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# CHANGES IN FLORISTIC COMPOSITION IN THE STATE FORESTS IN WORCESTER COUNTY (MASSACHUSETTS) OVER 34 YEARS

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# CHANGES IN FLORISTIC COMPOSITION IN THE STATE FORESTS IN WORCESTER COUNTY (MASSACHUSETTS) OVER 34 YEARS

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Accepted on the recommendation of

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| Chief Instructor | Second Reader |

# ABSTRACT

## CHANGES IN FOREST DIVERSITY OF STATE FOREST IN WORCESTER COUNTY, MASSACHUSETTS, OVER 34 YEARS PERIOD

The forest in Massachusetts has changed since the earliest colonial settlement and today the floristic composition is more homogeneous. This study investigates the potential change in the floristic composition over thirty years in Worcester County State Forests. Shannon, richness and evenness indices for two periods were compared, and Jaccard index was used to analyze similarity in composition between the periods. The possible influence of severe weather events was also analyzed.

It was found Changes in the floristic composition, but the magnitude of the changes were not statistically significant. The Jaccard similarity index showed statistically significant differences between north and south. There was also, significant differences between plots that experienced insects' attack or snow/ice damage compared to plots with no pest/ice damage.

The implications of the research findings indicate that diversity of the State Forest did not present statistically significant change. Petersham presented the highest diversity, while the lower value was for North Brookfield. The similarity of the forest did not change through the time, but there is significant difference between the north and the south.

## ACADEMIC HISTORY

Name: Flor Angela Monroe                                        Date: May 2016

Baccalaureate Degree:

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## DEDICATION

To my Husband and my son

For their patience and unconditional support,

and for keeping our home warm during all the time I have been

absent, dedicated to my studies.

To my parents

For whom I have been more than far away,

lowering the connection,

but who are always in my heart.

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Besides my advisors and the DCR I want to thanks to Professor Christopher Van Atten and my fellow classmate Rubi Rojas, who initially help me with some Excel functions to process the data, and Henry Mros for helping me in acquiring and processing the main weather events information.

I also want to thanks my fellow classmate Andrea Cabrera, with whom I shared long hours of study and discussion of topics to support points of view.

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## CHAPTER 1. INTRODUCTION

Central Massachusetts has had a history of changes in land cover vegetation. Before the Europeans arrived, the territory was almost completely forested, and the colonists transformed it into an agrarian area dominated by tilled fields, pastures, and woodlots. By the mid-19$^{th}$ century the forested area was less than 40%, but the changes in economy affected the intensity in the agricultural activities, and the abandonment of farms as a result, allowed time for forest regrowth (Foster et al, 1998).

In addition to the history of land use, the area has been also affected by different natural events over the time. Some of these events were climatic (Great New England Hurricane of 1938, tornadoes, and hurricanes in 1953 and 1954, Hurricane Gloria in 1985, an ice storm in 2008, and Hurricane Sandy in 2012, among others) and others were biological such as plagues and diseases (including Elm Leaf Beetle, Gypsy Moth, Leopard Brown Mottled, Chestnut Blight, Dutch Elm disease, Emerald Ash Borer, and Asian Long Horned Beetle.

Although the appearance, composition, and function is similar to the initial forest, different studies conducted in Harvard Forest, have found that the actual forest is more homogenous that it was before to the colonist arrived and that the correlation between weather and forest composition have changed dramatically (Foster et all, 1998).

Foster et al (1998) in a study of forest dynamics in Central New England, found a shift toward a regional homogeneity in floristic composition and loss of relationship with regional climate factors. In the study they found Oak as the most abundant taxa followed by Pine in the colonial period, but in the modern period Oak was less abundant and was practically matched for Maple, which was much less abundant in the colonial period, Pine also declined in the modern period (relation of percent of taxa found for colonial and modern periods in table 1).

Table 1: Mean taxa distribution in two time periods (%)

| Specie | Colonial period | Modern period |
|---|---|---|
| Maple | 7.6 | 24.8 |
| Beech | 6.7 | 2.9 |
| Hemlock | 9.9 | 11.6 |
| Oak | 32.6 | 24.1 |
| Hickory | 2.2 | 2.0 |
| Chestnut | 7.7 | 0.6 |
| Pine | 19.9 | 15.2 |
| Birch | 3.7 | 12.3 |
| Ash | 2.9 | 2.3 |
| Cherry | 0.5 | 2.1 |
| Spruce | 1.4 | 0.6 |
| Elm | 1.0 | 0.1 |
| Poplar | 2.0 | 0.5 |
| Larch | 0.6 | 0.0 |

Source: Foster et al, 1998

The actual composition of the forest, may be homogeneous with secondary forest species (Foster et al., 1998), with the presence of species such White Pine, Aspens, Black Cherry, Oak, Hemlock, Pin Cherry, Red Maple, White Ash, Red Oak, and Birches (Foster et al., 1998; Hibbs, 1983; and Leak and Yamasaki, 2010). Given the massive forest destruction caused for the Great Hurricane of 1938 (Grossi, 2008), the age of most of the forests in Central Massachusetts is about 88 years old, and the replacement of White Pine for species of the next stage such as Hemlock, Oak, Hickory, Beech among others, may have occurred.

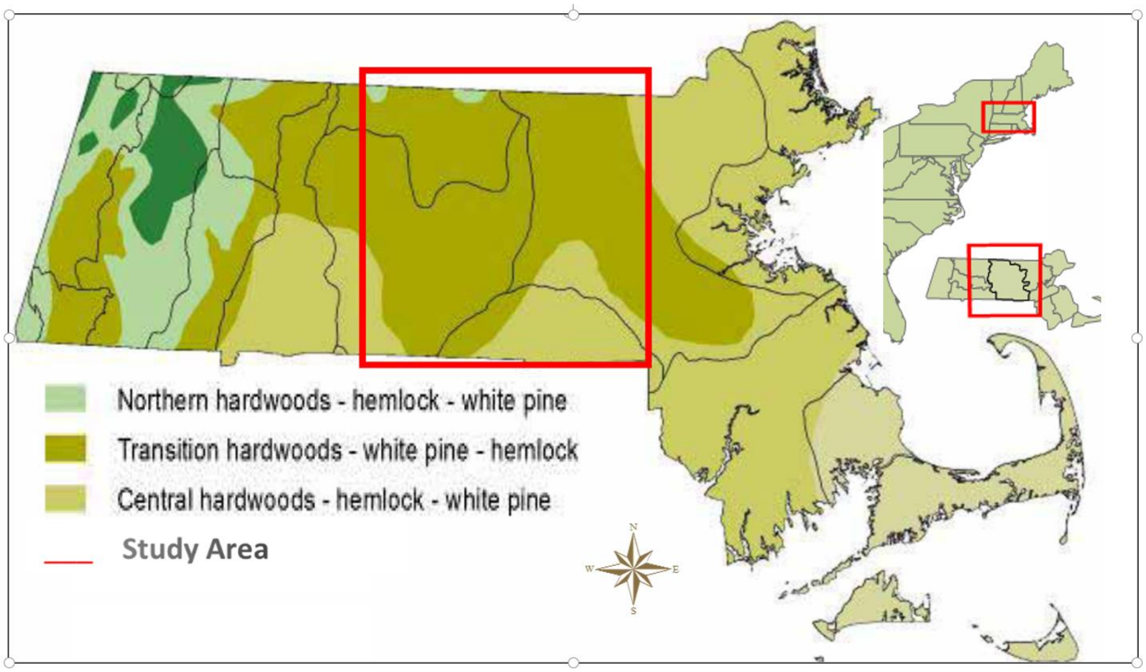
The studies showing the changes in floristic composition have analyzed the changes over long period of time and have primarily focused on northern New England, less is known about changes in forest diversity in part of Worcester County. With Worcester County as the study area, this research investigates whether over 34 years there have been changes in the floristic composition of the state forests. If so, what are the changes? Finally, I will explore if weather events have influenced those changes or if any disturbance or intervention may cause changes in diversity.

