A systematic review of the statistical scope of restoration ecology of invaded grassland ecosystems

Amanda R. Liczner

Department of Biology, York University, Canada. 4700 Keele St., Toronto, Ontario. M3J1P3. PH: 416.736.2100 ext 20588. FAX: 416.736.5698

E-mail: Liczner1@yorku.ca Tel. +1 416.736.2100 ext 20588. FAX: 416.736.5698

Abstract

Restoration ecology is a rapidly growing field of research. The statistical analyses and experimental designs used in this field have likely also expanded. In this review, the statistical scope of the restoration ecology of invaded grasslands will be investigated. A systematic review was conducted on 103 articles to examine the types of statistical tests used and how they changed over time, if assumptions are tested, and how the number of statistical tests and the experimental design influence both the citation rate of articles and the impact factor of journals where these articles are published. ANOVAs have consistently been the dominant test. Statistical test diversity has increased since the year 2000. Most articles did test the assumptions of statistical analyses. The number of tests, and sample size of experiments are both positively correlated with the average citation rate of articles and the impact factor of the journal while the number of factors was negatively correlated. GLMs are recommended as a statistical test to be used more frequently in the future over ANOVAs. There is room for improvement in terms of reporting statistics accurately, including testing assumptions. When possible, sample sizes should be increased to both increase the quality of data, and the citation rate and the journal impact where articles are published. When possible and appropriate, sample sizes and the number of statistical tests should be increased. Adding factors in experimental designs should only be done so without compromising sample size as it has been shown to hinder the citation rate and journal impact.

Keywords: grassland, invasion, PRISMA, restoration ecology, statistics, synthesis, systematic review

Introduction

The field of restoration ecology is a relatively new field that has rapidly developed within the last decade (Young et al. 2005). Restoration ecologists have a number of decisions regarding planning an effective experimental design, and the appropriate statistics for both the design and the type of data that is collected. A study by Michener (1997) described the kinds of statistical tests that could be used depending on the type of restoration experiment. These include ANOVAs and regressions for comparing the results of experimental designs such as testing the effect of a treatment, and ordinations for analyzing changes in community structure or species distributions, and finally time series analyses for examining pre and post restoration sampling. Since Michener's 1997 paper, there has not been a review of the types of statistical analyses used. A review of this kind is important to identify what statistics are being done and how in order for to identify potential weaknesses and give recommendations for future directions important to the advancement of this field.

Within the broader field of ecology and evolution there has been a push to incorporate more variables in experiments to better explain systems (Albert 2010) and there is a movement away from 'classical' statistical tests such as towards Generalized Linear Models and Generalized Linear Mixed Models (Bolker 2009). These movements have likely impacted the experimental designs, statistics and even the citation rate of restoration studies. The purpose of this review is to look at the statistical scope of restoration ecology. As the types of tests are likely to vary among this vast field, this review will focus on studies restoring invaded grasslands. Here, I will examine the type of statistical tests being used and how these have changed over time, whether statistical assumptions are being tested, and how statistical tests and the experimental design of studies might influence the citation rate of articles and the impact of the journal where these articles are published.

Literature Search

A systematic literature search was conducted using ISI Web of Knowledge on October 2, 2014 using the following search terms: (restor*) AND (grass* OR savanna) AND (non-native* OR invas* OR invad* OR alien). The search results were refined to the Web of Science category 'Ecology' and resulted in 340 articles. Each article was individually screened to exclude reviews and irrelevant articles. This resulted in 103 retained articles for the systematic review (Liczner 2014). A PRISMA flow diagram (Moher et al. 2009) was produced to outline the literature selection process (fig.1).

The publication year and the types of statistical tests performed were extracted from each study to analyze what statistical tests are used, and how this has changed over time. In this field, there is a high diversity of statistical tests, so, tests were grouped into broader categories to reduce variation and maximize the ability to visualize trends (table 1). The proportion of articles that tested the assumptions of their statistical analyses was recorded. It was assumed that assumptions were not tested if it was not reported in the article. To determine if the number of statistical tests or the experimental design influences the citation rate of articles or the impact of the journal where the articles are published the number of unique statistical tests, number of factors, and the sample size (per factor, n=) was extracted from each article. The average citation rate of each article was obtained from Web of Science. The journal impact factor was obtained from each journal's website (impact factor as of 2014). If more than one sample size was reported, the smallest sample size was extracted to be conservative.

Results

Diversity of statistical tests over time

All articles included some form of statistical analysis. ANOVAs are the most commonly used statistical test comprising more than half of all tests (fig. 2). Linear models and Generalized Linear Models (GLMs) are also frequently used in this field. T-tests, non-parametric tests, and tests classified as 'other' (see table 1) are used less often. ANOVAs have consistently been the most common statistical tests (fig. 3). ANOVAs, linear models, GLMs and ordinations were the only tests used from 1992-2000. After 2000, the diversity of tests increased to include t-tests, non-parametric tests and tests categorized as other.

Frequency of assumption testing

The majority of studies (60.9% versus 39.1%) tested the assumptions of the statistical tests used in their analyses.

Influence of statistics and experimental design on citation rate and impact factor

Articles that performed more statistical tests have a higher average citation rate per year compared to studies with fewer statistical tests (fig. 4a). These studies are also published in higher impact journals.

Increasing the number of factors tested has a negative impact on both the average citation rate per year and these articles were published in lower impact journals (fig. 4b).

The sample size of studies is positively correlated with both the average citation rate of the article (fig. 5a) and the impact of the journal where the article was published.

Discussion

Statistical analyses are included in all studies looking at restoring invaded grassland. ANOVAs are still the most common statistical tested used, although the diversity of tests has increased. ANOVAs may dominate because they are an appropriate test for most experimental designs in this field. The majority of articles tested the assumptions of the statistical tests included in their analysis. However, the proportion of studies that test assumptions may be underestimated because assumptions may have been tested but not reported. Both increasing the number of unique statistical tests and sample size positively influence the citation rate and impact of journal. This effect may be underestimated as recently published articles likely have a lower citation rate simply because there has not been enough time for them to be cited. This effect may also be underestimated as we citing a smaller proportion of studies then in the past with seminal articles receiving the most citations compared to other articles on the topic (Seglan 1997). Conversely, the effect on the impact factor of the journal may be inflated as the impact factor of journals generally increases over time (Chew et al. 2007, Lee et al. 2011) and high impact journals tend to publish studies with large effects (Barto and Rillig 2012) and studies that confirm hypotheses (Leimu and Koricheva 2004) regardless of the statistics or study design. There was a negative relationship between the number of factors and the citation rate of the article and the impact factor of the journal. This may be because samples size decreases with increasing factors (A1) and sample size may be a more important factor determining citation rate and impact of journal.

Future direction for statistical analyses of restoration studies

Although the experimental designs used in restoration ecology commonly require the use of ANOVAs, I am recommending a shift from ANOVAs towards Generalized Linear Models (GLMs). The types of experiments commonly used in this field of restoration ecology examine the response of a species, community, etc. to a set of categorical treatments (A2) (see some sample papers: Rinella et al. 2009; Robertson et al. 2013; Hill and Fischer 2014). Thus, ANOVAs are an appropriate test but, the data associated with these experiments (abundance, plant traits, environmental data, community composition etc.) usually violates one of the assumptions of ANOVAs which is the data are normally distributed (Bolker et al. 2009). To solve this, the data are transformed to fit a normal distribution, or non-parametric statistics are used. Recently, there has been rapid increased use of GLMs in the ecology and evolution literature (Bolker et al. 2009). GLMs may be a more useful analyses for ecologists as they do not require the data to be normally distributed and can handle random effects (though Generalized Linear Mixed Models or GLMMs), better than ANOVAs (Bolker et al. 2009). As GLMs have increased in popularity within the ecological and evolution literature, it is predicted that this trend will soon pass over to the restoration ecology literature and the ratio of ANOVAs to GLMs will decline.

