Forest Management Efficacy Secondary Analysis

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Abstract

The purpose of this secondary analysis study was to analyze archival data on three forest management strategies (carbon addition, prescribed burning, and thinning) to assess their effectiveness in terms of increasing plant diversity. This data was previously analyzed by Clark et al. (2019) using a meta-analytic mixed effects linear regression in R. This study utilizes a nonlinear approach (decision trees) to determine if nonlinear interactions might better explain some of the differences in the effect sizes across the studies. The results of this study indicate that thinning methods were optimal, and the best results were obtained for coniferous forests in terms of species richness. These results are compared to the original meta-analysis and the limitations and recommendations for future research and practice are provided.

Introduction

Forest ecosystems provide habitats for various plant and animal species, and the quality of these ecosystems influence the degree of species diversity. A critical factor in determining the health of a forest ecosystem is the quality and the characteristics of the soil. Some of these characteristics include the degree of Nitrogen (N) deposition from the atmosphere (soil N availability) and soil acidification, which ultimately impacts plant diversity (Clark et al., 2019; Midolo et al., 2018). Given the important role that soil plays in plant diversity, identifying the optimal forest management strategy for improving soil quality is mission critical (e.g., prescribed burn, thinning, carbon additions).

Prescribed burning is a forest management strategy that helps minimize the spread of disease and pest insects, minimizes the likelihood of extreme fires by reducing hazardous fuels, kills invasive or other unwanted species that harm native species, helps endangered species by improving their habitat, helps to recycle nutrients back to the soil, and can also promote tree and plant growth (U.S Department of Agriculture, n.d.). Thinning also helps to reduce fire risk, and it helps to restore a more natural structure in terms of tree species distribution, tree density, natural gaps in canopy, and tree age distribution. Furthermore, tree reduction lessens the competition and stress in forest ecosystems that are susceptible to disease and insects (Westover, 2021). Carbon additions are hypothesized to reduce N availability to plants by causing microbial immobilization of N (Blumenthal & Russelle, 2003).

While there are numerous published studies examining the effectiveness of these forest management strategies on plant diversity, there are mixed and somewhat conflicting results regarding which forest management strategy is optimal, and how that relationship may be moderated by other factors such as habitat type and the metric used (e.g., species richness, abundance, Shannon diversity index, Simpson diversity index) for measuring plant diversity (Clark et al., 2019; Midolo et al., 2018). For example, Midolo et al. (2018) conducted a meta-analysis and found that greater annual experimental additions of N resulted in greater plant diversity declines across all metrics, though the effect size varied as a function of the experimental and environmental context. Similarly, Clark et al. (2019) conducted a meta-analysis and found that the results depended on the type of metric with positive results for species richness and negative results for the Shannon and Simpson diversity indices. However, the authors did not look at habitat type specifically.

One limitation of Clark et al. (2019) is that they used a linear model to analyze the data. Nonlinear models, such as decision trees, are more appropriate for detecting potential nonlinear relationships. A linear model assumes a linear relationship between variables, where the values of one variable consistently increase or decrease (covary) with the values of another variable. Nonlinear models do not assume that a relationship is always positive or always negative. In fact, in a nonlinear model, the relationship between two variables can be positive at one point of the scale and be negative at another point of the scale. Similarly, linear models are not always as powerful in detecting moderator effects whereby the relationship between two variables depends on the level of a third variable. For example, the relationship between prescribed burning and species diversity might depend on the type of habitat. Decision trees have been successfully implemented in conservation research (Ebrahimi, 2015).

Given the significance of conservation initiatives, it is imperative that we have high quality evaluations of their impact and results. Specifically, we need to better understand the characteristics and practices that differentiate between effective and ineffective approaches so that future efforts can be designed based on effective strategies. The purpose of this secondary analysis study was to reanalyze the data from the Clark et al. (2019) study with the following modifications: (1) analyze the Shannon index and Simpson index separately, (2) examine the specific impact of type of habitat as a potential moderator of forest management effectiveness, and (3) employ a nonlinear approach. The hypothesis to be tested via this study is that prescribed burns will yield the most consistent effects (across habitat types) and the strongest positive effects on forest biodiversity given that prescribed burns appear to be a more comprehensive and robust strategy.