This research do not show statistically significant difference in diversity during 34 years period, but it shows significant differences between north and south of the study area. The species that showed more dynamism were White Pine, White Spruce, Hemlock, Red Maple, Northern Red Oak, and Scarlet Oak. The most important changes were the dramatic decline of White Spruce and the high increase of Northern Red Oak, along with other shade tolerant species.

## CHAPTER 2. METHODS

### 2.1 Study Area

The study area is the entirety of Worcester County in Massachusetts (Figure 1). This area represents a transition between central and northern forest types and the main type of forest is the Transition Hardwoods-White Pine-Hemlock, but there also are small areas with Central Hardwoods-Hemlock-White Pine in the southern end the study area as well as two very small areas with Northern Hardwoods-hemlock-White Pine in the north (De la Crétaz et al., 2010).




De la Crétaz (2010), courtesy of the USDA Forest Service, with modifications

Figure 1: Study area, type of forests

The soils in Worcester County tend to be acidic (with the exception of the river flood plains), and with relatively low nutrient levels (De la Crétaz, 2010). The acidity affects many soil characteristics such decreasing nutrient availability (phosphorous, magnesium, calcium, and nitrogen among others) and could limit root growth interfering the development of vegetation, and the organic matter decomposition (Umass Extension, 2011).

The winter in the study area is cold with average temperatures of 26 degrees Fahrenheit an average daily minimum of 16 degrees, and the average of snowfall of 65 inches; summer is moderately warm with occasional hot spells, with temperatures of 70 degrees, with average daily maximum of 82 degrees. The annual average precipitation is 24 inches falling between April and September (National Data Climate Service, 2015; Taylor and Hotz, 1985). Tornadoes are not common for Massachusetts but still there is an average of three tornadoes in the state each year, most of them small (National Climate Data Service, 2015). Climatic information for Worcester city, located at the center of the study region, is presented in Table 1.

Table 2: Climatic reports for Worcester City

| **Climate Variable** | **Value** |
|---|---|
| Snowfall (in.) | 55.8 |
| Precipitation Days | 120 |
| Sunny Days | 197 |
| Avg. temperature July High (F$^o$) | 81.4 |
| Avg. temperature Jan. Low (F$^o$) | 13.5 |

(Source: www.bestplaces.net)

## 2.2. Data

To analyze and compare floristic composition of the forest in Worcester County in two different periods of time, in this research I analyzed a subset of Continuous Forest Inventory Program (CFI) dataset, corresponding to the County. The CFI was instituted in 1957, starting with 93 plots established on the October Mountain State

Forest in Berkshire County. Today a total of 1760 plots have been established across Massachusetts in the State Forest, constituting the Management Forest Program under the administration of the Massachusetts Department of Conservation and Recreation (DCR) (Department of Conservation and Recreation, 2014).

The CFI dataset used for this study contains information from 127 permanent plots stablished across 20 state forests and have been monitored in two periods. The first period was through the years 1966 to 1969, and 1971 (T1) and the second period during the years 1998 to 2000 (T2). The plots have been established on a wide range of sites across Massachusetts and can also be considered to be representative of privately-owned forests characteristics (DCR, 2014)

The CFI study unit consists in a circular area with 52.7' radius (0.198 acres=801.39 $m^2$) in which all trees with 5" diameter at breast height (DBH) or greater have been measured and different data related to the tree and plot has been collected. The procedure for plot establishment as well as data collection is described in detail in the Manual for Continuous Forest Inventory Field Procedures (DCR, 2014). Information about specie, date of measurement, type of disturbance or intervention and date of occurrence, were extracted from the dataset and processed using Excel 2003 to calculate diversity and similarity indices and to realize comparisons. Information of diameter class was used to interpret recruitment for some species.

Weather events information was acquired from the National Oceanic and Atmospheric Administration (NOAA) website and consisted in a dataset with the storms occurred in North Atlantic Basin from 1966 to 2000 in format ATCF (NOAA, 2016). The information was used to extract the main weather events occurred during the study period and graphic their path to identify plots located in the influence area to determine possible disturbances caused by the tornadoes.

## 2.3. Methods of analysis

The analyzed information is a CFI subset of data of Worcester County grouped in period one (T1) years 1966 to 1969, and 1971; and period two (T2) years 1998 to 2000, with a total of 127 plots measured in both periods. With the species present and the number of individuals, I calculated the diversity indices and Jaccard index for each plot/period.

Biodiversity or biological diversity is a variety and abundance of species in a unit of study (Magurran, 2004) and could be evaluated through different measures. Changes over the time could be assessed, evaluating diversity similitude of samples in different periods of time or study units. I evaluated diversity using richness, evenness and Shannon indices, and the change through the time was evaluated using Jaccard index.

Shannon is the most popular diversity index, is design to capture both components of diversity: species richness and relative abundance or evenness

(Gotelli and Chao 2013). Shannon index value usually falls between 1.5 and 3.5, rarely surpassing 4, higher values show more diversity for the sample (Magurran, 2004). The index is calculated using the expression

$$Sh = -\sum_{i=1}^{s} P_i * \ln P_i$$

(S: number of species, i*th:* species, and $p_i$: relative abundance)

Richness is the number of species present in the study unit and give the same treatment for abundant and rare species, the more species present in a sample, the 'richer' is the sample.

Evenness is the variability in species abundance in terms of population size of each species present. A community is even if it has approximately the same number of individuals for each specie present (Magurran, 2004). The index is lower when some species have greater number of individuals than others; the value ranges from 0 to maximum 1 when all the species are present with approximately the same number of individuals. Evenness is calculated using the mathematical expression

$$Ev = -\frac{Exp(Shannon)}{Richness}$$

A community with one or two species is considered to be less diverse than one in which several different species with similar abundance are present. If both species richness and evenness increase, diversity increases (Gonzaga, 2016).

Jaccard index evaluates similarity of two samples comparing the number of species that they have in common (shared species). The index compares the number of shared species to the total number of species in the combined assemblages and is thus a comparison based on total diversity. Jaccard is calculated using the mathematical expression

$$Jaccard = \frac{\#Species\ shared}{\#Total\ of\ species}$$

The maximum value for the index is 1 when two samples share all the species, which means total similarity between them (Gotelli & Chao, 2013).