There is another trend in ecology towards studies that include more explanatory variables in their models in order to better describe the systems ecologists are working in (Albert et al. 2010). As restoration ecology will likely follow this trend, the proportion of data reduction techniques such as ordinations will likely increase. Ordinations are powerful explanatory tools when trying to look at how multiple variables are influencing a system and restoration ecologists should consider designs appropriate for ordinations when trying to explain large scale changes or influences of multiple variables (see for examples Marrs et al. 1998; Garcia-Palacios et al. 2010; Kulmatiski 2011).

Statistical reporting needs improvement

Although the majority of articles did test the assumptions of their statistical tests, the number of articles that did test assumptions is still high, work must be done to ensure accurate reporting and testing is done. Without assumption testing, it is difficult to determine if the results and interpretations presented by a study are valid as the results obtained may be due to the fact that the data was inappropriate for the particular statistical test (Van Horn et al. 2012). There appears to be a large portion of statistical errors (including not testing assumption) reported in published articles, even in articles published in very prestigious journals such as Nature (McGuigan 1995)

Statistical and experimental design influences citation rate and journal impact

Although increased number of unique statistical tests can positively influence citation rate and impact of journal it is not recommended to do more statistical tests, unless the data and research questions warrant it and it would better explain or reveal data trends. There should be a push towards quality and not quantity in statistical tests in terms of appropriateness and reporting. Increasing sample size also had a positive relationship with citation rate and journal impact factor. Usually, logistical constraints limit sample sizes, but if it is feasible future studies should consider increasing sample sizes not only to increase the citation rate of articles and the impact of journal articles are published in, but also to increase the quality of data and experimental designs within this field. It is not recommended to increase the number of factors at the expense of the sample size as increasing factors alone has been shown to decrease the citation rate of articles and these articles are published in less impactful journals. This is likely due to the fact that overall, studies with more factors had smaller sample sizes (A2) and thus a lower citation rate and are published in less prestigious journals.

Conclusion:

Currently, ANOVAs are the most common statistical test used in restoration of invaded grasslands. It is recommended that GLMs and GLMMs be used more frequently in ecological studies. As GLMs have increased in popularity in ecology they will also likely increase in popularity in restoration ecology. Data reduction techniques such as ordinations will likely also increase over time as experimental designs begin to incorporate more variables to better explain systems. Although the assumptions of statistical tests were reported in the majority of the articles, there is still room for improvement in testing assumptions and properly reporting statistics. Increasing the number of tests will influence the citation rate and the type of journal articles are published in, redundancy among tests should be avoided. Sample size also positively influenced citation rate and journal quality and sample sizes (when possible) should be increased not only to improve citation rates and get into higher impact journals, but also to improve the quality of data. This is more important than increasing the number of factors at the expense of sample size as sample size is shown to be more important at determining citation rate and journal impact.

References

Abella, S. R., D. J. Craig, S. D. Smith, and A. C. Newton. 2012. Identifying native vegetation for reducing exotic species during the restoration of desert ecosystems. Restoration Ecology **20**:781-787.

Albert, C. H., Thuiller, W., Yoccoz, N. G., Soudant, A., Boucher, F., Saccone, P. and Lavorel, S. 2010. Intraspecific functional variability: extent, structure and sources of variation. Journal of Ecology **98**: 604–613

Ambrose, L. G., and S. D. Wilson. 2003. Emergence of the introduced grass *Agropyron cristatu*m and the native grass *Bouteloua gracilis* in a mixed-grass prairie restoration. Restoration Ecology **11**:110-115.

Ammondt, S. A., C. M. Litton, L. M. Ellsworth, and J. K. Leary. 2013. Restoration of native plant communities in a Hawaiian dry lowland ecosystem dominated by the invasive grass *Megathyrsus maximus*. Applied Vegetation Science **16**:29-39.

Baer, S. G., J. M. Blair, S. L. Collins, and A. K. Knapp. 2004. Plant community responses to resource availability and heterogeneity during restoration. Oecologia **139**:617-629.

Baer, S. G., and J. W. Groninger. 2004. Herbicide and tillage effects on volunteer vegetation composition and diversity during reforestation. Restoration Ecology **12**:258-267.

Baker, W. L., J. Garner, and P. Lyon. 2009. Effect of Imazapic on Cheatgrass and Native Plants in Wyoming Big Sagebrush Restoration for Gunnison Sage-grouse. Natural Areas Journal **29**:204-209.

Bakker, J. D., and S. D. Wilson. 2004. Using ecological restoration to constrain biological invasion. Journal of Applied Ecology **41**:1058-1064.

Barto, E. K. and Rillig, M. C. 2012. Dissemination biases in ecology: effect sizes matter more than quality. Oikos. **121**: 228–235.

Beltran, E., A. Valiente-Banuet, and M. Verdu. 2012. Trait divergence and indirect interactions allow facilitation of congeneric species. Annals of Botany **110**:1369-1376.

Bolker, B. M., Brooks, M. E., Clark, C. J., Geange, S. W., Poulsen, J. R., Stevens, M. H. H., White, J. S. 2009. Trends in Ecology and Evolution **24**: 127-135

Britton, A. J., R. H. Marrs, P. D. Carey, and R. J. Pakeman. 2000. Comparison of techniques to increase *Calluna vulgaris* cover on heathland invaded by grasses in Breckland, South East England. Biological Conservation **95**:227-232.

Bugg, R. L., C. S. Brown, and J. H. Anderson. 1997. Restoring native perennial grasses to rural roadsides in the Sacramento Valley of California: Establishment and evaluation. Restoration Ecology **5**:214-228.

Cabin, R. J., S. G. Weller, D. H. Lorence, S. Cordell, L. J. Hadway, R. Montgomery, D. Goo, and A. Urakami. 2002. Effects of light, alien grass, and native species additions on Hawaiian dry forest restoration. Ecological Applications **12**:1595-1610.

Cabin, R. J., S. G. Weller, D. H. Lorence, T. W. Flynn, A. K. Sakai, D. Sandquist, and L. J. Hadway. 2000. Effects of long-term ungulate exclusion and recent alien species control on the preservation and restoration of a Hawaiian tropical dry forest. Conservation Biology **14**:439-453.

Chew, M., Villanueva, E. V., & Van Der Weyden, M. B. (2007). Life and times of the impact factor: retrospective analysis of trends for seven medical journals (1994-2005) and their Editors' views. Journal of the Royal Society of Medicine. **100:** 142-150.

Clark, D. L., and M. V. Wilson. 2001. Fire, mowing, and hand-removal of woody species in restoring a native wetland prairie in the Willamette Valley of Oregon. Wetlands **21**:135-144.

Cox, R. D., and E. B. Allen. 2008. Stability of exotic annual grasses following restoration efforts in southern California coastal sage scrub. Journal of Applied Ecology **45**:495-504.

Craven, D., J. Hall, and J. M. Verjans. 2009. Impacts of herbicide application and mechanical cleanings on growth and mortality of two timber species in *Saccharum spontaneum* grasslands of the Panama Canal watershed. Restoration Ecology **17**:751-761.