Methods

Data Acquisition & Description

The data for this study was publicly available for reuse from data.world. The archival dataset was downloaded to a local computer as an Excel file, and contained meta-analysis data that was originally collected by Clark et al. (2019) for their meta-analysis focusing on the effectiveness of forest management strategies. The original dataset contained 2158 inputs (rows) relating to forest management strategies, but not all of the cases included in the spreadsheet were relevant and/or had sufficient data to be included in the analysis. For the current study, the focus was on plant diversity only. There were 154 effect sizes analyzed in the study, representing 21 different studies.

Table 1 features the number of studies and effect sizes associated with the four different forest management strategies. As indicated in Table 1, there were no studies that featured liming as a management strategy for plant diversity, and only one study (two effect sizes) that pertained to carbon additions.

Table 1

Forest Management Strategy Studies and Effect Sizes for Plant Diversity

Management Strategy	Number of Studies	Number of Effect Sizes
Carbon additions	1	2
Liming	0	0
Prescribed burning	10	66
Thinning	10	86

Data Cleaning & Preparation

The primary reasons for data removal included (1) a lack of sufficient information such as missing means, standard deviations and/or sample sizes, (2) the study was conducted prior to 1996, (3) the cases pertained to outcomes that were not affiliated with the three outcomes of interest (species richness, Shannon diversity index, and Simpson diversity index). After removing missing and non relevant data, the sample size was 154. Effect sizes were computed by dividing the two sets of means (experimental and control group) by the pooled standard deviation using Cohen’s d method (Cooper & Hedges, 1994). In the original study, the authors computed a log transformed ratio of means for soil alkalinity and plant diversity. Positive effect sizes indicate a positive effect of the management strategy while negative values indicate a negative effect.

Data Analysis

The data for this study was first descriptively analyzed to examine the univariate and multivariate distributions of the effect sizes, and to determine potential nonlinear relationships between management approach and habitat type for each of the diversity outcomes (species richness, Shannon index, and Simpson index). All data manipulations and analysis were conducted in Anaconda using a Jupyter Notebook. The dataset was read into the notebook as a csv file and converted to a Pandas Dataframe. Boxplots were used to assess the distributional characteristics for effect size. The Matplotlib and Plotly packages were used to create the charts. A decision tree model was used to analyze the data and to test the research hypothesis. To conduct the analysis and create the decision tree diagram, the researcher imported DecisionTreeRegressor from sklearn.tree and export_graphviz, and imported datasets and tree from sklearn.

Results

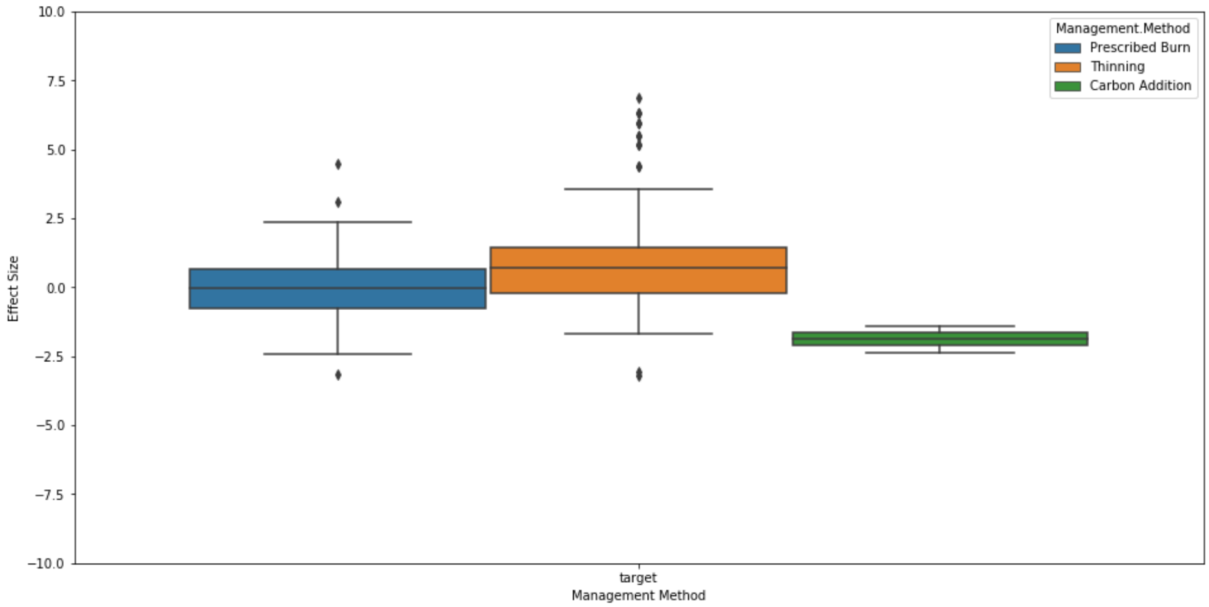
Prior to discussing the results of the current study, it is important to indicate the results that were found in the original study for comparative purposes. The results in the Clark et al. (2019) study found that carbon addition was effective at reducing soil N availability, liming was effective at increasing soil alkalinity, and prescribed burning and thinning were associated with non-significant increases in species richness, but non-significant decreases in diversity.

