Instituto Nacional de Investigación y Tecnología Agraria y Alimentaria (INIA)
Available online at www.inia.es/forestsystems
http://dx.doi.org/10.5424/fs/2013223-04766

Forest Systems 2013 22(3): 578-581
ISSN: 2171-5068
eISSN: 2171-9845

Short communication. Application of meta-analysis in forestry related topics

K. Kitikidou*, E. Milios, A. Stampoulidis and A. Papageorgiou

Department of Forestry and Management of the Environment and Natural Resources. Democritus University of Thrace. Pantadizou, 193. 68200 Orestianda, Greece

Abstract

Aim of study: Provision of the necessary knowledge to foresters in order carry out objective literature research, through meta-analysis.

Area of study: Mediterranean.

Material and methods: We describe in detail the methodology of meta-analysis. Then, we apply a meta-analysis in a set of independent studies of density of Aleppo pine (*Pinus halepensis* Mill.), a common forest species of the Mediterranean.

Research highlights: Making high quality meta-analyses, can help foresters in making the most of individual forest studies by synthesize them. In this work:

— We provide details on approaches for undertaking a meta-analysis.

— We use a silvicultural example to demonstrate our idea.

— We show how the method of meta-analysis could be applied to forestry also (besides the classical medical study reviews).

— We have as ultimate goal the use of this article as a reference from other researchers as regards the application of meta-analysis to their area of expertise.

Key words: literature research; systematic review.

Introduction

Nowadays, the plethora of publications make difficult to evaluate them and apply an evidence-based research practice. The meta-analysis is essentially a quantitative systematic review. The cost is minimal, compared to the cost of basic research, while interest from the readers becomes greater.

A meta-analysis includes formulation of the query, a thorough search of the literature, studies' evaluation and selection, as well as statistical composition of individual studies and interpretation of results (Borenstein *et al.*, 2009). However, meta-analysis is inappropriate for studies with different methodology, subject to systematic errors and with incompatible results (Cooper, 2010).

The aim of this work was to provide the necessary knowledge to foresters to carry out proper meta-analyses, with an example of Aleppo pine density responses to burning 12-144 months after fire and with no thinning treatments.

Material and methods

There is a number of researchers who have proposed specific instructions for the conducting a meta-analysis (Lipsey and Wilson, 2000; Borenstein *et al.*, 2009; Cooper, 2010). Stages of a meta-analysis are described below.

Problem definition

Forms of research findings, which are suitable to meta-analysis, are:

1. Central tendency research (prevalence rates).
2. Pre-post contrasts (growth rates).
3. Group contrasts:

— Experimentally created groups (comparison of outcomes between treatments and no-treatment).

* Corresponding author: kkitikid@fmenr.duth.gr
Received: 23-07-13. Accepted: 20-08-13.

— Naturally occurring groups.
4. Association between variables:
— Generalization.
— Correlation between variables.

The key to meta-analysis is the effect size (*ES*). It is the dependent variable that standardizes findings across studies so they can be compared. Different meta-analyses may use different effect size indices.

Document retrieval

It is critical to have an explicit inclusion and exclusion criteria of studies. There is a methodological quality dilemma: we should include or exclude low quality studies? Being too restrictive may restrict ability to generalize. On the other hand, being too inclusive may weaken the confidence that can be placed in the findings. Therefore, we must strike a balance that is appropriate to our research question.

Potential sources for identification of documents are:
— Electronic bibliographic databases.
— Internet search engines (google).
— Authors working in the research domain.
— Conference proceedings.
— Dissertations.
— Review articles.
— Research articles.
— Government reports.

Effect sizes and computation

There are many different types of *ES* measures, and each *ES* type may have multiple methods of computation.

The standardized mean difference *ES* type represents a standardized group contrast on an inherently continuous measure. With the Direction Calculation Method (Lipsey and Wilson, 2000), *ES* is calculated as:

$$ES = \frac{\bar{X}_{G1} - \bar{X}_{G2}}{S_{pooled}}, \quad S_{pooled} = \sqrt{\frac{s_1^2(n_1-1)+s_2^2(n_2-1)}{n_1+n_2-2}}$$

G_i are the groups studied with sizes n_i, while S_{pooled} is the pooled standard deviation.

The "odds-ratio" (Lipsey and Wilson, 2000) has the same use as the standardized mean difference *ES* type, and is based on a 2 by 2 contingency table, such as:

	Frequencies	
	Success	**Failure**
Treatment Group	a	b
Control Group	c	d

were $ES = \frac{ad}{bc}$

The "correlation coefficient *r*" *ES* type (Lipsey and Wilson, 2000) is suitable for association between variables research. Here, the $ES = r$ represents the strength of association between two inherently continuous measures and it is generally reported as *r* (the Pearson correlation).

