Succession forestière après feu: Où la forêt en est-elle rendue 100 ans plus tard?

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Study Information

1. Title

Succession forestière après feu : Où la forêt en est-elle rendue 100 ans plus tard?

2. Authorship

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3. Description

Natural and anthropogenic disturbances such as fire, logging and insect epidemics have a significant impact on population dynamics in forest ecosystems. These disturbances can lead to changes not only in species abundance and composition, but also in forest structure and ecosystem functions[1,2]. Secondary succession is an ecological process that can occur after a major disturbance in a forest. Plant communities recover gradually, starting with the establishment of pioneer species, mostly shade intolerant[3]. Over time, these give way to more tolerant species such as sugar maple and American beech[4,5]. This process leads to the formation of more mature and stable species communities, which eventually reach a state of equilibrium known as climax[6]. In Quebec, the territory is divided into bioclimatic domains corresponding to late-successional stands in mesic environments[7].

The study area, located on the west shore of Lac Croche at the Station de biologie des Laurentides (SBL) of the Université de Montréal, is in the bioclimatic range of the yellow birch maple stand[7]. However, it has been found that yellow birch maple stands are practically non-existent on the territory[8]. Interesting questions then arise… If the ecoforest communities are not yellow birch maple stands, what are they? What ecological processes are responsible for the composition of ecoforest communities in the study area? At what spatial scales do they operate?

4. Hypotheses

This was an exploratory study. No specific hypotheses were made *a priori*.

Design Plan

5. Study Type

- Observational Study - Data is collected from study subjects that are not randomly assigned to a treatment. This includes surveys, natural experiments, and regression discontinuity designs.

6. Blinding

- No blinding is involved in this study.

7. Is there any additional blinding in this study?

- Not applicable.

8. Study Design

During the summer of 2021, as part of Myriam Cloutier's Master's project, a student in Etienne Laliberté's Plant Functional Ecology Laboratory (LEFO), high-resolution RGB imagery was acquired by drone on several occasions over SBL. Flights were carried out every month from May to October using the *DJI Phantom 4 RTK* to obtain images showing the phenological changes in the trees throughout the season.. Then, using *Agisoft Metashape Professional* photogrammetry software[9], an orthomosaic was generated for each flight mission. During the summer of 2021, as part of the Master's project of Myriam Cloutier, a student in Etienne Laliberté's Plant Functional Ecology Laboratory (LEFO), high-resolution RGB imagery was acquired by drone on several occasions over SBL. In this software, but also for all the spatial analyses carried out afterwards, the reference datum chosen is the Canadian Spatial Reference System, NAD83 (CSRS) epoch 1997 (also known as version 2), and the projection is the Modified Transverse Mercator (MTM) for zone 8 (EPSG: 2950).

These drone flights covered around 43 hectares of forest, divided into zones 1, 2 and 3. An exhaustive tree inventory was carried out by a field team led by Myriam and three research assistants during the same summer. They geo-referenced, identified and annotated every tree reaching the canopy, and therefore visible on the orthomosaics produced. These annotations consist of tree polygons that were hand-drawn using a drawing surface and *ArcGIS Pro software*[10] to delineate tree crowns.

Figure 1 (Appendix 1) shows the various spatial components of the sampling design.

For the purposes of this project, the study area will be limited to zone 1, covering an area of around 20 hectares.

9. Randomization

- Not applicable.

Sampling Plan

10. Existing data

- Registration following analysis of the data: As of the date of submission, you have accessed and analyzed some of the data relevant to the research plan. This includes preliminary analysis of variables, calculation of descriptive statistics, and observation of data distributions. Please see cos.io/prereg for more information.

11. Explanation of existing data

Unfortunately, this pre-registration form was completed after the study. The data has therefore already been analyzed at this stage. However, I can confirm that the data had not already been explored prior to this study.

12. Data collection procedures

During the summer 2021, high-resolution RGB imagery was acquired by drone on several occasions over SBL. These drone flights covered around 43 hectares of forest, divided into zones 1, 2 and 3.

Flights were carried out every month from May to October using the *DJI Phantom 4 RTK*. Then, using *Agisoft Metashape Professional* photogrammetry software[9], an orthomosaic was generated for each flight mission.

An exhaustive tree inventory was carried out by a field team during the same summer. They geo-referenced, identified and annotated every tree reaching the canopy, and therefore visible on the orthomosaics produced. These annotations consist of tree polygons that were hand-drawn using a drawing surface and *ArcGIS Pro software*[10] to delineate tree crowns.