Descriptive Statistics

Box plots were the primary visualization to assess the distributions. Figure 1 shows that when looking at the results overall (averaged across all three diversity metrics and habitat types), thinning yielded the most favorable results. However, there is still quite a bit of variability across the studies and therefore other factors are likely playing a role in these results. It is important to note that only deciduous forests fell within the carbon addition category.

Figure 1

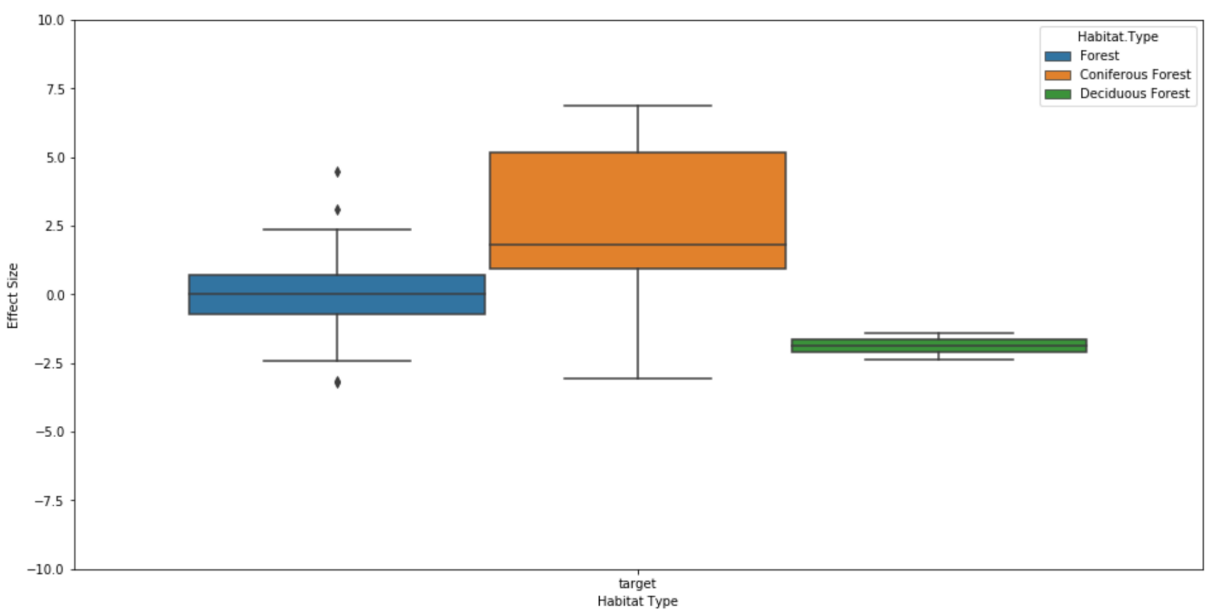
Effect Size Distributions by Management Method



The box plots by habitat type featured in Figure 2 indicate that coniferous forests had the greatest amount of variability, but also the most favorable overall results. The forest habitat category represents studies that didn't specify a specific forest type (Clark et al., 2019).