Cuevas, Y. A., and S. M. Zalba. 2010. Recovery of native grasslands after removing invasive pines. Restoration Ecology **18**:711-719.

Daehler, C. C., and E. M. Goergen. 2005. Experimental restoration of an indigenous Hawaiian grassland after invasion by Buffel grass (*Cenchrus ciliaris*). Restoration Ecology **13**:380-389.

Davies, K. W. 2010. Revegetation of medusahead-invaded sagebrush steppe. Rangeland Ecology & Management **63**:564-571.

Davies, K. W., and R. L. Sheley. 2011. Promoting native vegetation and diversity in exotic annual Grass infestations. Restoration Ecology **19**:159-165.

DeMeester, J. E., and D. D. Richter. 2010. Restoring restoration: removal of the invasive plant *Microstegium vimineum* from a North Carolina wetland. Biological Invasions **12**:781-793.

Dickens, S. J. M., and E. B. Allen. 2014. Exotic plant invasion alters chaparral ecosystem resistance and resilience pre- and post-wildfire. Biological Invasions **16**:1119-1130.

Doll, J. E., K. A. Haubensak, E. L. Bouressa, and R. D. Jackson. 2011. Testing disturbance, seeding time, and soil amendments for establishing native warm-season grasses in non-native cool-season pasture. restoration ecology **19**:1-8.

Donohue, K. 2009. Completing the cycle: maternal effects as the missing link in plant life histories. Philosophical Transactions of the Royal Society B-Biological Sciences **364**:1059-1074.

Dyer, A. R., and K. J. Rice. 1997. Intraspecific and diffuse competition: The response of *Nassella pulchra* in a California grassland. Ecological Applications **7**:484-492.

Emery, S. M., and J. A. Rudgers. 2012. Impact of competition and mycorrhizal fungi on growth of *Centaurea stoebe*, an invasive plant of sand dunes. American Midland Naturalist **167**:213-222.

Ewing, K. 2002. Effects of initial site treatments on early growth and three-year survival of Idaho fescue. Restoration Ecology **10**:282-288.

Facelli, J. M., P. Chesson, and N. Barnes. 2005. Differences in seed biology of annual plants in arid lands: A key ingredient of the storage effect. Ecology **86**:2998-3006.

Fehmi, J. S., K. J. Rice, and E. A. Laca. 2004. Radial dispersion of neighbors and the small-scale competitive impact of two annual grasses on a native perennial grass. Restoration Ecology **12**:63-69.

Firn, J., A. P. N. House, and Y. M. Buckley. 2010. Alternative states models provide an effective framework for invasive species control and restoration of native communities. Journal of Applied Ecology **47**:96-105.

Flory, S. L. 2010. Management of *Microstegium vimineum* Invasions and Recovery of Resident Plant Communities. Restoration Ecology **18**:103-112.

Flory, S. L., and K. Clay. 2009. Invasive plant removal method determines native plant community responses. Journal of Applied Ecology **46**:434-442.

Forrester, J. A., D. J. Leopold, and S. D. Hafner. 2005. Maintaining critical habitat in a heavily managed landscape: Effects of power line corridor management on

Karner blue butterfly (*Lycaeides melissa samuelis*) habitat. Restoration Ecology**13**:488-498.

Fraser, L. H., and E. B. Madson. 2008. The interacting effects of herbivore exclosures and seed addition in a wet meadow. Oikos **117**:1057-1063.

Garcia-Palacios, P., S. Soliveres, F. T. Maestre, A. Escudero, A. P. Castillo-Monroy, and F. Valladares. 2010. Dominant plant species modulate responses to hydroseeding, irrigation and fertilization during the restoration of semiarid motorway slopes. Ecological Engineering **36**:1290-1298.

Gonzales, E. K., and P. Arcese. 2008. Herbicory more limiting than competition on early and established native plants in an invaded meadow. Ecology **89**:3282-3289.

Gonzales, E. K., and D. R. Clements. 2010. Plant community biomass shifts in response to mowing and fencing in invaded oak meadows with non-native grasses and abundant ungulates. Restoration Ecology **18**:753-761.

Gosse, J., L. Hermanutz, B. McLaren, P. Deering, and T. Knight. 2011. Degradation of Boreal Forests by Non-native Herbivores in Newfoundland's National Parks: Recommendations for Ecosystem Restoration. Natural Areas Journal **31**:331-339.

Hagen, D., and M. Evju. 2013. Using short-term monitoring data to achieve goals in a large-scale restoration. Ecology and Society **18**.

Hamman, S. T., and C. V. Hawkes. 2013. Biogeochemical and microbial legacies of non-native grasses can affect restoration success. Restoration Ecology **21**:58-66.

Hansen, M. J. 2007. Evaluating management strategies and recovery of an invasive grass (*Agropyron cristatum*) using matrix population models. Biological Conservation **140**:91-99.

Hatch, D. A., J. W. Bartolome, J. S. Fehmi, and D. S. Hillyard. 1999. Effects of burning and grazing on a coastal California grassland. Restoration Ecology **7**:376-381.

Hendrickson, J. R., and C. Lund. 2010. Plant community and target species affect responses to restoration strategies. Rangeland Ecology & Management **63**:435-442.

Hill, K. C., and D. G. Fischer. 2014. Native-exotic species richness relationships across spatial scales in a prairie restoration matrix. Restoration Ecology **22**:204-213.

Hooper, E., P. Legendre, and R. Condit. 2005. Barriers to forest regeneration of deforested and abandoned land in Panama. Journal of Applied Ecology **42**:1165-1174.

Hopwood, J. L. 2008. The contribution of roadside grassland restorations to native bee conservation. Biological Conservation **141**:2632-2640.

Humphrey, L. D., and E. W. Schupp. 2004. Competition as a barrier to establishment of a native perennial grass (Elymus elymoides) in alien annual grass (Bromus teetorum) communities. Journal of Arid Environments **58**:405-422.

Iannone, B. V., and S. M. Galatowitsch. 2008. Altering light and soil n to limit phalaris arundinacea reinvasion in sedge meadow restorations. Restoration Ecology **16**:689-701.

Jackson, R. D., L. K. Paine, and J. E. Woodis. 2010. Persistence of native c4 grasses under high-intensity, short-duration summer bison grazing in the eastern tallgrass prairie. Restoration Ecology **18**:65-73.

Jakubowski, A. R., M. D. Casler, and R. D. Jackson. 2010. Landscape Context predicts reed canarygrass invasion: implications for management. Wetlands **30**:685-692.

Jenkins, A. M., D. R. Gordon, and M. T. Renda. 2004. Native alternatives for non-native turfgrasses in central Florida: Germination and responses to cultural treatments. Restoration Ecology **12**:190-199.

Kimball, S., M. E. Lulow, K. A. Mooney, and Q. M. Sorenson. 2014. Establishment and management of native functional groups in restoration. Restoration Ecology **22**:81-88.

Kimball, S., and P. M. Schiffman. 2003. Differing effects of cattle grazing on native and alien plants. Conservation Biology **17**:1681-1693.

Kotowski, W., P. Dzierza, M. Czerwinski, L. Kozub, and S. Snieg. 2013. Shrub removal facilitates recovery of wetland species in a rewetted fen. Journal for Nature Conservation **21**:294-308.

Kruk, B. C., and R. L. Benech-Arnold. 2000. Evaluation of dormancy and germination responses to temperature in *Carduus acanthoides* and *Anagallis arvensis* using a screening system, and relationship with field-observed emergence patterns. Seed Science Research **10**:77-88.