Changes in diversity through the time, were evaluated comparing the indices for each plot in period one (T1), to period two (T2); posteriorly comparisons between all plots across the study area and groups were also performed. Similarity among plots and groups across the area were evaluated comparing Jaccard index. All comparisons were realized using paired t-Test for means for two samples, with alpha equal to 0.05 (95% of confidence), assuming equal variances. Subsets with one plot, were excluded from the statistical comparisons.

The groups were conformed using different criteria such geographic location, disturbances, and interventions according to the categories of the CFI. Table 3 content the information of groups, number of plots for each one, and region of the study area in which they were located; figure 2 show plots' location.

Table 3: Groups of plots for comparisons

| Site/Group | Region | Number of plots |
|---|---|---|
| All Plots | Entire area | 127 |
| Ashburnham Park | N | 5 |
| Barre Park | C | 1 |
| Blackstone River Park | S | 1 |
| Close Tornadoes | S | 8 |
| Disturbance Snow-Ice | N | 3 |
| Douglas Park | S | 19 |
| Harvest Park | N | 9 |
| Harvest Park | C | 2 |
| Hubbardston Park | N | 7 |
| Insects | N | 2 |
| Lancaster Park | N | 1 |
| Leominster Park | N | 26 |
| North Brookfield Park | S | 1 |
| Oakham Park | C | 5 |
| Otter Park | N | 6 |
| Petersham Park | N | 2 |
| Plots Central | C | 6 |
| Plots Disturb from T1 to T2 | Entire area | 27 |
| Plots Norte | N | 47 |
| Plots Sur | S | 49 |
| Spencer Park | S | 5 |
| Stand Improvement | N | 6 |
| Stand Improvement | S | 2 |
| Sutton Park | S | 5 |
| Templeton Park | N | 6 |
| Upton Park | S | 18 |
| Wachusset Mountain Park | N | 11 |
| Wells Park | S | 4 |
| West Brookfield Park | S | 1 |
| Westminster Park | N | 1 |
| Winchendon Park | N | 2 |

N: North, C: Central, S: South

## 2.4 Weather events

The dataset for weather events was processed with ArcGIS 10.3 to obtain the event path as continuous lines crossing Worcester County. The major weather events registered for the period of study across the area, were the short lived Tornado Chris on August 21/1988 with speed of 29 m/p/h and Tornado Floyd on September 7/1999 with speed of 29 m/p/h. Figure 2 shows tornado paths as well as plots distribution according with their location. The closest plots to the tornadoes were located in the State Parks of Spencer and Wells in the south. The CFI database, does not show information indicating disturbances or effects of either tornados Chris or Floyd on the plots in their path.

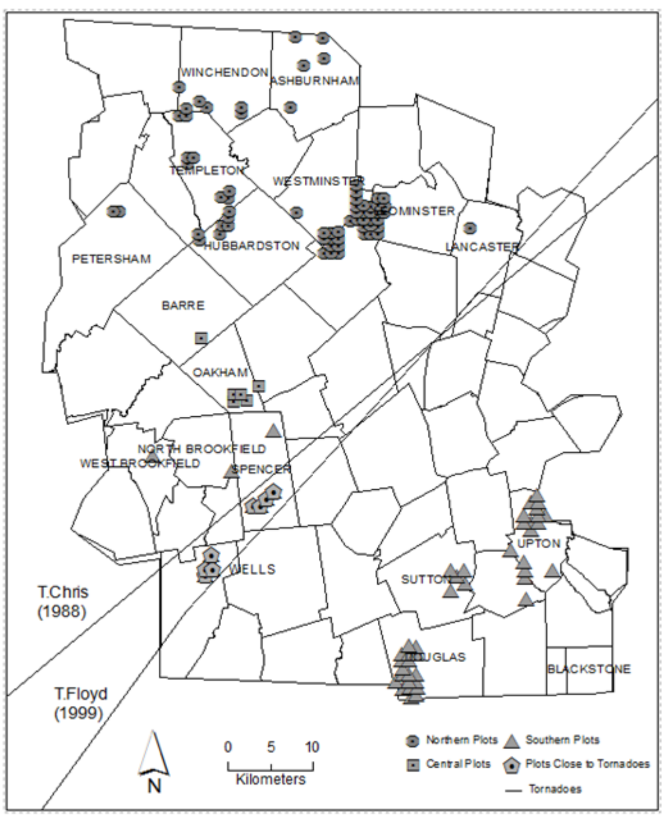


Figure 2. Tornado paths and study units

## CHAPTER 3. RESULTS AND DISCUSSION

Thirty eight species were found for the entirety county during 1966 to 2000, 32 in the north and 28 in the south (with 22 species shared), and 14 in the central area. In the first period the most abundant species were White pine, Red Maple, Black Oak, White Spruce, Northern Red Oak, Hemlock, Red Pine, White Oak and White Birch in the second period the most abundant species were Red Maple, White Pine, Northern Red Oak, Black Oak, hemlock, Red Pine, and White Oak (Comparative of number of individuals by specie by period is shown in figure 3).

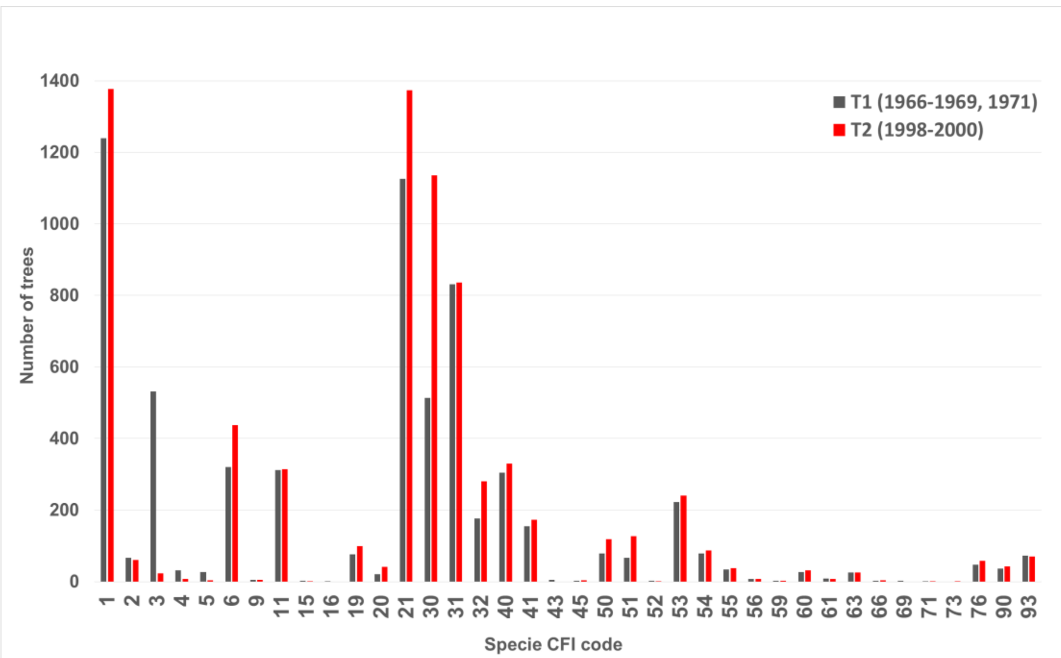



Figure 3. Number of trees by species per period

T1: period one, T2: period two, specie CFI code: 1: White pine, 2: Red spruce, 3: White spruce, 4: Others spruce, 5: Firs, 6: Hemlock, 9: Pitch pine, 11: Red pine, 15: Other pine, 16: American Larch, 19: Norway spruce, 20: Sugar maple, 21: Red Maple, 30: Northern Red Oak, 31: Black Oak, 32: Scarlet Oak, 40: White Oak, 41: Chestnut Oak, 43: White Oak Swamp, 45: Other Oak, 50: Yellow Birch, 51: Black Birch, 52: Red Birch, 53: White Birch, 54: Beech, 55: White Ash, 56: Other Ash, 59: Yellow Poplar, 60: Hickory (all), 61: Elm (all), 63: Aspen Poplar, 66: Black Gum (Tupelo), 69: Locust (all), (Tupelo), 71: Butternut, 73: Chestnut, 76: Black Cherry, 90: Other, 93: Gray Birch.

