to determine structure of response data (no. of treatments, no. of response parameters, no. of unique treatment: control response values).

5. Highlight/annotate all meta- and response data to be entered into master database via data extraction spreadsheet.

6. Enter data needed for calculation of effect sizes into extraction spreadsheet. Each entry should contain a unique response value and all meta-data associated with it.

7. Save annotated PDF, move reference to accepted reference library. Denote reference as having been entered into database by displaying its accession number in a field in the reference library.

Figure 5.3. Flow chart and decision tree involved with managing the literature database in a meta-analysis. The filtered reference library in step 1 has passed an initial examination for relevance based on viewing the title and abstract, and hence each reference merits examination of its full text. This important initial process is detailed in Chapter 4. Stored electronic copies of the papers (the PDF files) are linked to their citation information within the bibliographic software. Extracted data are linked to the citation information and the PDF file through a unique accession number (step 4).

The data extraction protocol

Complementing the data spreadsheet itself is the set of instructions, or extraction protocol, which guides the coding decisions that will need to be made by anyone entering data. While this is especially critical for groups working together, it is also important for individuals working alone to increase accuracy and reduce potential bias. For example, we found that it was important to create uniform standards for the determination of rooting volume from reported pot dimensions to correctly code “pot size” on the CO_2 effects extraction spreadsheet (Fig. 5.1), or for handling missing data (Chapter 13). It may even be necessary to establish a protocol for identifying control and treatment groups. For example, Gurevitch et al. (1992) were interested in studies in which the densities of organisms were manipulated to determine responses to competition. They defined the “controls” in the meta-analysis to be the groups whose densities were close to natural densities in the field, and the “experimental” groups were those in which densities were higher or lower than natural densities. These definitions were not always congruent with those of the studies’ authors. If quality assessments are made (see “Critical Appraisal of the Data,” below), it is very important that clear guidelines for interpreting possible sources of bias within studies and assigning quality scores are provided. Accurate coding is critical and the extraction protocol should be concise enough to be practical yet provide sufficient detail to prevent erroneous decisions. The authors of the data extraction spreadsheet and protocol should practice using them and be involved in training any other people who will use them.

Establishing precisely which data points within a study are the appropriate ones to extract requires careful thought and explicit direction in the extraction protocol. This necessity for careful thought and direction is often encountered in studies reporting time series or other types of data exhibiting nonindependence. Working with nonindependent data is covered in detail in Chapter 16 and if a meta-regression model is appropriate, careful coding of measurement time, treatment duration, and so forth will be important. A common strategy in ecological and evolutionary meta-analyses has been to avoid nonindependence by extracting only a single data point per measurement time series; examples are at the end of the treatment or at peak standing biomass. There are two problems with this approach: studies with shorter durations may not be appropriate to combine with those having longer durations (results may be very different after two months and five years), and also there is a substantial loss of data. For example, trends over time may be the most interesting and valuable part of the results, and these will be lost if only a single point is extracted. Clear guidelines for selecting data from a time series would then be a necessary part of the extraction protocol. Similar considerations and the need for guidelines arise with single studies reporting response data from multiple treatments, species, locations, outcomes, and so forth.

Another common source of ambiguity in data extraction is determining the correct sample size associated with a reported statistic. Hence, rules for converting degrees of freedom to sample size need to be clear, as does the basis for determining sample size from a complex or ambiguously reported experimental design. The meta-analyst may be required to calculate necessary values, such as determining standard deviation from standard error, sample size from degrees of freedom, or conversion of test statistics to r (see Chapter 6). It is critically important for sample size, means and standard deviation to agree—that is, they must reflect the same group of sampling units. This must be specified and done in a way that is uniform across studies, and often may be performed within a separate database spreadsheet. One reason this may be difficult to do repeatedly in ecological and evolutionary studies is that data reporting in ecological and evolutionary journals often is haphazard, and because a wide range of very different and often complex experimental designs are used. Where subjective decisions are required in completing the extraction form, or if extracted data are transformed or otherwise altered from those that were reported, these should be noted in the “Comments” input cell.

The last stage in preparing for data extraction is pilot testing and modification of the extraction spreadsheet and protocol. Invariably, users will identify input that either is not needed or falls into a field that is missing from the spreadsheet. A small but representative sample of primary studies should be selected for this exercise with several data extractors taking part. In this way, both the completeness of the spreadsheet and the reliability of data extraction can be assessed. If several people will be inputting data it is quite important to evaluate the degree to which their assessments of the same study differ (e.g., with a kappa analysis; see Chapter 4) and to develop a plan for comparing data and resolving disagreements. Where the number of studies is manageable, it is possible to use two coders and double code every study, resolving any differences by discussion. This builds intercoder agreement directly into the data extraction procedure. Finally, changes to the spreadsheet and/or protocol may be needed to improve data collection reliability.

THE META-ANALYSIS DATABASE

The extraction spreadsheet may simply be appended to a growing database stored in a single spreadsheet (also known as “flat file database”) (e.g., Microsoft Excel, Lotus, Quattro Pro), but it may be advantageous to develop relational databases (e.g., by using Microsoft Access, Paradox or dBase software), particularly for large or complex data. It should be kept in mind, however, that most meta-analytic software requires a “flat” data matrix of rows and columns, and thus if a relational database is used, a single spreadsheet will have to be created and used with the statistical software for the actual meta-analysis. One database model is illustrated in Figure 5.2 in which extracted data are stored in one spreadsheet, and citation information in another. A paper’s accession number links the two databases. In Microsoft Access, this would be accomplished by assigning the accession number to the primary key field linking the separate databases. Specialized bibliographic databases such as EndNote or Mendeley can easily substitute for the spreadsheet-based reference database shown here. Where data syntheses involve examining many different subgroups or multiple effect sizes for different variables or times of measurement, it may be advantageous to organize the data in separate group-level or effect size-level files. Working within a relational database would facilitate the organization of complex analyses involving many subgroups. It may be desired to make the extracted database available online; however, doing so emphasizes the need for clear documentation of all input fields and points to the general advantage of simple data matrices over more complex designs and those requiring specialized software to read.