Kulmatiski, A. 2011. Changing soils to manage plant communities: activated carbon as a restoration tool in ex-arable fields. Restoration Ecology **19**:102-110.

Ledgard, N., and M. Davis. 2004. Restoration of mountain beech (Nothofagus solandri var. cliffortioides) forest after fire. New Zealand Journal of Ecology **28**:125-135.

Lee, C.H., Shih, C.P., Chang, Y.C. and Chaou, C.H. 2011. The evolution of academic performance in emergency medicine journals: Viewpoint from 2000 to 2009 Journal Citation Reports. Academic Emergency Medicine **18**: 898–904

Leimu, R., and Koricheva J. 2004. Cumulative meta-analysis: a new tool for detection of temporal trends in publication bias in ecology. Proceedings of the Royal Society B-Biological Sciences. **271:** 1961-1966

Leger, E. A., E. M. Goergen, and T. F. de Queiroz. 2014. Can native annual forbs reduce *Bromus tectorum* biomass and indirectly facilitate establishment of a native perennial grass? Journal of Arid Environments **102**:9-16.

Lesica, P., and B. Martin. 2003. Effects of prescribed fire and season of burn on recruitment of the invasive exotic plant, *Potentilla recta*, in a semiarid grassland. Restoration Ecology **11**:516-523.

Liczner A. 2014. Articles retained for a systematic review of the stats used in restoration ecology. figshare. http://dx.doi.org/10.6084/m9.figshare.1209305

Loo, S. E., R. Mac Nally, D. J. O'Dowd, and P. S. Lake. 2009. Secondary invasions: Implications of riparian restoration for in-stream invasion by an aquatic grass. Restoration Ecology **17**:378-385.

Luken, J. O. 2005. *Dionaea muscipula* (Venus flytrap) establishment, release, and response of associated species in mowed patches on the rims of Carolina bays. Restoration Ecology **13**:678-684.

Lulow, M. E. 2008. Restoration of California native grasses and clovers: the roles of clipping, broadleaf herbicide, and native grass density. Restoration Ecology **16**:584-593.

Luzuriaga, A. L., A. Escudero, J. M. Olano, and J. Loidi. 2005. Regenerative role of seed banks following an intense soil disturbance. Acta Oecologica-International Journal of Ecology **27**:57-66.

Mack, M. C., and C. M. D'Antonio. 2003. Exotic grasses alter controls over soil nitrogen dynamics in a Hawaiian woodland. Ecological Applications **13**:154-166.

Madsen, M. D., K. W. Davies, D. L. Mummey, and T. J. Svejcar. 2014. Improving restoration of exotic annual grass-invaded rangelands through activated carbon seed enhancement technologies. Rangeland Ecology & Management**67**:61-67.

Mangold, J. M., and R. L. Sheley. 2008. Controlling performance of bluebunch wheatgrass and spotted knapweed using nitrogen and sucrose amendments. Western North American Naturalist **68**:129-137.

Marrs, R. H., S. W. Johnson, and M. G. Le Duc. 1998. Control of bracken and restoration of heathland. VIII. The regeneration of the heathland community after 18 years of continued bracken control or 6 years of control followed by recovery. Journal of Applied Ecology **35**:857-870.

Marrs, R. H., and J. E. Lowday. 1992. Control of bracken and the restoration of heathland .2. regeneration of the heathland community. Journal of Applied Ecology **29**:204-211.

McGuigan, S. M. 1995. The use of statistics in the British Journal of Psychiatry. British Journal of Psychiatry. **167**: 683-688.

Michener, W. K. 1997. Quantitatively Evaluating Restoration Experiments: Research Design, Statistical Analysis, and Data Management Considerations. Restoration Ecology **5**: 324–337

Minchinton, T. E., J. C. Simpson, and M. D. Bertness. 2006. Mechanisms of exclusion of native coastal marsh plants by an invasive grass. Journal of Ecology **94**:342-354.

Moher D, Liberati A, Tetzlaff J, Altman DG, Group TP. 2009**.** Preferred reporting items for systematic reviews and meta-analyses: the PRISMA statement. *BMJ* 339:b2535 DOI 10.1136/bmj.b2535.

Moreno-Penaranda, R., F. Lloret, and J. M. Alcaniz. 2004. Effects of sewage sludge on plant community composition in restored limestone quarries. Restoration Ecology **12**:290-296.

Morghan, K. J. R., and K. J. Rice. 2006. Variation in resource availability changes the impact of invasive thistles on native bunchgrasses. Ecological Applications **16**:528-539.

Muranaka, T. 2009. The restoration of gravelly floodplain vegetation and endemic plants to riparian habitat in a Japanese river. Landscape and Ecological Engineering **5**:11-21.

Norbury, G., A. Byrom, R. Pech, J. Smith, D. Clarke, D. Anderson, and G. Forrester. 2013. Invasive mammals and habitat modification interact to generate unforeseen outcomes for indigenous fauna. Ecological Applications **23**:1707-1721.

O'Dell, R. E., and V. P. Claassen. 2006. Relative performance of native and exotic grass species in response to amendment of drastically disturbed serpentine substrates. Journal of Applied Ecology **43**:898-908.

Ogden, J. A. E., and M. Rejmanek. 2005. Recovery of native plant communities after the control of a dominant invasive plant species, *Foeniculum vulgare*: Implications for management. Biological Conservation **125**:427-439.

Orrock, J. L., and M. S. Witter. 2010. Multiple drivers of apparent competition reduce re-establishment of a native plant in invaded habitats. Oikos **119**:101-108.

Orrock, J. L., M. S. Witter, and O. J. Reichman. 2009. Native consumers and seed limitation constrain the restoration of a native perennial grass in exotic habitats. Restoration Ecology **17**:148-157.

Ortega, Y. K., and D. E. Pearson. 2011. Long-term effects of weed control with picloram along a gradient of spotted knapweed invasion. Rangeland Ecology & Management **64**:67-77.

Oviedo, R., M. Faife-Cabrera, A. Noa-Monzon, J. Arroyo, A. Valiente-Banuet, and M. Verdu. 2014. Facilitation allows plant coexistence in Cuban serpentine soils. Plant Biology **16**:711-716.

Price, C. A., and J. F. Weltzin. 2003. Managing non-native plant populations through intensive community restoration in Cades Cove, Great Smoky Mountains National Park, USA. Restoration Ecology **11**:351-358.

Prober, S., S. Taylor, R. Edwards, and B. Mills. 2009. Effectiveness of repeated autumn and spring fires for understorey restoration in weed-invaded temperate eucalypt woodlands. Applied Vegetation Science **12**:440-450.

Prober, S. M., and I. D. Lunt. 2009. Restoration of Themeda australis swards suppresses soil nitrate and enhances ecological resistance to invasion by exotic annuals. Biological Invasions **11**:171-181.

Prober, S. M., K. R. Thiele, I. D. Lunt, and T. B. Koen. 2005. Restoring ecological function in temperate grassy woodlands: manipulating soil nutrients, exotic annuals and native perennial grasses through carbon supplements and spring burns. Journal of Applied Ecology **42**:1073-1085.

Ries, L., D. M. Debinski, and M. L. Wieland. 2001. Conservation value of roadside prairie restoration to butterfly communities. Conservation Biology **15**:401-411.

Rinella, M. J., and B. J. Hileman. 2009. Efficacy of prescribed grazing depends on timing intensity and frequency. Journal of Applied Ecology **46**:796-803.