In the first period Red Maple was present in 77% of the plots, White Pine in 60%, Black Oak in 55% and Northern Red Oak in 46% (513 individuals); in the second period Red Maple continued with more presence in 81% of the plots, but this time followed by Northern Read Oak present in 78 % (1117 individuals), White Pine in 65%, Black Oak in 55%, and White Oak in 47%.  White Spruce, one of the most abundant species in the first period, present in 31% of the plots with 532 individuals, remained present just in 3% of the plots in the second period with 23 individuals.  All the species present in the study area, with number of individuals by region and frequency per period can be seen in Table 4

Other changes besides the dramatic declining of White Spruce and the considerable increase of Northern Red Oak and Red Maple; are the increase of Hemlock, and Scarlet Oak; the declining of Gray Birch, and the recruitment of one individual of Chestnut in Leominster Park.  Most of the individuals of Northern Red Oak registered in the database, basically in the north and in the south, are in the diameter class 8 (7 to 9 inches DBH), and a big number were recruited in the diameter class 6 (5 to 7 inches DBH).

White Spruce declined totally in the State parks of Otter, Ashburnham, Templeton, Westminster, Leominster and Hubbardston, all of them located at the north of the study area.  Some of the plots were intervened with harvest cut or stand improvement, but in the majority of the plots no intervention or disturbance was

Table 4: Species across the Worcester county regions with number of individuals by period

| CFI CODE | COMMON NAME | NORTH (# Trees) | | CENTRAL (# Trees) | | SOUTH (# Trees) | | FRECUENCIA (% Plots with the sp) | |
|---|---|---|---|---|---|---|---|---|---|
| | | T1 | T2 | T1 | T2 | T1 | T2 | T1 | T2 |
| 1 | White pine | 690 | 751 | 95 | 98 | 455 | 480 | 60 | 65 |
| 2 | Red spruce | 59 | 53 | | | 8 | 8 | 13 | 9 |
| 3 | White spruce | 532 | 23 | | | | | 31 | 3 |
| 4 | Others spruce | 32 | 7 | | | | | 9 | 2 |
| 5 | Firs | 27 | 4 | | | | | 7 | 2 |
| 6 | Hemlock | 266 | 353 | 31 | 50 | 23 | 34 | 28 | 29 |
| 9 | Pitch pine | 0 | 0 | 1 | 1 | 4 | 4 | 3 | 3 |
| 11 | Red pine | 304 | 306 | | | 8 | 8 | 6 | 5 |
| 15 | Other pine | 2 | 1 | | | | | 2 | 1 |
| 16 | American Larch | 1 | | | | | | 1 | 0 |
| 19 | Norway Spruce | 55 | 75 | | | 21 | 24 | 2 | 2 |
| 20 | Sugar maple | 13 | 28 | 8 | 12 | 0 | 1 | 2 | 7 |
| 21 | Red Maple | 688 | 843 | 100 | 116 | 388 | 401 | 77 | 81 |
| 30 | Northern Red Oak | 129 | 680 | 29 | 31 | 355 | 347 | 46 | 78 |
| 31 | Black Oak | 248 | 250 | 31 | 32 | 552 | 509 | 55 | 55 |
| 32 | Scarlet Oak | 0 | 1 | 3 | 3 | 174 | 273 | 20 | 22 |
| 40 | White Oak | 5 | 30 | 5 | 6 | 294 | 296 | 37 | 47 |
| 41 | Chestnut Oak | | | | | 155 | 173 | 6 | 6 |
| 43 | White Oak Swamp | | | | | 5 | 4 | 1 | 0 |
| 45 | Other Oak | | | | | 3 | 0 | 2 | 2 |
| 50 | Yellow Birch | 45 | 72 | 4 | 7 | 30 | 40 | 13 | 20 |
| 51 | Black Birch | 49 | 75 | | | 18 | 52 | 19 | 29 |
| 52 | Red Birch | 2 | 1 | | | | | 2 | 1 |
| 53 | White Birch | 214 | 224 | | 1 | 8 | 8 | 27 | 28 |
| 54 | Beech | 73 | 83 | | | 6 | 4 | 10 | 13 |
| 55 | White Ash | 28 | 29 | 3 | 1 | 3 | 3 | 13 | 13 |
| 56 | Other Ash | 7 | 7 | | | | | 1 | 1 |
| 59 | Yellow Poplar | | | | | 2 | 2 | 1 | 1 |
| 60 | Hickory (all) | 10 | 12 | | | 17 | 15 | 7 | 6 |
| 61 | Elm (all) | 3 | 1 | | | 6 | 6 | 3 | 2 |
| 63 | Aspen Poplar | 9 | 9 | | | 16 | 16 | 7 | 7 |
| 66 | Black Gum (Tupelo) | 2 | 4 | 1 | 4 | | | 2 | 2 |
| 69 | Locust (all) | | | | | 2 | | 1 | 0 |
| 71 | Butternut | | | 1 | 1 | | | 1 | 1 |
| 73 | Chestnut | 0 | 1 | | | | | 0 | 1 |
| 76 | Black Cherry | 40 | 50 | | | 7 | 6 | 18 | 20 |
| 90 | Other (unknown) | 32 | 37 | 1 | 1 | 3 | 4 | 13 | 14 |
| 93 | Gray Birch | 50 | 50 | | | 23 | 20 | 17 | 17 |
| TOTAL BY REGION/PERIOD | | 3615 | 4060 | 313 | 364 | 2586 | 2738 | | |

registered. The causes of the declining of this species are mechanical such extreme competition, crook or sweep, limbiness, flooding, and suppression.  In very few cases in addition to the mechanical loss is also registered a biological agent, but in many cases there is no report of the loss cause in the database.

The increase of Northern Red Oak occurred not only in the plots where the specie was already present, but also for the recruitment of the specie some plots in Otter, Ashburnham, Templeton, Westminster, Leominster, Barre, Spencer, and Hubbardston Parks in the second period, where, as noted above, in plots of the majority of this parks, the White Spruce disappear. Other species that increased their number, but not such a large amount as the Northern Red Oak, were Hemlock, Chestnut Oak, Yellow Birch, Beech, Sugar Maple, White Ash, and Hickory.