13. Sample size

Drone flights covered around 43 hectares of forest, divided into zones 1, 2 and 3. For this work, we only used zone 1.

In order to represent the standards of the forest plots produced during government forest inventories, the orthomosaic on which the tree polygons were plotted was cut into 20 m $\times$ 20 m plots using a grid. 402 georeferenced plots were included in the analyses, including a total of 8917 trees.

For the cluster analysis aiming to determine the number of tree communities, we plan on having between 3 to 6 clusters.

14. Sample size rationale

The area overflown by the drone during the flights was determined according to the visual limit in order to see the drone at all times during the flights. From a legal point of view, it is necessary to be able to see the drone at all times.

15. Stopping rule

- Not applicable.

Variables

16. Manipulated variables

- Not applicable.

17. Measured variables

The explanatory matrix consists of five topographic variables: topographic elevation (meters), slope (%), slope orientation (represented by degree of exposure to the east and north; radians) and topographic wetness index (quantitative; unitless). All these variables are extracted or calculated from LiDAR-derived products from the[11];[11] ecoforestry data . Initially, they were all represented using raster data, so it was necessary to extract the average of the values of these variables for each of the 20 × 20 m plots.

Elevation and topographic wetness index were extracted directly from LiDAR products, respectively from the digital terrain model (DTM) and the topographic wetness index (TWI). The slope was obtained using a *slope* function[12] applied to the DTM, then giving a slope in degrees (0-360°). Then, given that the values were all located in the first quadrant (0-90°), it was possible to report these values out of 100 to obtain a slope percentage. For the slope orientation variables, the degrees of exposure (*eastness/northness exposure*) were derived directly from the intermediate variables of east and north orientation (*eastness/northness*).

To do this, an *aspect* function[12] indicating the direction (in degrees, 0-360°) towards which the slope faces was applied to the DTM, then transformed into radians. Being a circular variable, the trigonometric transformations $sin(\theta)$ and $cos(\theta)$ were then applied to the *aspect* variable[13].

The *eastness* and *northness* variables were then calculated according to the following equations:

$$eastness = sin(aspect(mnt) * \pi/180)$$
$$northness = cos(aspect(mnt) * \pi/180)$$

These were then related to the slope in radians in order to better represent the topography of the territory[14,15].

$$pente = (slope(mnt) * \pi)/180$$

et

$$eastnessexposure = sin(pente) * eastness$$
$$northnessexposure = sin(pente) * northness$$

18. Indices

- Not applicable.

Analysis Plan

19. Statistical models

Cluster analysis into ecoforest communities

In order to separate the forest plots into communities, a cluster analysis with spatial contiguity constraint was carried out for 3, 4 and 5 groups. The list of connectivity links between forest plots was obtained by Delauney triangulation, from which links longer than 30 meters were removed to retain only side-by-side forest plot links[16]. The forest plots were then clustered using Ward's log-Chord-transformed Euclidean distance matrix.

Simple ordination (principal component analysis)

Given that the dataset is one of species abundance, principal component analysis (PCA) is appropriate for this study. The interpretation of principal component analysis in framing 1 is particularly relevant for observing the species that have contributed most to the formation of ecoforest communities. Furthermore, as with previous analyses, ordination was performed on data transformed using the log-Chord transformation to preserve distances between elements.[17,18]

Canonical ordination (redundancy analysis)

In order to relate the topographical variables to the distribution of species on the territory, a redundancy analysis (RDA), which is an asymmetrical canonical analysis, was performed on the transformed raw data (log-Chord transformation, as for PCA)[18].

First, it was necessary to select the explanatory variables in order to retain only those with a significant influence on species distribution. A forward selection was then carried out by means of a permutational test using 999 permutations.

20. Transformations

Firstly, the matrix of topographical variables was centered-reduced to make their dimensions homogeneous and, thus, enable the explanatory variables to be compared with each other.

Then, several statistical analyses, such as principal component analysis (PCA) and redundancy analysis (RDA), require that the data respect the Euclidean distance[18,19]. However, the latter is not adapted to raw abundance data, notably due to the presence of the "double zero problem". When comparing the species composition of different inventory plots, the presence of the same species on two plots suggests that they probably have similar conditions. However, when two plots have no species in common, this does not indicate a similarity between them, as this could be due to many factors other than the absence of a suitable ecological niche for that species. The Euclidean distance does not allow these double absences to be taken into account. Therefore, for species abundance data, it is often preferable to use alternative distance measures.[18,20]

Given that many measures can be used to address this problem, the data from different transformations were put in relation to the environmental variables by means of canonical ordination to determine which one explained the greatest proportion of variance. After comparing the adjusted R^2 values, the log-Chord transformation was chosen to be applied to the raw abundance data.

