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# Change Point Analysis to Detect the Effect of Pruning Severity on Tree Growth

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## Abstract

The effect of pruning severity on tree growth was analyzed by change point detection using segmented regression. The present study applied this analysis to a well-known published data set including diameter growth response, tree age, pruning severity and pretreatment crown size. First, multiple regression analysis was performed to assess the effect of tree age, pruning severity and pretreatment crown size on diameter growth response. Next, segmented regression analysis was performed to assess the effect of pruning severity on diameter growth response. The results of the multiple regression showed that diameter growth response was significantly influenced by pruning severity and pretreatment crown size. The results of the segmented regression showed that in the whole data set, an abrupt change toward a decrease in diameter growth response was detected at 25% of the live crown removed. However, in the group of fully crowned and open-grown, diameter growth response continuously decreased with increasing pruning severity with no significant abrupt change, whereas in the group of 70% - 90% live crown, diameter growth response did not significantly decrease up to the break point (53% crown removed) and then abruptly decreased. This may be the first study to show the numerical evaluation of the effect of pruning severity on tree growth by change point analysis.

## Keywords

Regression Analysis, Crown Removal Limit, Tree Growth, Pretreatment, Abrupt Change

## 1. Introduction

Tree pruning aims to craft canopy structure and shape by removing and shortening branches and encouraging growth in selected areas of the crown (Gilman et al., 2006). However, there has been a long-standing controversial issue of how pruning severity affects tree growth (Clark & Matheny, 2010). Pruning can negatively affect growth through excessive intensity (Rais et al., 2020). Therefore, most pruning prescriptions are based on empirical data combining operational needs with tree growth responses (Maurin & DesRochers, 2013; Shimada, 2017) or based on previous pruning studies. For example, O'Hara (1991) has been frequently cited as a well-known review suggesting that one-third of the live crown could be pruned without serious growth impact (Robbins, 2000; Clark & Matheny, 2010; Rais et al. 2020; Suchocka et al., 2021). However, O'Hara (1991) did not show how the removal limit of one-third was estimated.

The present article proposes a change point analysis to detect the effect of pruning severity on tree growth. Regarding O'Hara's (1991) estimation, it seems plausible that there exists an abrupt change point in the relationship between pruning severity and tree growth. Therefore, the present article aims to introduce a segmented regression model as a tool of the detection of an abrupt change point (Muggeo, 2008) and apply it to the data of O'Hara (1991).

Segmented regression models (also called broken-line models) are regression models where the relationships between the response and one or more explanatory variables are piecewise linear, namely represented by two or more straight lines connected at unknown values (Muggeo, 2008). Change point analysis using segmented regression models has been rarely reported in arboriculture and its related fields except for Hilbert et al. (2022). Therefore, the use of segmented regression and the results shown here may help further studies explore the relationship between pruning severity and tree growth.

As mentioned by O'Hara (1991) as well as other studies (Pothier et al., 2013, Shimada, 2023), the growth of diameter or circumference at breast height is considered an index of tree vigor. Therefore, the present article explores the relationship between diameter growth response and other measurement variables shown in O'Hara (1991) in order to evaluate the effect of pruning severity on tree growth.

## 2. Materials and Methods

### 2.1. Data and Analysis

The data analyzed here were obtained from **Table 1** of O'Hara (1991). Some pruning severity values (% crown removed) were shown as the interval such as 15 - 35. In this case, the mid-value of the interval such as 25 was used for computational convenience.

In the following sections, a multiple regression analysis is first performed to examine the influence of the tree age, pruning severity and pretreatment crown size on diameter growth response. Next, a segmented regression model is employed to detect a change point in the relationships between pruning severity and growth response diameter.

Statistical analysis was performed using the stats, car, and segment packages in the R software (R Core Team, 2023) at a significance level of 0.05.

**Table 1.** Multiple regression analysis showing the predictors of diameter growth response.

| Variable | Regression Coefficient | SE | *t* value | df | *p* value |
|---|---|---|---|---|---|
| Pruning Severity | −0.72 | 0.08 | −8.07 | 23.1 | 0.00 |
| Age | −0.09 | 0.27 | −0.32 | 16.5 | 0.76 |
| Pretreatment Crown Size | | | | | |
| 80% Live Crown | −8.65 | 10.93 | −0.79 | 22.2 | 0.44 |
| 90% Live Crown | −5.70 | 10.07 | −0.57 | 23.1 | 0.58 |
| Fully Crowned | −13.79 | 5.74 | −2.40 | 22.3 | 0.03 |
| Open−grown | −14.91 | 7.76 | −1.92 | 22.8 | 0.07 |

### 2.2. Multiple Regression Analysis

In the multiple regression analysis, the response variable was diameter growth response, and the explanatory variables were tree age, pruning severity (percent of crown removed), and pretreatment crown size. There were missing data in the Table 1 of O'Hara (1991). Therefore, multiple imputation was used to fill in the missing data. The calculation was performed using the function mice in the mice package and the function lm in the stats package.

The variable pretreatment crown size was defined as a categorical variable The category names were derived from the Table 1 of O'Hara (1991): 70% live crown, 80% live crown, 90% live crown, fully crowned, and open-grown. The 70% live crown category served as the reference category

### 2.3. Multiple Regression Analysis

In the segmented regression analysis, the response variable was diameter growth response, and the explanatory variable was pruning severity. The analysis was performed using the function segmented in the segmented package. In order to avoid multiple values of the response variable for one value of the explanatory variable, small random numbers with the range [−0.01, 0.01] were added to the explanatory variable. The random numbers were created by the function runif in the stats package. Score test by the function pscore.test in the segmented package was also used to test for the existence of a breakpoint.