It is important to highlight that Northern Red Oak, Red Maple, Black Oat, White Oak, and Hemlock are shade tolerant species and White Spruce, White Pine, and Scarlet Oak are shade intolerant. So that all dynamic of declining of some shade intolerant species and increasing of shade tolerant species could be an indicator that the forest in this area is advancing to the next seral stage. The species are classified in shade intolerant or pioneer, middle shade tolerant or pre-climax and shade tolerant or climax, depending on how tolerant they are to the sunlight and in which stage of the succession they thrive (Cline, 1942).

Figure 4 shows the percent of participation in the share of species for characteristics species in different stages, according with Cline (1942) reports.  The graphic represents the percent of participation of the top nine tolerant species, one

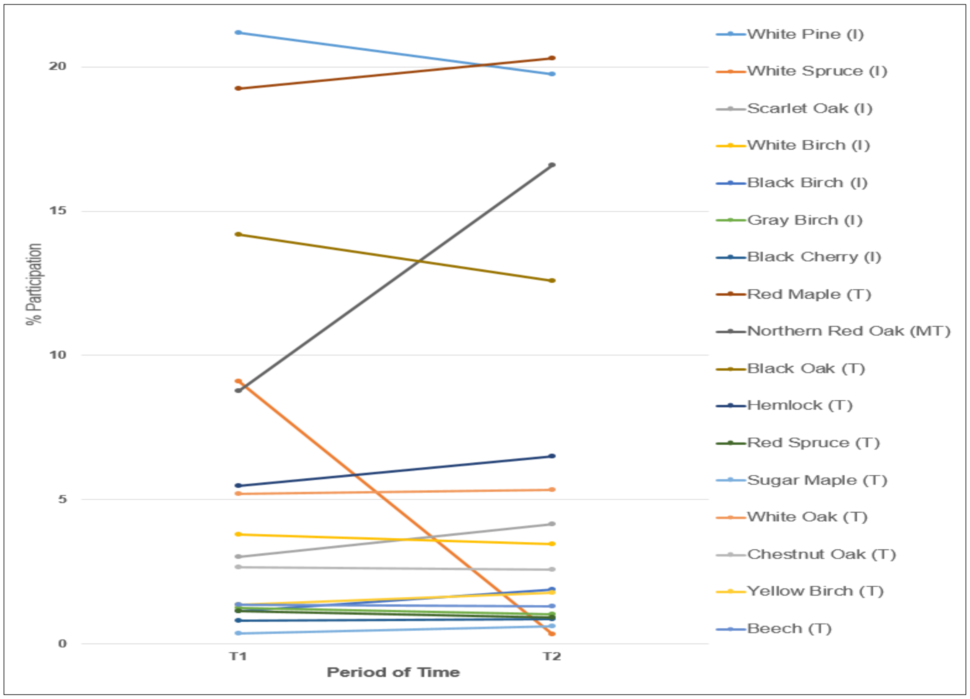



Figure 4. Participation in the share of species and change over the time for some species
I: shade intolerant, MT: middle shade tolerant, T: shade tolerant.

middle tolerant, and seven intolerant species, and the change over the period of study. The figure shows less participation in the second period for some intolerant species (or pioneer) such White Pine (despite being the most numerous specie), White spruce (the biggest loser), and White Birch. It also shows more participation for the middle tolerant (pre-climax) specie Northern Red Oak with the biggest increase for the period, as well as the increase for tolerant (climax) species such Red Maple, White Oak, Yellow Birch, Hemlock (the most aggressive climax specie according with Cline, 1942), and in lesser amount Sugar Maple, the latter one of the most late successional species in the North American Deciduous Forest according with Connell and Slayter (1977).

Figure 4 allows to see the rapid increasing of Northern Red Oak and also the slightly increased in participation of Red Maple, both species shade tolerant. These two species constitute the highest percentage of participation in the total share of species. This dynamic showing more participation of shade-tolerant species, allow us to infer that the forests of these areas could be advancing to a next seral stage.

White pine, shade intolerant specie, has some degree of tolerance to shade conditions and for that reason remain in the forest for longer periods, surviving other pioneers species. Leak et al. (1995) refer that this specie can endure partial shade, regenerating under partial overstories or very small openings, and Cline (1942) considered White Pine a pre-climax specie, persisting until shortly before the climax.

The average Shannon index as well as richness and evenness indices for parks and groups and the statistics for comparisons between periods, can be observed on table 5. The maximum Shannon index values was obtained in Douglas State Park with value of 2.1 in both periods, the plot had 54 individuals distributed in 11 species in the first period and 58 individuals distributed in 12 species in the second period. With the average of plots value per parks, the maximum Shannon value occurred in Petersham State Park with 1.81 in the first period and 1.89 in the second distributed in 11 species. According with Magurran (2004), who state that the index could range from 1.5 to 3.5 rarely surpassing 4, with higher index value representing more diversity; the conclusion is that the values obtained in this study indicate low diversity.