The "risk ratio" *ES* type can be applied to group differences research (naturally occurring groups), and inherently dichotomous construct. In a 2 by 2 contingency table,

$$ES = \frac{a/(a+b)}{c/(c+d)}$$

The "proportion" *ES* type suits for central tendency research, while the "standardized gain score" can estimate the gain or change between two measurement points on the same variable.

In this study, we used the "proportion" *ES* type. Assuming that stand density decreases over time (Matis, 2004; Franklin *et al.*, 2009), we calculated the *ES* as a product of density (N/m^2) of Aleppo pine seedlings multiplied by the number of months after fire. Eight studies have been included: 1: Goudelis *et al.*, 2007; 2: Herranz *et al.*, 1997; 3: Martínez-Sánchez *et al.*, 1999; 4: Papageorgiou, 2011; 5: Pausas *et al.*, 2003; 6: Pausas *et al.*, 2004; 7: Thanos *et al.*, 1996; 8: Tsitsoni, 1997.

Analysis of effect sizes

Assuming we have an independent set of effect sizes (*ES*) (*i.e.* number of cases), for each effect size we have an inverse variance weight (w). The mean *ES* is equal to:

$$\overline{ES} = \frac{\sum (w \times ES)}{\sum w}$$

The standard error of the mean is: $se_{\overline{ES}} = \sqrt{\frac{1}{\sum w}}$

The 95% confidence interval is:

$$Lower = \overline{ES} - 1.96(se_{\overline{ES}})$$

$$Upper = \overline{ES} + 1.96(se_{\overline{ES}})$$

Homogeneity analysis tests whether the assumption that all of the effect sizes are estimating the same population mean is a reasonable assumption. The index Q (Cochran's Q statistic, Hardy and Tompson, 1988) is:

$$Q = \sum (w \times ES^2) - \frac{\left[\sum \left(w \times ES\right)\right]^2}{\sum w}$$

which is distributed as a chi-square (df = number of *ES*s-1).

If the calculated Q is less than the critical value for a chi-square with known df and p-value (*e.g.* 0.05), we fail to reject the null hypothesis of homogeneity. Conversely, if *ES*s distribution is heterogeneous, we should analyze the excess variability between studies. For categorical variables, this is analogous to the one-way ANOVA (meta-ANOVA), while for continuous variables, this is analogous to weighted multiple regression (meta-regression) (Yusuf *et al.*, 1991; Thompson and Higgins, 2002).

A graphical method, the so-called forest plot, has been developed for detecting heterogeneity (Panagiotakos, 2006). In a typical forest plot, the results of studies are represented as squares, while the edges of the horizontal line through each square represent the limits of the confidence interval for each study. The overall assessment of the meta-analysis is placed in a vertical line, while a diamond dot reflects the study closest to the vertical line.

Fixed effects model assumes that all of the variability between effect sizes is due to sampling error, while random effects model assumes that the variability between effect sizes is due to sampling error plus variability in the populations.

Fixed effects model weights each study by the inverse of the sampling variance:

$$w_i = \frac{1}{se_i^2}$$

Random effects model weights each study by the inverse of the sampling variance plus a constant that represents the variability across the population effects:

$w_i = \dfrac{1}{se_i^2 + \hat{v}_\theta}$, where $\hat{v}_\theta$ is the random effects variance component.

The random effects variance component is based on Q. The formula is:

$$Q_v = \frac{Q - k - 1}{\sum w - \left(\frac{\sum w^2}{\sum w}\right)}$$

The biggest difference we will notice in comparing random effect with fixed effect results, is in the mean *ES* and confidence intervals. If sample size is highly related to *ES*, then mean *ES* will differ between the two models, while confidence intervals will get bigger in the random effects model.

Results and discussion

The eight studies that measured the density (N/m^2) of Aleppo pine seedlings, 12-144 months after fire and with no thinning treatments, are proven to be significantly heterogeneous, since the calculated Q is bigger than the chi-square critical value (Table 1). Random effects model had bigger mean effect size and confidence intervals than fixed effects model, confirming the biological assumption that the number of months after fire is highly related to the seedlings density.

In the forest plot (Fig. 1) the diamond dot represents the study that is closer to the average *ES*. The *ES* values in the x-axis are multiplied by 100 and transformed in

Table 1. Meta-analysis statistics

	Fixed effects model	**Random effects model**	**Number of studies (*k*)**	**Degrees of freedom (df)**	**Chi-square critical value**
Q	64,149.508	17.625	8	7	14.067
$\overline{ES}$	40.532	109.208			
$se_{\overline{ES}}$	0.265	23.734			
Confidence intervals (lower-upper)	40.012-41.052	62.689-155.727			