## 3. Results

### 3.1. Results of Multiple Regression Analysis

The results of the multiple regression analysis are shown in Table 1. Diameter growth response was significantly influenced by pruning severity and pretreatment crown size. In the categories of pretreatment crown size, the fully crowned category significantly influenced diameter growth response and the open-grown category was almost significant.

### 3.2. Results of Segmented Regression Analysis

First, a segmented regression was applied to all the data sets of pruning severity and diameter growth response. The results are depicted in Figure 1. A breakpoint was found at 25% crown removed and almost significantly supported by score test ($p = 0.07$). The first segmented line ($\beta = -0.25$, $0 < \text{severity} < 25$) was not significant ($p = 0.57$).

Second, based on the results of the multiple regression analysis, the data were divided into two groups regarding pretreatment crown size: one consists of fully crowned and open-grown, and the other consists of 70% live crown, 80% live crown, and 90% live crown. The results of the segmented regression are depicted in Figure 2.

In the group of fully crowned and open-grown, a breakpoint was found at 67% crown removed, but not significantly supported by score test ($p = 0.78$). The first segmented line ($\beta = -0.81$, $0 < \text{severity} < 67$) was significantly negative ($p < 0.001$) (Figure 2(a)).

On the other hand, in the group of 70% - 90% live crown, a breakpoint was found at 53% crown removed and significantly supported by score test ($p < 0.001$). The first segmented line ($\beta = -0.16$, $0 < \text{severity} < 53$) was not significant ($p = 0.14$) (Figure 2(b)).

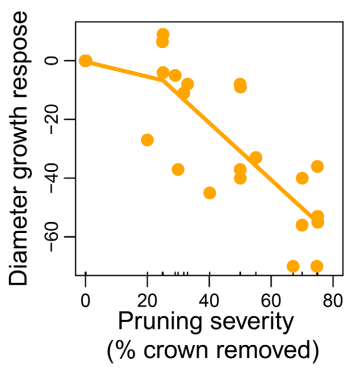


Figure 1. Segmented regression of diameter growth response on pruning severity. The data were obtained from the Table 1 of O'Hara (1991).

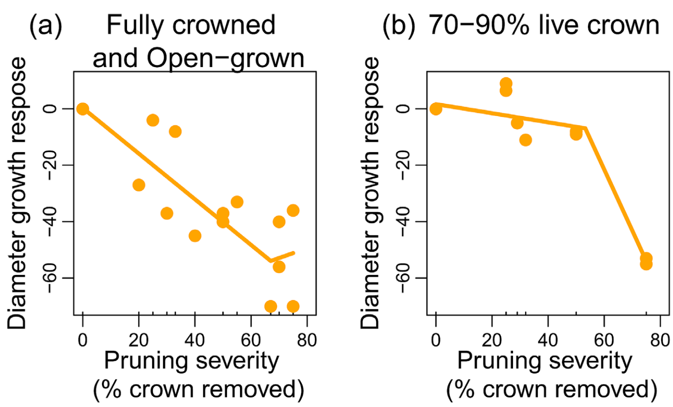


Figure 2. Segmented regression of diameter growth response on pruning severity in the two groups based on pretreatment crown size. (a) Fully crowned and open-grown and (b) 70% - 90% live crown. The data were obtained from the Table 1 of O'Hara (1991).

## 4. Discussion

Several previous studies have referred to O'Hara (1991) and explained that the removal of up to one-third, or 33% of the live crown did not noticeably reduce diameter growth (Robbins, 2000; Clark & Matheny, 2010; Kirby, 2016; Rais et al. 2020; Suchocka et al., 2021). Nevertheless, there remained the question of how the limit value of 33% was obtained by calculation.

The present study applied segmented regression to the data of O'Hara (1991) and revealed that in the whole data set, an abrupt change toward a decrease in diameter growth response was detected at 25% of the live crown removed. This value was a little smaller than the limit value of 33% estimated by O'Hara (1991) and cited by the above-mentioned studies.

O'Hara (1991) mentioned the effect of different pretreatments on tree growth, but did not take it into consideration when evaluating the crown removal limit. However, the present results revealed that the different pretreatments produced different relationships between pruning severity and growth response diameter.

In the group of fully crowned and open-grown, diameter growth response continuously decreased with increasing pruning severity with no significant abrupt change. Therefore, it seemed difficult to determine the crown removal limit. However, in the group of 70% - 90% live crown, diameter growth response did not significantly decrease up to the break point (53% crown removed) and then abruptly decreased. Consequently, the difference in pretreatments was found to have a great impact on the relationships between pruning severity and growth response diameter.

## 5. Conclusion

This article performed statistical analysis of the data of O'Hara (1991) to evaluate the effect of pruning severity on tree growth. First, the multiple regression analysis showed that diameter growth response was significantly influenced by pruning severity and pretreatment crown size. Second, the segmented regression analysis showed that in the whole data set, an abrupt change toward a decrease in diameter growth response was detected at 25% of the live crown removed. Finally, the segmented regression analysis showed different results for the two groups. In the group of fully crowned and open-grown, diameter growth response continuously decreased with increasing pruning severity with no significant abrupt change, whereas in the group of 70% - 90% live crown, diameter growth response did not significantly decrease up to the break point (53% crown removed) and then abruptly decreased.

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manuscript preparation.

## Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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