21. Inference criteria

The standard $p<0.05$ criteria was used to determine if the permutational tests suggested that the results were significantly different from those expected if the null hypothesis were correct. Permutational tests were performed using 999 permutations.

22. Data exclusion

In order to represent the standards of the forest plots produced during government forest inventories, the orthomosaic on which the tree polygons were plotted was cut into 20 m × 20 m plots using a grid. A selection was then made so as to retain only plots with more than 40% of their area annotated, in order to have only those that were representative of a natural forest. This operation eliminated the boundaries of the annotations, as well as a few plots crossed by hiking trails.

23. Missing data

- Not applicable.

24. Exploratory analysis

This was an exploratory study as a whole, so no section was identified as an exploratory analysis specifically.

Other

25. Other

- Not applicable.

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Appendix 1. Figures

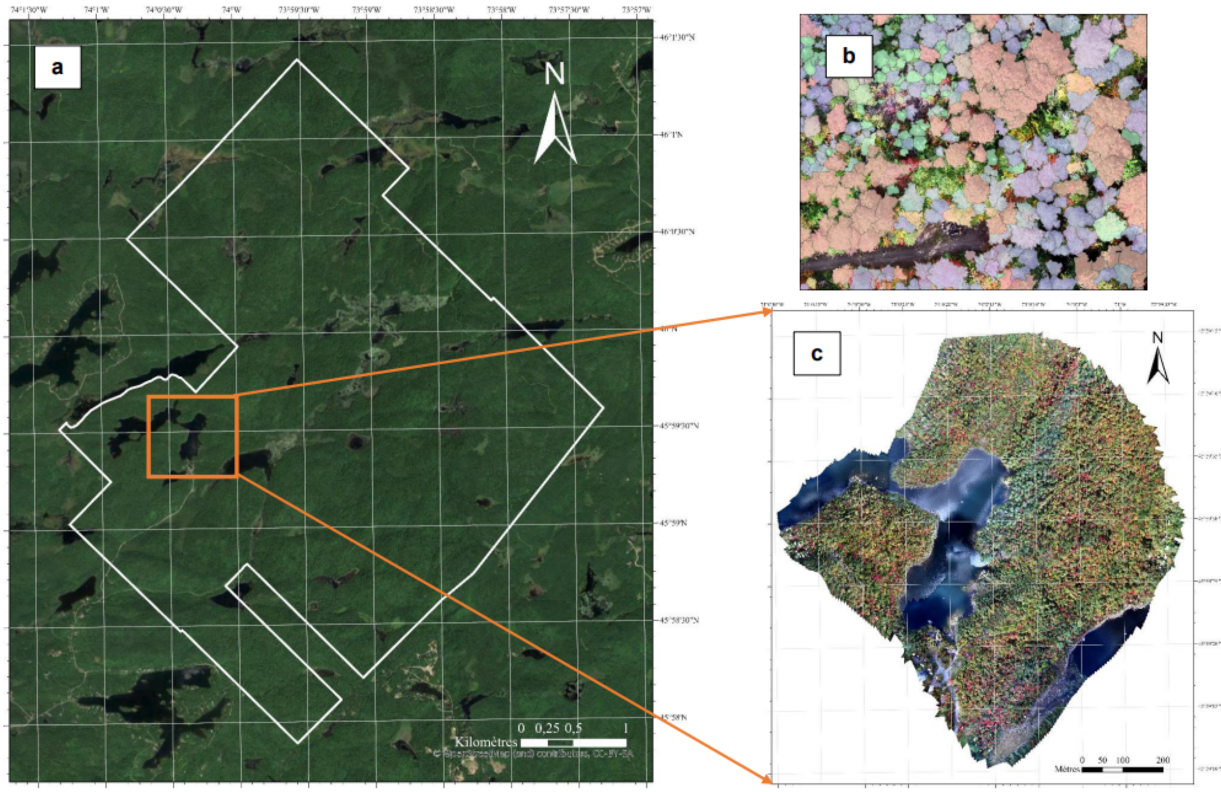

Figure 1: Location of the study area. a : Boundary map of the Station de biologie des Laurentides. The orange rectangle targets zones 1, 2 and 3. b: Map of all three zones. The brown rectangle targets zone 1. c: Part of the tree crown polygons annotated in *ArcGIS Pro*.