Table 5. Diversity, Jaccard Indices and Statistics for comparisons over the time

| SITE/GROUP | INDEX/STATISTIC | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | SHANNON (Mean) | | | | RICHNESS (Mean) | | | | EVENNESS (Mean) | | | | JACCARD |
| | T1 | T2 | t | p | T1 | T2 | t | p | T1 | T2 | t | p | Average |
| All Plots | 1.14 | 1.23 | -1.59 | 0.11 | 5.64 | 5.99 | -1.38 | 0.17 | 0.63 | 0.63 | 0.03 | 0.98 | 0.79 |
| Plots Norte | 1.18 | 1.26 | -0.93 | 0.35 | 5.91 | 6.25 | -0.90 | 0.37 | 0.63 | 0.62 | 0.28 | 0.78 | 0.69 |
| Plots Central | 1.07 | 1.18 | -0.41 | 0.69 | 5.00 | 5.50 | -0.45 | 0.66 | 0.70 | 0.62 | 1.01 | 0.34 | 0.85 |
| Plots Sur | 1.10 | 1.21 | -1.27 | 0.21 | 5.37 | 5.72 | -1.01 | 0.32 | 0.62 | 0.64 | -0.63 | 0.53 | 0.91 |
| All Plots Disturb T1-T2 | 1.17 | 1.26 | -0.99 | 0.33 | 5.78 | 6.37 | -1.37 | 0.18 | 0.59 | 0.59 | 0.17 | 0.86 | 0.76 |
| Disturbance Snow-Ice (N) | 1.33 | 1.32 | 0.05 | 0.96 | 5.67 | 5.67 | 0.00 | 1.00 | 0.67 | 0.67 | 0.06 | 0.96 | 1.00 |
| Insects (N) | 1.01 | 1.32 | -3.22 | 0.08 | 7.50 | 7.50 | 0.00 | 1.00 | 0.37 | 0.56 | -1.01 | 0.42 | 0.75 |
| Stand Improvement (N) | 0.95 | 1.06 | -0.44 | 0.67 | 5.33 | 6.33 | -1.15 | 0.28 | 0.51 | 0.48 | 0.43 | 0.68 | 0.63 |
| Stand Improvement (S) | 1.10 | 1.17 | 0.30 | 0.79 | 5.00 | 5.50 | -1.00 | 0.42 | 0.61 | 0.59 | 0.28 | 0.80 | 0.92 |
| Harvest (N) | 1.22 | 1.34 | -0.70 | 0.50 | 5.78 | 6.78 | -1.12 | 0.28 | 0.63 | 0.60 | 0.46 | 0.65 | 0.67 |
| Harvest ( C) | 1.38 | 1.39 | -0.05 | 0.96 | 6.00 | 6.00 | 0.00 | 1.00 | 0.67 | 0.68 | -0.18 | 0.87 | 1.00 |
| Otter Park | 0.97 | 0.95 | 0.07 | 0.48 | 4.80 | 4.60 | 0.10 | 0.46 | 0.75 | 0.75 | 0.01 | 0.49 | 0.74 |
| Winchedon | 1.32 | 1.51 | -0.44 | 0.35 | 8.00 | 6.50 | 1.00 | 0.21 | 0.50 | 0.72 | -1.12 | 0.19 | 0.90 |
| Ashburnham | 0.97 | 0.96 | 0.12 | 0.50 | 5.60 | 5.60 | 0.00 | 0.50 | 0.51 | 0.50 | 0.07 | 0.47 | 0.83 |
| Templeton | 1.01 | 1.09 | -0.28 | 0.39 | 6.67 | 7.17 | -0.30 | 0.38 | 0.45 | 0.46 | -0.12 | 0.46 | 0.68 |
| Westminster | 1.10 | 1.57 | x | x | 7.00 | 9.00 | x | x | 0.43 | 0.53 | x | x | 0.78 |
| Lancaster | 0.79 | 0.82 | x | x | 5.00 | 5.00 | x | x | 0.44 | 0.45 | x | x | 1.00 |
| Petersham | 1.81 | 1.83 | -0.12 | 0.46 | 8.50 | 8.50 | 0.00 | 0.50 | 0.72 | 0.74 | -0.27 | 0.41 | 1.00 |
| Hubbardston | 1.41 | 1.43 | -0.16 | 0.44 | 6.86 | 7.00 | -0.11 | 0.46 | 0.64 | 0.64 | 0.01 | 0.50 | 0.66 |
| Oakham | 1.28 | 1.29 | -0.36 | 0.74 | 5.80 | 5.60 | 1.00 | 0.37 | 0.64 | 0.67 | -0.91 | 0.41 | 0.98 |
| Barre | 0.00 | 0.62 | x | x | 1.00 | 5.00 | x | x | 1.00 | 0.37 | x | x | 0.20 |
| North Brookfield | 0.29 | 0.29 | x | x | 3.00 | 3.00 | x | x | 0.45 | 0.45 | x | x | 1.00 |
| West Brookfield | 1.58 | 1.65 | x | x | 8.00 | 8.00 | x | x | 0.61 | 0.65 | x | x | 1.00 |
| Spencer | 1.26 | 1.29 | -0.15 | 0.89 | 6.40 | 6.60 | -0.14 | 0.89 | 0.59 | 0.60 | -0.11 | 0.92 | 0.92 |
| Blackstone River | 1.47 | 1.47 | x | x | 6.00 | 6.00 | x | x | 0.72 | 0.72 | x | x | 0.50 |
| Sutton | 1.14 | 1.22 | -0.24 | 0.82 | 5.80 | 5.80 | 0.00 | 1.00 | 0.57 | 0.63 | -0.63 | 0.55 | 1.00 |
| Douglas | 1.04 | 1.20 | -1.06 | 0.30 | 5.05 | 5.63 | -0.89 | 0.38 | 0.63 | 0.65 | -0.26 | 0.89 | 0.84 |
| Wachusset Mtn | 1.36 | 1.40 | -0.29 | 0.78 | 5.91 | 6.18 | -0.60 | 0.55 | 0.69 | 0.68 | 0.16 | 0.88 | 0.91 |
| Wells | 1.16 | 1.23 | -0.30 | 0.78 | 5.00 | 5.00 | 0.00 | 1.00 | 0.65 | 0.70 | -0.54 | 0.61 | 1.00 |
| Leominster | 1.17 | 1.29 | -1.04 | 0.31 | 5.58 | 6.23 | -1.09 | 0.28 | 0.65 | 0.63 | 0.52 | 0.61 | 0.51 |
| Upton | 1.10 | 1.20 | -0.73 | 0.47 | 5.33 | 5.72 | -0.70 | 0.49 | 0.62 | 0.63 | -0.17 | 0.86 | 0.93 |
| Close Tornadoes | 1.17 | 1.24 | -0.38 | 0.71 | 5.50 | 5.62 | -0.14 | 0.89 | 0.62 | 0.66 | -0.58 | 0.57 | 0.95 |

Comparable with the highest value in this study, extreme low diversity was reported by Ostertag et al. (2014) in a study for two tropical forest in Hawaii, areas in which the Shannon index values found were 1.98 in Montane Wet Forest and 1.15 in Lowland Dry Forest, with 21 and 15 species respectively. Greatest diversity indices have been found in other areas, such in tropical forests in Brazil, where Gris et al (2013), found indices of 2.71 in Iguacu National Park and 3.37 in an area heavily disturbed; with 58 and 70 species respectively.

The park less diverse in the first period was Barre with the lowest Shannon index ("0") and the presence of 50 individuals of one specie; in the second period North Brookfield at the south, presented the lowest value. Ashburnham, Templeton, Sutton, Douglas and Lancaster State Parks maintained an index value close to 1, Winchendon, Leominster, Oakham, Spencer, Wells, and Upton presented an average index close to 1.3. The average for Hubbardston and Wachusett Mountain, as well as Blackstone River, was close to 1.4, and West Brookfield had and average value of 1.6.

Most of the parks did not change the Shannon Diversity value between periods, but Winchendon and Westminster Parks in the north, and Barre in the center, increased the index value from the first to the second period due to a recruitment of more species. The statistical comparison of Shannon index between periods was not significant.

In relation with the study units with some disturbance, three of them located in Wachusett Mountain State Park with snow/ice events, did not change their Shannon diversity value between periods; two plots that suffered, insect attack, located in Winchendon and Leominster State Parks, increased their Shannon index in period two, but not statistically significate. In these parks important events occurred such recruitment of White Pine, Northern Red Oak, and White Oak, and Scarlet Oak (in one plot) and increase of number of individuals of Red Maple and Black Birch (in other plots.

The richness express the diversity in term of number of species in the unit area, as more species found, the richer is the area. In this study the richest plot was located in Hubbardston park with 12 species. Nevertheless, averaging the richness values within a park, the highest value was for Petersham with 8.5, followed by West Brookfield with richness equal to 8 in the first period and in the second period the richer parks were Hubbardston with 9 and Petersham with 8.5 species. Not statistical significant differences were found for plots, parks or groups between the two periods (see table 5).