Rinella, M. J., B. D. Maxwell, P. K. Fay, T. Weaver, and R. L. Sheley. 2009. Control effort exacerbates invasive-species problem. Ecological Applications **19**:155-162.

Robertson, S., K. R. Hickrnan, K. R. Harmoney, and D. M. Leslie. 2013. Combining glyphosate with burning or mowing improves control of yellow bluestem (*Bothriochloa ischaemum*). Rangeland Ecology & Management **66**:376-381.

Rosas, H. L., P. Moreno-Casasola, and I. A. Mendelssohn. 2006. Effects of experimental disturbances on a tropical freshwater marsh invaded by the African grass Echinochloa pyramidalis. Wetlands **26**:593-604.

Sambatti, J. B. M., and K. J. Rice. 2006. Local adaptation, patterns of selection, and gene flow in the Californian serpentine sunflower (Helianthus exilis). Evolution **60**:696-710.

Seglen, P. O. 1997. Why the impact factor of journals should not be used for evaluating research. British Medical Journal **314**: 498-502

Simmers, S. M., and S. M. Galatowitsch. 2010. Factors affecting revegetation of oil field access roads in semiarid grassland. Restoration Ecology **18**:27-39.

Simmons, M. T., S. Windhager, P. Power, J. Lott, R. K. Lyons, and C. Schwope. 2007. Selective and non-selective control of invasive plants: The short-term effects of growing-season prescribed fire, herbicide, and mowing in two Texas prairies. Restoration Ecology **15**:662-669.

Skorka, P., J. Settele, and M. Woyciechowski. 2007. Effects of management cessation on grassland butterflies in southern Poland. Agriculture Ecosystems & Environment **121**:319-324.

Snow, C. S. R., and R. H. Marrs. 1997. Restoration of Calluna heathland on a bracken Pteridium-infested site in north west England. Biological Conservation **81**:35-42.

Stanley, A. G., P. W. Dunwiddie, and T. N. Kaye. 2011. Restoring Invaded Pacific Northwest Prairies: Management Recommendations from a Region-Wide Experiment. Northwest Science **85**:233-246.

Thaxton, J. M., S. Cordell, R. J. Cabin, and D. R. Sandquist. 2012. Non-native grass removal and shade increase soil moisture and seedling performance during hawaiian dry forest restoration. Restoration Ecology **20**:475-482.

Urbanek, R. E., C. K. Nielsen, G. A. Glowacki, and T. S. Preuss. 2012. Effects of white-tailed deer (*Odocoileus virginianus* Zimm.) herbivory in restored forest and savanna plant communities. American Midland Naturalist **167**:240-255.

Van Horn, M. L., Smith, A. A., Fagan, A. A., Jaki, T., Feaster, D. J., Masyn K., Hawkins, J. D., Howe, G. 2012. Structural Equation Modelling: A Multidisciplinary Journal **19**:227-249

Verdu, M., and A. Valiente-Banuet. 2011. The relative contribution of abundance and phylogeny to the structure of plant facilitation networks. Oikos **120**:1351-1356.

Wagner, V., and C. R. Nelson. 2014. Herbicides can negatively affect seed performance in native plants. Restoration Ecology **22**:288-291.

Wainwright, C. E., E. M. Wolkovich, and E. E. Cleland. 2012. Seasonal priority effects: implications for invasion and restoration in a semi-arid system. Journal of Applied Ecology **49**:234-241.

Wang, W. Y., Q. J. Wang, and H. C. Wang. 2006. The effect of land management on plant community composition, species diversity, and productivity of alpine Kobersia steppe meadow. Ecological Research **21**:181-187.

Weiler, A., B. Von Holle, and D. M. Nickerson. 2013. Reducing biotic and abiotic land-use legacies to restore invaded, abandoned citrus groves. Restoration Ecology **21**:755-762.

White, C. S., and S. R. Loftin. 2000. Response of 2 semiarid grasslands to cool-season prescribed fire. Journal of Range Management **53**:52-61.

Wilcox, J. C., M. T. Healy, and J. B. Zedler. 2007. Restoring native vegetation to an urban wet meadow dominated by reed canarygrass (*Phalaris arundinacea* L.) in Wisconsin. Natural Areas Journal **27**:354-365.

Wilson, M. V., and D. L. Clark. 2001. Controlling invasive *Arrhenatherum elatius* and promoting native prairie grasses through mowing. Applied Vegetation Science **4**:129-138.

Wilson, S. D., and B. D. Pinno. 2013. Environmentally-contingent behaviour of invasive plants as drivers or passengers. Oikos **122**:129-135.

Young, T. P., Petersen, D. A. and Clary, J. J. 2005., The ecology of restoration: historical links, emerging issues and unexplored realms. Ecology Letters **8**: 662–673.

Young, S. L., J. N. Barney, G. B. Kyser, T. S. Jones, and J. M. DiTomaso. 2009. Functionally Similar Species Confer Greater Resistance to Invasion: Implications for Grassland Restoration. Restoration Ecology **17**:884-892.

Young, S. L., G. B. Kyser, J. N. Barney, V. P. Claassen, and J. M. DiTomaso. 2011. The Role of Light and Soil Moisture in Plant Community Resistance to Invasion by Yellow Starthistle (*Centaurea solstitialis*). Restoration Ecology **19**:599-606.