Figure 2

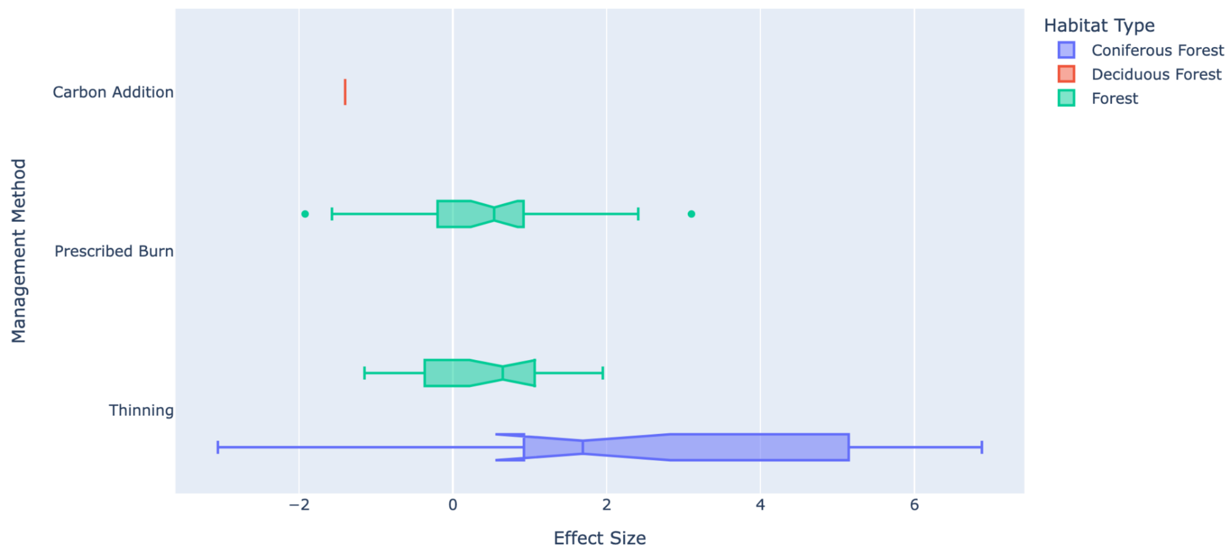
Effect Size Distributions by Habitat Type



When looking at the interaction between habitat type and management method for species richness specifically (refer to Figure 3), we see that the most variability was found for coniferous forests within the thinning management strategy, but the overall mean was greatest for thinning within that habitat type. There was only one study with deciduous forests that had data for the species richness metric.

Figure 3

Effect Size Distributions by Habitat Type & Management Method: Species Richness



The distributions for habitat type by management method for the Shannon diversity index featured in Figure 4 indicate that only studies that specified forests in the general sense had data, and the results varied greatly across studies but were mostly negative for both prescribed burn and thinning. There was one study that had a very high effect size for prescribed burn, which was quite different from the rest of the distribution.