Evenness indicates the diversity in terms of distribution of the species (number of individuals by specie), the study area is more even, expressed in values close to the unit, when each specie is represented by approximately the same number of individuals (Magurran, 2004). In the study area the maximum possible value of one for evenness, was presented in five plots in the first period three of them located in Douglas, Oakham, Hubbardston, Leomisnter and Templeton Parks; in the second period just one plot in Otter Park reached the unit.  At park level, the most even in the first period was Barre Park and Otter Park in the second period. The lowest evenness indices were for Lancaster in the first period and Barre in the second period.

Despite that the evennes index for Barre in the first period reached the maximum evenness index value, is important to notice that in the same period its Shannon index was cero, so the evenness index reflected the fact that all the individuals in the park were just one specie.

Graphic representation for Shannon, richness and evenness indices for the state parks can be seen on figure 5 in which slightly changes between the periods can be observved. In this graphic is possible to observe Barre State Park values and how its floristic composition changing from one specie in the first period to 5 species in the second period, is reflected in Shannon and evenness values. Other visible changes observed in the graphic are the increase in indices values for Winchendon and Westminter Parks in the second period

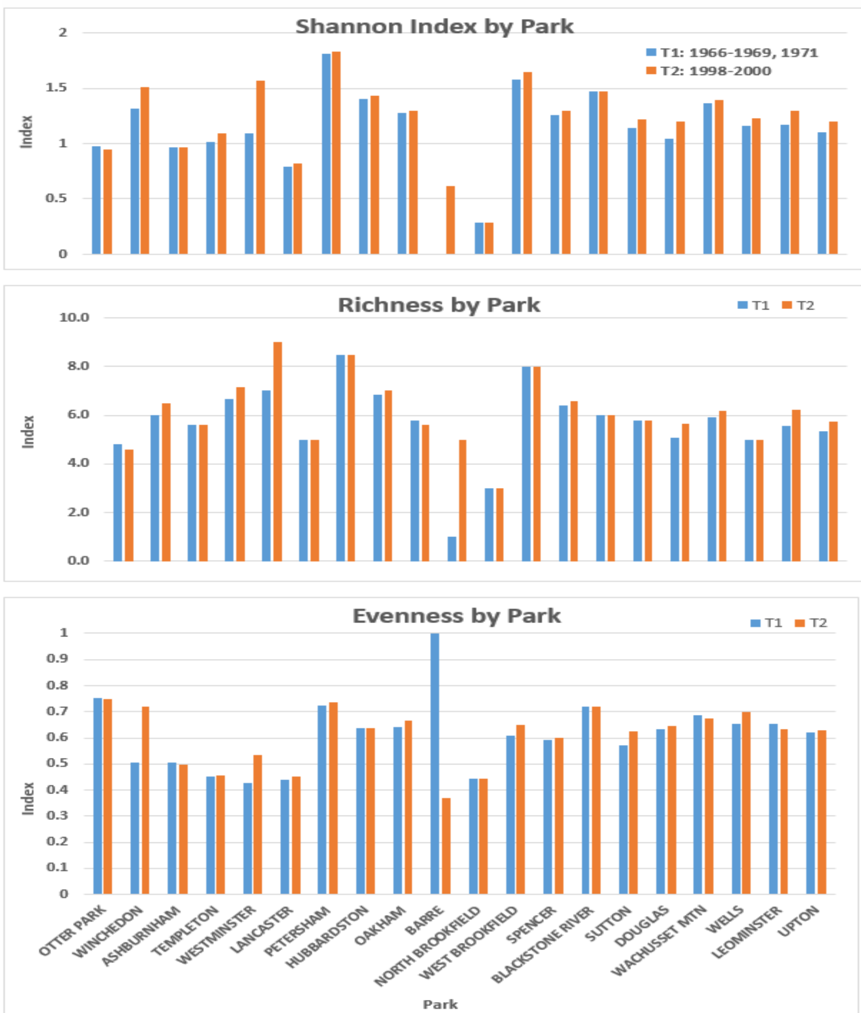


Figure 5. Diversity Indices by Park

But despite that statistically significant difference in diversity were no found within the plots, parks or region, visible differences in number of individuals and species could be observed and the significant increase and in some cases recruitment of shade tolerant species as well as shade intolerant species are evidence of the dynamic of the forest, especially in the northern region of the county.

The changes of diversity indices over the time and across the area, were no statistical significant, which give the idea of similar composition for both periods, and in the whole county, despite of all the changes explained above. Since Shannon, richness and evenness use number of species and do not consider the changes in floristic composition, I used Jaccard index to evaluate the resemblance of the study units comparing the species composition, both throughout the time and across the area.

Jaccard use the number of species present in each period and define the number of species shared to determine the similarity between samples; the maximum value the index can reach is 1, when the species present in both samples are the same, and is lower when the floristic composition change between samples and the number of species shared is lower. With Jaccard the comparison can be done between units of study in different location or the same unit in different periods of time.

Jaccard indices for parks and groups were usually high, indicating that the species were shared over the time, and therefore it was not significant change in composition between periods of measurement. Values of Jaccard index can be seen in table 5 and graphic representation of Jaccard index distribution over the area by groups in Figure 6.

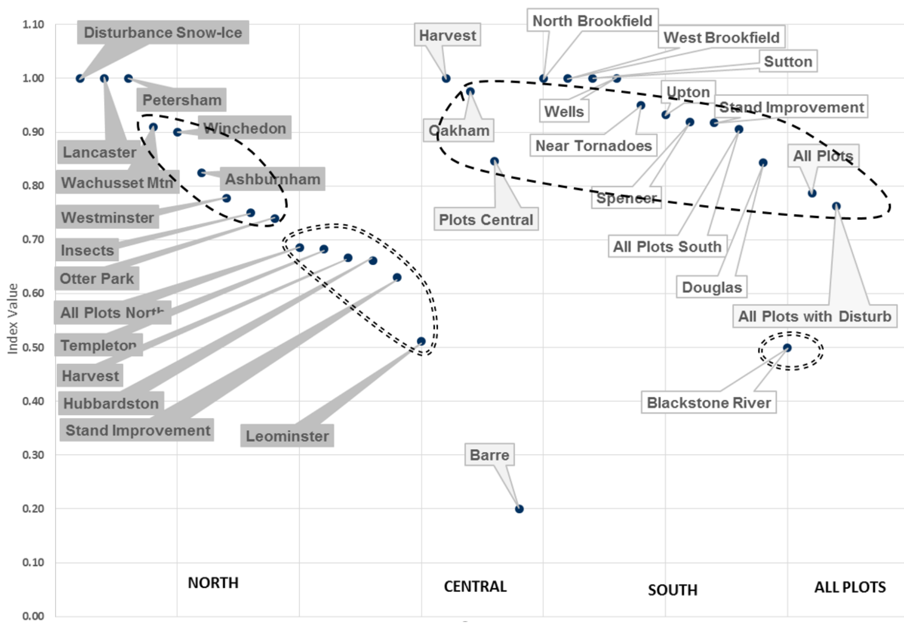



Figure 6. Jaccard value for parks and groups
Dark grey: North, Light grey: Central, Lightest grey: all plots, white: South

The figure shows several groups with the maximum value of Jaccard index indicating total similarity (or not changes) between periods. The majority of the groups (single dashes clouds) have values over 0.7 indicating not total similarity but some changes in the composition. Capers, in a study of submerged plant community in Whalebone Cove (wetland close to Connecticut River) found Jaccard index mostly over 0.8 and he concluded that the composition was stable, “reflected by high community similarity scores, especially on the Jaccard index”.