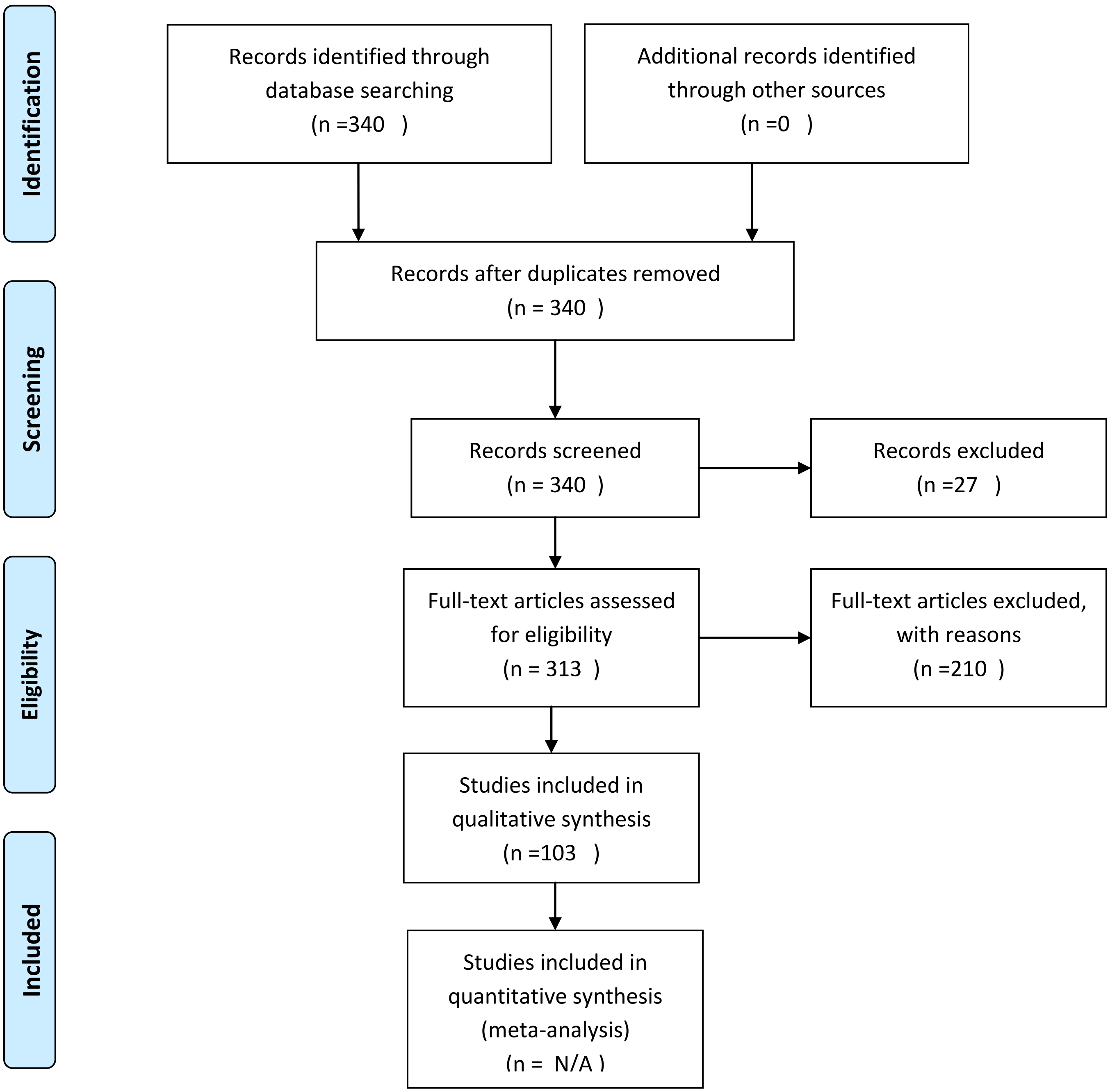
Tables and Figures

Table 1: All statistical tests were grouped into their broader groups to reduce the variation in tests and to improve the visualization of trends

Group	Statistical tests included within each group
ANOVA	ANOVA, ANCOVA, RM-ANOVA, permutated ANOVA, MANOVA, RM-MANOVA
Linear model	Regression, correlation, logistic regression, multiple linear regression,
GLM	GLM, GLMM
Ordination	PCA, CCA, NMDS, polar ordination
t-test	t-test, paired t-test
Other	Bayesian statistics, power analysis, Chi-Square, Fisher's exact test, Friedman's block test
Non-parametric	Mann-Whitney U test, Wilcoxin, Spearmann’s rank correlation

List of figures:

Figure 1:



Identification
Screening
Eligibility
Included
Records identified through database searching (n =340)
Additional records identified through other sources (n =0)
Records after duplicates removed (n = 340)
Records screened (n = 340)
Records excluded (n =27)
Full-text articles assessed for eligibility (n = 313)
Full-text articles excluded, with reasons (n =210)
Studies included in qualitative synthesis (n =103)
Studies included in quantitative synthesis (meta-analysis) (n = N/A)

Figure 2:

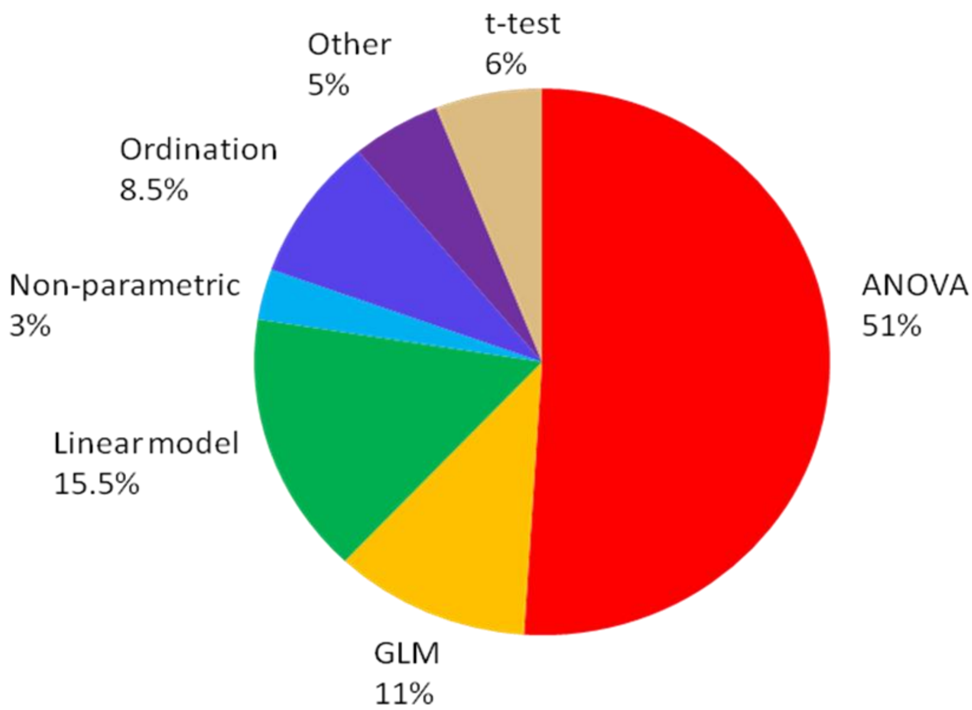
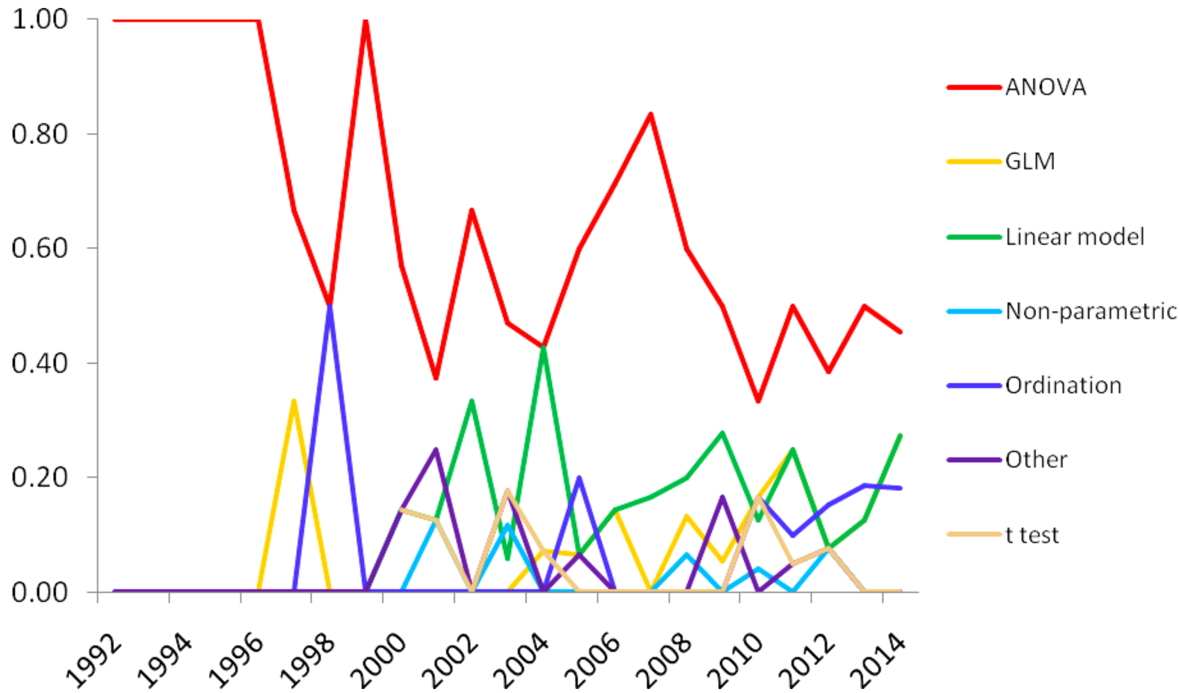
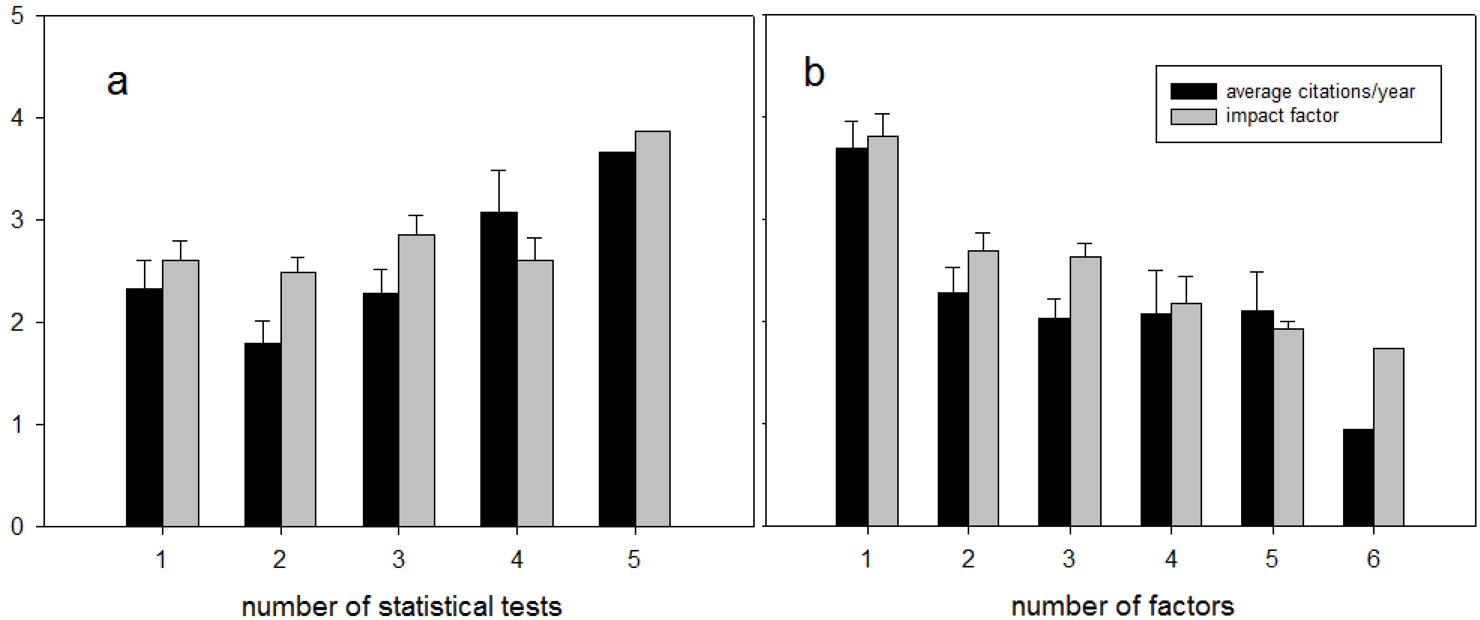