CRITICAL APPRAISAL OF THE DATA

During the process of data extraction the investigator has an opportunity for critical appraisal of data quality. Methods for assessing data quality have received considerable attention by meta-analysts in medicine and the social sciences, but how or even whether to incorporate quality measures in the meta-analysis is controversial (Herbison et al. 2006). We recognize that scientific studies vary in quality and therefore it seems reasonable to assume that combining poor-quality studies with those of higher quality will weaken the inferential capacity of any subsequent analysis. Put another way, a poorly designed or executed study is considered more likely to be influenced by systematic errors (low accuracy) although the random sampling error for such a study might be quite low (i.e., it can have high precision). In a research review, poor-quality studies can add to the unexplained variance among studies; if they are of sufficient weight or number, these studies can materially affect mean effect size estimates (e.g., EPA 1992).

One approach to quantitative assessment of study quality has been the use of numerical scales in which points are assigned to specific elements of the study and summed to produce an overall quality score (e.g., Jadad et al. 1996, Levine 2001). Although many such quality assessment tools have been developed, a variety of serious problems with their application have been identified, including the comingling of questions of methodological quality with those of reporting quality, reliance on “accepted criteria” from textbooks rather than empirical evidence of bias, and poor reporting of inter-rater reliability or concordance (Moher et al. 1995, Jüni et al. 1999, Sanderson et al. 2007). Herbison et al. (2006), in a study applying 45 different quality scales to 65 separate meta-analyses, concluded that none of the scales measured quality in a valid manner and that while study quality is important, summed scores as a method for assessing this should be abandoned. We concur with this assessment.

An alternative to summative scores is a more qualitative evaluation of the degree to which a given study is free from known sources of experimental bias (Pullin and Stewart 2006, Higgins and Green 2011). Some design features common to ecology and evolutionary biology may be readily identifiable as calling into question a study's quality, such as pseudoreplication, inappropriate controls, or highly variable sample size across treatments. Many others, however, will be specific to the research area or study, but nonetheless identifiable as potential sources of bias by knowledgeable practitioners. A high-quality study is defined as being free from these sources of bias whereas a lower-quality study might suffer from one or more potential sources of bias. This approach yields a relatively small number of categorical groups from which subgroup and sensitivity analyses can be conducted to test whether between-group heterogeneity exists among quality levels, and whether inclusion of studies with a high likelihood of biases (i.e., lower-quality studies) significantly affects the overall outcome of the review.

Although formal tests of the utility of quality groupings in ecology and evolutionary biology meta-analyses have not yet been undertaken, quality scales have been used in conjunction with sensitivity analyses within individual meta-analyses (e.g., Tyler et al. 2006; Stewart, Pullin, and Coles 2007). If these are used, it is critical that clear guidelines for evaluating sources of bias are articulated in the extraction protocol and that inter-rater reliability (degree of agreement among raters) is established if more than one person is coding for study quality. The latter can be achieved by a kappa analysis (see Chapter 4). It should be emphasized that poor reporting quality should not be confused with poor study quality although separating the two in practice can be challenging.

It also is possible to avoid any explicit quality ranking in favor of clearly defined study inclusion criteria combined with careful coding of methodological variation among included studies. Inclusion criteria initially can be set to exclude studies that lack specified design features, such as proper replication or appropriate controls, making transparent any a priori "quality" standard applied to a given review. Remaining methodological variation then is coded within the data extraction protocol and examined statistically using subgroup or sensitivity analyses. If specific methods are associated with different outcomes those studies can be reported separately. For example, in research on plant responses to elevated CO_2, a small pot size (i.e., small rooting volume) for experimental plants was considered by some (though not all) investigators to be a serious design flaw leading to biased results. Curtis and Wang (1998) coded all studies in their meta-analysis for pot size (Fig. 5.2) and found that plants grown in pots less than 0.5 L acclimated photosynthetically to elevated CO_2 much more than plants grown in larger pots. They used that result as a basis to exclude particular studies from further consideration. The goal of this approach, then, is to focus on testable relationships between specific methodological features and study outcomes, and away from attempts to assign quality measures to individual studies. This is our recommended strategy for handling perceived differences in study quality within the meta-analysis database.

CONCLUSIONS

It is not uncommon for those without experience building a meta-analysis database to suppose that this part of the review process will be relatively straightforward and proceed rapidly. Surely, extracting data from published sources must be faster and easier than collecting and analyzing it yourself! Unfortunately, this often is not the case. However, initial time spent developing clear data extraction protocols and testing data extraction spreadsheets will both speed the extraction process and reduce errors in the final database. While the thorny issue of distinguishing among high- and low-quality studies remains with us, use of transparent inclusion criteria and coding of specific method features allows for subsequent statistical tests of the impact of variable study quality on the outcome of the meta-analysis. Finally, electronic journal archives linked to bibliographic software have greatly simplified the process of documenting the data gathering process and retrieving papers for analysis, a clear boon for the meta-analyst. The end result should be a more transparent, repeatable, and error-free database, albeit in many cases its formation still comprises a large part of the time committed to the overall project.

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