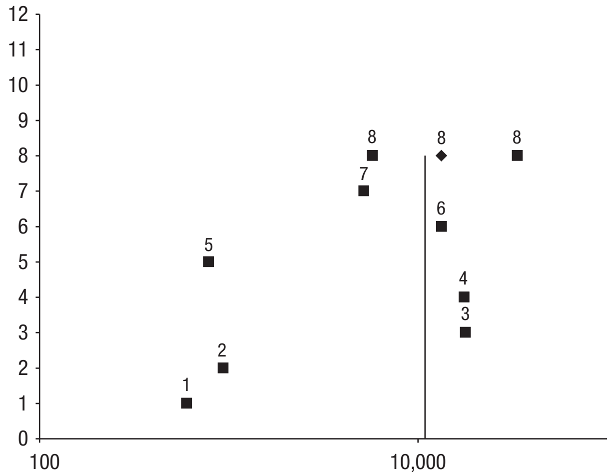

Figure 1. Forest plot of the meta-analysis.

a logarithmic scale, for an easier interpretation through graphical illustration. We can distinguish three groups: one with big effect sizes (studies 3, 4, 6 and two fractions of the 8th study), one with smaller effect sizes (study 7 and a fraction of the 8th study) and one group with the smallest effect sizes (studies 1, 2 and 5). A forester could further investigate which are the factors that lead to this grouping; stand structure prior burning, density of re-sprouters, competition regime post fire, climatic conditions post fire or other factors, single or combined (Oliver and Larson, 1996).

Conclusion

The application of meta-analysis, a statistical method applied in medicine mostly, when applied in forest research, helped us notice the following:

— Is a replicable and defensible method of synthesizing findings across forest studies

— Can point out gaps in the literature research, providing a solid foundation for the next generation of research on a forestry topic

— Illustrates the importance of replication

— Facilitates generalization of the knowledge gain through individual evaluations.

Acknowledgements

We would like to thank Bodossaki Foundation for the financial support of the 3rd author, Mr. Stampoulidis.

References

Borenstein M, Hedges L, Higgins J, Rothstein H, 2009. Introduction to meta-analysis (statistics in practice). John Wiley and Sons, UK.

Cooper H, 2010. Research synthesis and meta-analysis: a step-by-step approach. SAGE Publications, UK.

Franklin O, Aoki K, Seidl R, 2009. A generic model of thinning and stand density effects on forest growth, mortality and net increment. Ann For Sci 66(815): 11.

Goudelis G, Ganatsas P, Spanos I, Karpi A, 2007. Effect of repeated fire on plant community recovery in Penteli, central Greece. In: Eco- and ground bio-engineering: the use of vegetation to improve slope stability (Stokes *et al.,* eds). Springer. pp: 337-343.

Hardy R, Thompson S, 1998. Detecting and describing heterogeneity in meta-analysis. Stat Med 17: 841-856.

Herranz J, Martínez-Sánchez J, Marin A, Ferrandis P, 1997. Postfire regeneration of *Pinus halepensis* Miller in a semi-arid area in Albacete province (southeastern Spain). Ecoscience 4(1): 86-90.

Lipsey M, Wilson D, 2000. Practical meta-analysis (applied social research methods). SAGE Publications, UK.

Martínez-Sánchez J, Ferrandis P, De las Heras J, Herranz M, 1999. Effect of burnt wood removal on the natural regeneration of *Pinus halepensis* after fire in a pine forest in Tus valley (SE Spain). For Ecol Manage 123: 1-10.

Matis K, 2004. Forest biometry II. Dendrometry. Pigasos publications, Thessaloniki, Greece.

Oliver C, Larson B, 1996. Forest stand dynamics, update edition. John Wiley, New York, USA.

Panagiotakos D, 2006. Methodology of research and data analysis for the health sciences. Kostakis Publications, Athens, Greece.

Papageorgiou A, 2011. Social differentiation analysis of trees in *P. halepensis* stands which were initiated after the fires of 1990 and 1998 in the Peninsula of Kassandra in Chalkidiki, Greece. MSc thesis. Dimokritos University, Department of Forestry and Management of the Environment and Natural Resources.

Pausas J, Ouadah N, Ferran A, Gimeno T, Vallejo R, 2003. Fire severity and seedling establishment in *Pinus halepensis* woodlands, eastern Iberian Peninisula, Plant Ecol 169: 205-213.

Pausas J, Ribeiro E, Vallejo R, 2004. Post-fire regeneration variability of *Pinus halepensis* in the eastern Iberian Peninsula. For Ecol Manage 203: 251-259.

Thanos C, Daskalakou E, Nikolaidou S, 1996. Early postfire regeneration of a *Pinus halepensis* forest on Mount Parnis, Greece. J Vegetation Sci 7: 273-280.

Thompson S, Higgins J, 2002. How should meta-regression analyses be undertaken and interpreted? Stat Med 21: 1559-1573.

Tsitsoni T, 1997. Conditions determining natural regeneration after wildfires in the *Pinus halepensis* (Miller, 1768) forests of Kassandra Peninsula (North Greece). For Ecol Manage 92: 199-208.

Yusuf S, Wittes J, Probstfield J, Tyroler H, 1991. Analysis and interpretation of treatment effects in subgroups of patients in randomized clinical trials. JAMA 266: 93-98.