t-test
6%
Other
5%
Ordination
8.5%
Non-parametric
3%
ANOVA
51%
Linear model
15.5%
GLM
11%

Figure 3



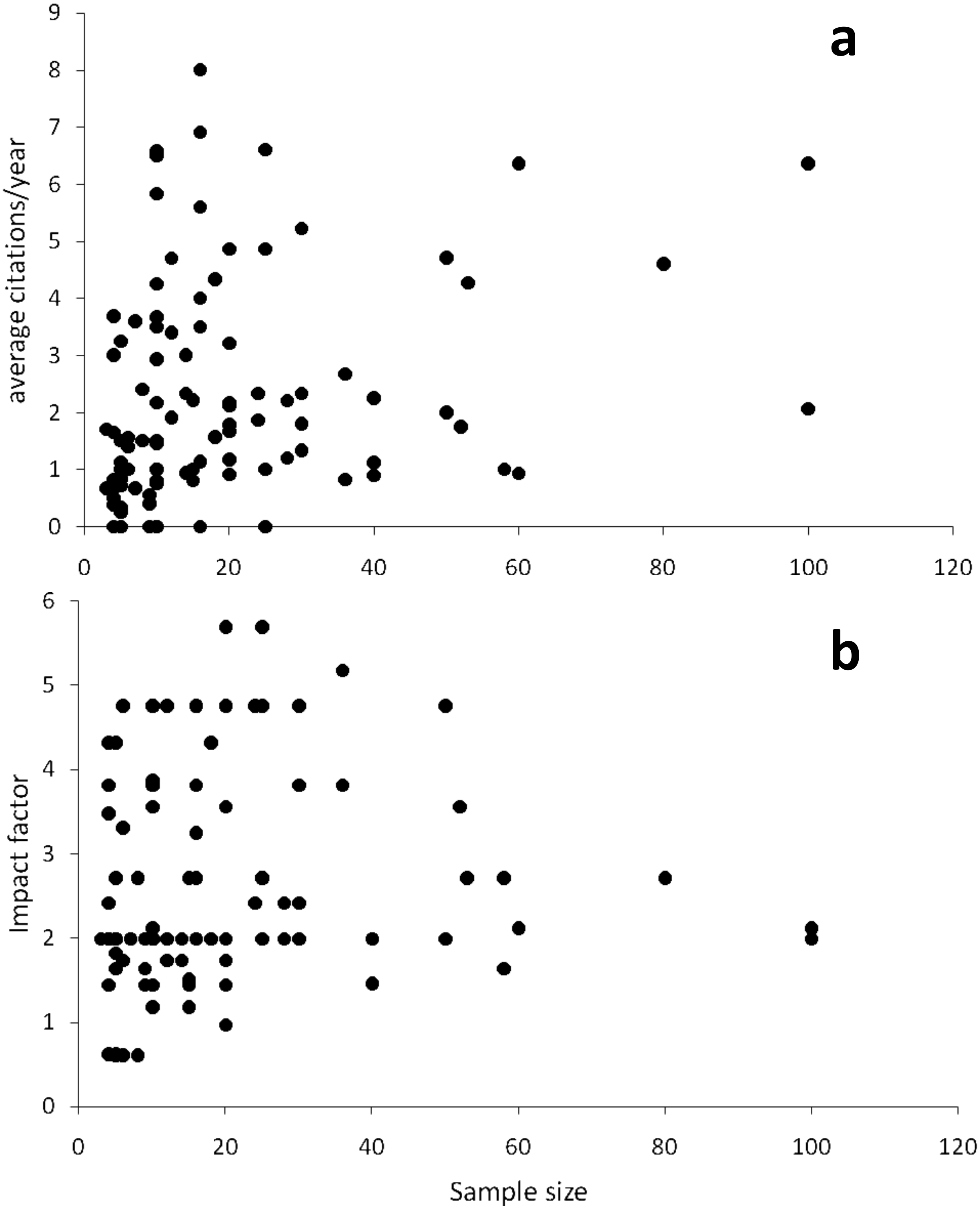
PeerJ PrePrints | http://dx.doi.org/10.7287/peerj.preprints.558v1 | CC-BY 4.0 Open Access | rec: 24 Oct 2014, publ: 24 Oct 2014

Figure 4:



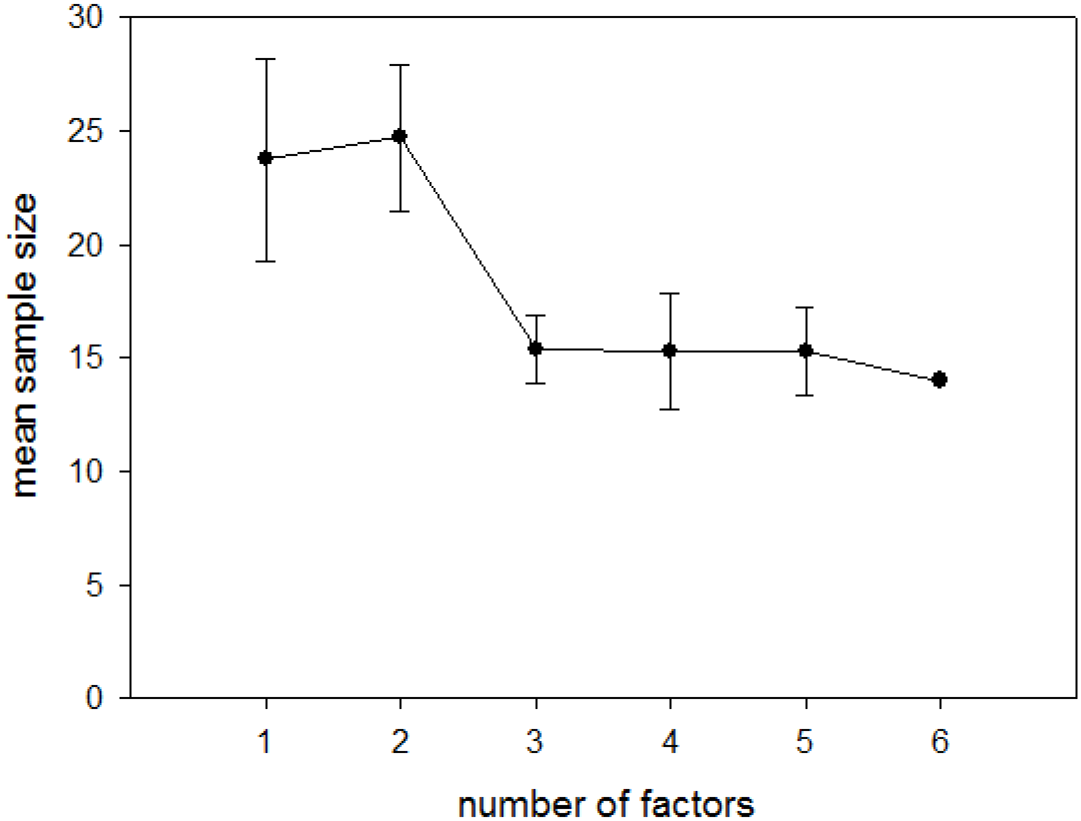
a
b
average citations/year
impact factor
0
1
2
3
4
5
1
2
3
4
5
6
number of statistical tests
number of factors

Figure 5



a
average citations/year
0
1
2
3
4
5
6
7
8
9
0
20
40
60
80
100
120
b
Impact factor
0
1
2
3
4
5
6
0
20
40
60
80
100
120
Sample size

Appendix



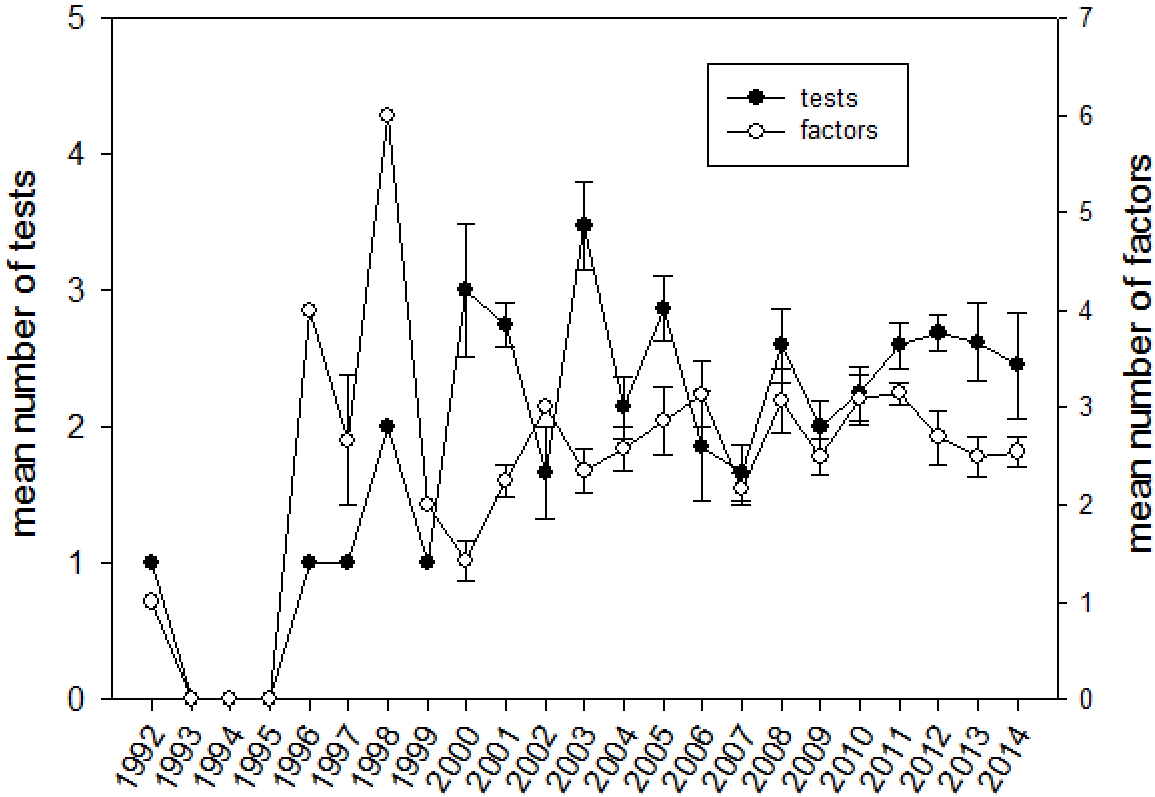
A1: The influence of the number of factors included in the experimental design on the mean sample size (per factor) for each article.

PeerJ PrePrints | http://dx.doi.org/10.7287/peerj.preprints.558v1 | CC-BY 4.0 Open Access | rec: 24 Oct 2014, publ: 24 Oct 2014

A2: The types of factors tested in the restoration of invaded grasslands. Factors were separated into five broad groupings and the restoration goals associated with each were described. Each factor within the groups as well as the frequency of each factor is listed.

Factor group	Factors included in group	Frequency
Removal technique	Mechanical removal	54
	Herbicide application	24
	Grazing	17
	Fire	10
Plant responses	Seed additions	27
	Site	24
	Species identity	11
	Functional group	6
	Plant density	4
	Competitor presence	5
	Plant age	2
Resource manipulations	Nutrient addition	16
	Water addition	7
	Light manipulation	4
	Mycorrhiza inoculation	1
Timing	Seasonal	15
	Annual	6
Soil disturbance	Soil modification	8
	Litter modification	3
	Soil depth	2

PeerJ PrePrints | http://dx.doi.org/10.7287/peerj.preprints.558v1 | CC-BY 4.0 Open Access | rec: 24 Oct 2014, publ: 24 Oct 2014



A3: The mean number of tests and factors included in studies over time (from 1992-2014)