Figure 4

Effect Size Distributions by Habitat Type and Management Method: Shannon Index

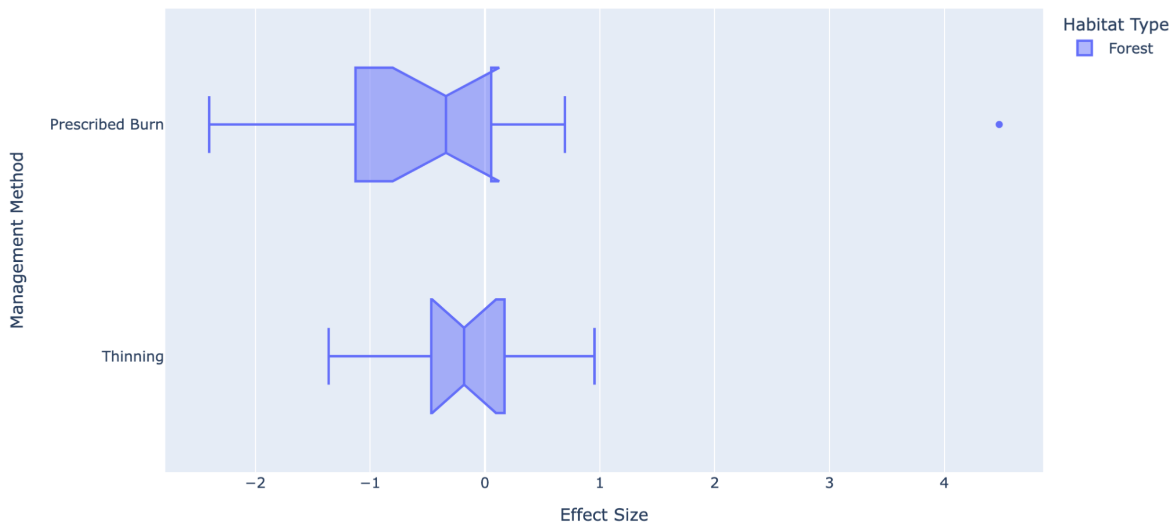
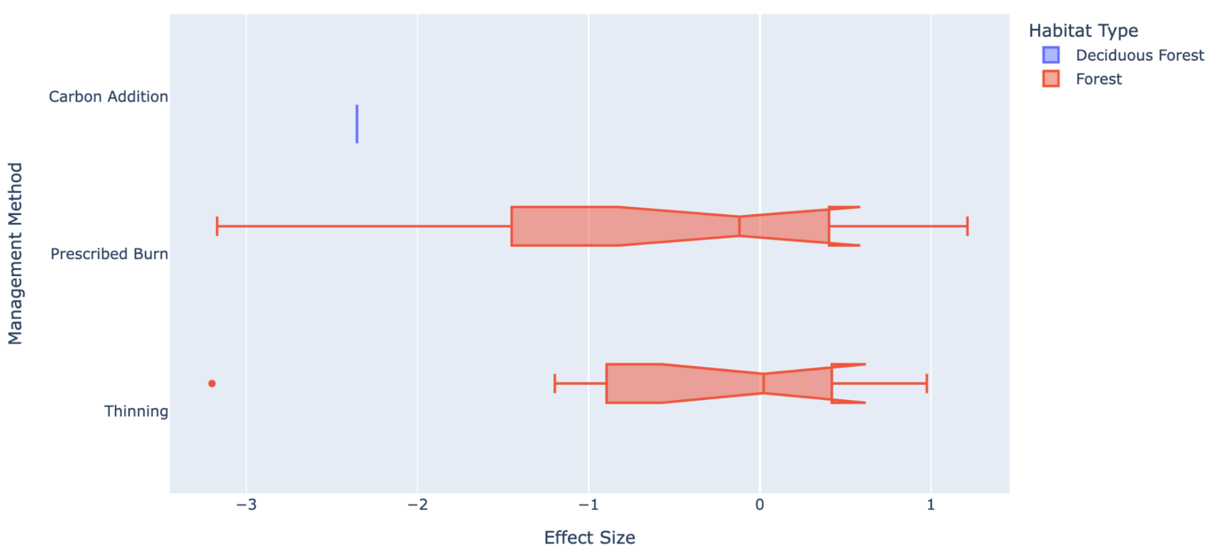


Figure 5 presents the effect size distributions by habitat type and management method based on the Simpson Index specifically. Coniferous forests were not included in this chart because there was no Simpson index data for those studies. Also, there was only one study that had an effect size estimate for carbon additions, and that was for a deciduous forest.

Figure 5

Effect Size Distributions by Habitat Type and Management Method: Simpson Index

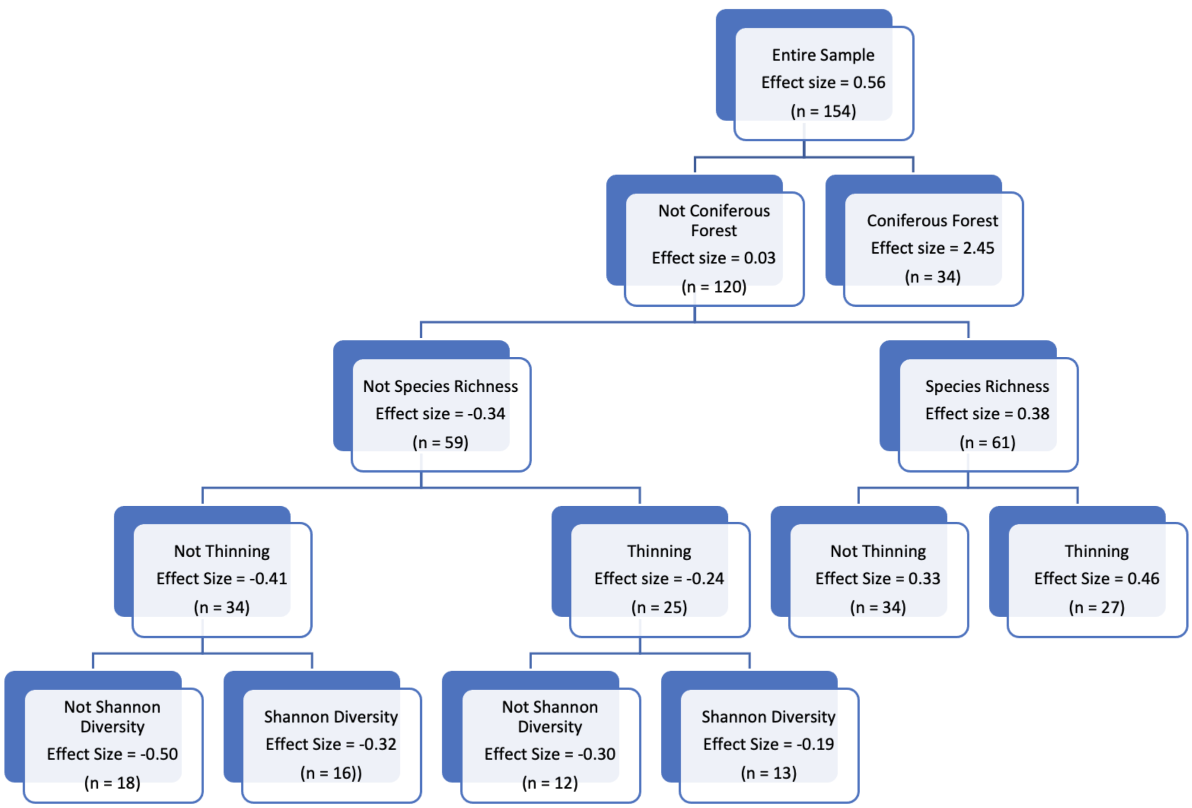


Decision Tree Results

The decision tree results presented in Figure 6 indicate that the most optimal outcomes were detected in terms of the species richness metric, and the most effective strategy was thinning, particularly within coniferous forests. The least effective results were found for the Shannon and Simpson diversity metrics, and potentially harmful outcomes were found with non-coniferous forests. The research hypothesis that prescribed burns will yield the most consistent effects (across habitat types) and the strongest positive effects on forest biodiversity is not supported.

Figure 6

Decision Tree Diagram



Discussion

The results of this study suggest that the habitat type (coniferous, deciduous, or other forest) and the metric used for determining plant diversity (species richness, Shannon diversity index, Simpson diversity index) do influence the results and therefore the conclusions made. However, the research hypothesis of prescribed burning being the most effective method was not supported. In fact, thinning yielded the most favorable results, and positive outcomes were only seen for coniferous forests. While the results of this study are relatively consistent with the findings from the original meta-analysis, this study provides additional insights regarding thinning being favored over prescribed burning, and coniferous forests being the only habitat with favorable results.

This research extends prior research, but there are still some significant limitations. For example, spatial and structural characteristics of the forests were not considered, nor was the topography of the forests. However, these characteristics are critically important when selecting forest management strategies for supporting biodiversity (Kouba, et al., 2014).

Action Component

I plan to share my findings with my colleagues, and if I have the time and resources, I will make this study more publication ready and try to publish it. I will use this research as an opportunity to communicate the need for data science in conservation, and discuss the importance of open source data for data sharing and results replication. Another possibility is to share this research with students from my local high school (Lockport High School). I could contact my son’s biology teacher and volunteer to present my study to students to generate interest in conservation science and to teach the application of data science to test hypotheses, etc.

Conclusions

The purpose of this secondary analysis study was to reanalyze the data from the Clark et al. (2019) study with the following modifications: (1) analyze the Shannon index and Simpson index separately, (2) examine the specific impact of type of habitat as a potential moderator of forest management effectiveness, and (3) employ a nonlinear approach. The results of this study indicate that positive outcomes were found for species richness, particularly within coniferous forests. Negative effects were found for the Shannon and Simpson diversity metrics, and potentially harmful outcomes were found with non-coniferous forests.

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