Some groups in the north and just one in the south presented index below 0.7 but greater than 0.5 (double dashes cloud) which indicates less similarity across the time that the group with index over 0.7. The average for the group “All Plots north” a little lower that 0.7, should be reflecting the low index values for some of the groups in that area.

Figure 6 shows less changes over the time for the southern and central study units with index values for most of the groups over 0.75, while the north of the county with several plots with values between 0.5 and 0.7, allow to infer greater dynamic. The biggest changes seem to have occurred in the State Parks of Barre, Blackstone River and Leominster.

Barre was the only State Park with Jaccard index very low (0.2), indicating change in similarity between periods of measure. It was no possible to realize statistical comparison because of the unit size (one plot), but it happened a big change in diversity from period one to period two.

Values of Jaccard index found in this study are comparable with values obtained by Dolan et al. (2015) in two peri-urban preserves in Central Indiana during ten years period monitoring herbaceous. They found Jaccard values of 0.56 and 0.43 and they did not find statistical significant changes in diversity during the period of study. Holland (1978) found similar results in mature deciduous forest in Quebec from 1969 to 1976, monitoring trees, shrubs, grass, ferns, herbs, and bulb plants, he found that mean number of species remained virtually constant per study unit. Both researches showed no changes in number of species but in species composition, concluding that species turnover had occurred in the study areas, concept defined as biotic changes or species replacement during the time, by Magurran (2004).

Figure 7 show a closer look in the State Parks of Barre, Blackstone River and Leominster, I have included Templeton, which is the last state park with index below 0.7. In the graphic is possible to see that the majority of the plots with value below 0.5 in the north are located in Leominster Park. Some of these plots were harvested, but in the majority of them, the change is due to the declining of White Spruce and the recruitment of Northern Red Oak, even in one of the plots, White Oak and Beech were also recruited. This dynamic could evidence species replacement during the time. This topic also is treated by Mac Donald et al. (2005) who reports that zones with abrupt change in species composition may coincide with high species turnover, and in this case, the area of study lies in the transition zone of Central and Northern forest types.

The diversity change in Leominster Park as measure for Shannon, richness and evenness is not significant statistically, because the mathematical expressions to calculate the indices take in account the number of species, and do not consider the floristic composition, aspect noticed by Jaccard index which analyze what are the species present in each study unit.

Some of the plots lowering the Jaccard index for the state parks of Otter, Templeton, Blackstone River and Barre were harvested or intervened for stand improvement during the period of study, but in Barre occurred also recruitment of new species (Red Maple, Northern Red Oak, Yellow Birch, and White Birch).

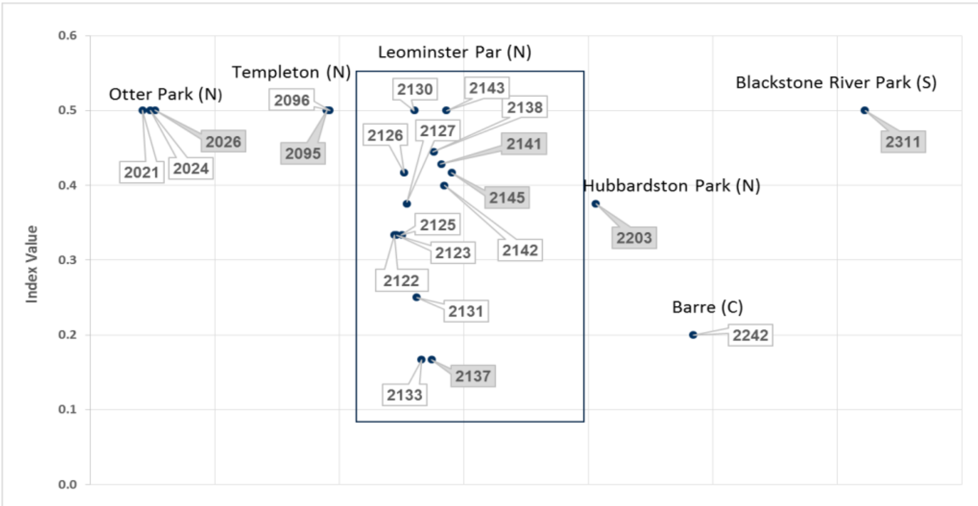


Figure 7. Study Units with lowest Jaccard Index values
Dark grey: intervention/disturbance

As said before, statistical comparison in diversity over the were not significant as measure for Shannon, richness and evenness. With Jaccard index I realized statistical comparison between the groups to analyze similarity throughout the study area. The statistics for the comparison are summarize in table 6.

With Jaccard index statistically significant differences were found between north and south, between plots that experienced insect attack and snow/ice damage and with them and plots with no disturbance, among others.

The closest plots to the tornadoes were located in the State Parks of Spencer and Wells in the south and it was not found statistically significant difference in diversity over the time and Jaccard index for this plots were very close to the unit (table 5). According with this, we can interpret that the tornadoes did not affect species composition or number of species and thus this climatic events did not influence the diversity. The result is consistent with the findings of Foster (1998) for

Table 6: Statistical comparison of Jaccard Index between groups

| DISTURBANCE | DISTURBANCE TYPE/STATISTIC | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Insects N | | Stand Improvement N | | Stand Improvement S | | Harvest N | | Harvest C | | N no disturbed | | S no disturbed | | C no disturbed | | Near Tornadoes | |
| | t | p | t | p | t | p | t | p | t | p | t | p | t | p | t | p | t | p |
| Snow-ice N | *-6.71 | 0.01 | *2.92 | 0.02 | 1.34 | 0.27 | 1.96 | 0.08 | 1.34 | 0.27 | *2.31 | 0.03 | 1.02 | 0.31 | 1.02 | 0.36 | 1.18 | 0.27 |
| Insects N | | | 0.75 | 0.48 | -1.72 | 0.23 | 0.40 | 0.70 | *-5 | 0.04 | *0.44 | 0.00 | -1.47 | 0.15 | -0.07 | 0.95 | *-3.55 | 0.01 |
| Stand Improv N | | | | | -2.39 | 0.25 | -0.27 | 0.79 | -2.34 | 0.06 | 0.42 | 0.68 | -0.07 | 0.95 | -0.74 | 0.48 | *-4.02 | 0.00 |
| Stand Improv S | | | | | | | 1.18 | 0.27 | -1.00 | 0.42 | 1.40 | 0.17 | 0.07 | 0.95 | 0.51 | 0.64 | -0.53 | 0.02 |
| Harvest N | | | | | | | | | -1.58 | 0.15 | -0.07 | 0.94 | *-3.78 | 0.00 | -0.54 | 0.60 | *-2.72 | 0.02 |
| Harvest C | | | | | | | | | | | 1.89 | 0.07 | 0.84 | 0.41 | 0.80 | 0.47 | -1.35 | 0.21 |
| N no dist | | | | | | | | | | | | | *-5.75 | 0.04 | -1.51 | 0.07 | *-3.81 | 0.00 |
| S no dist | | | | | | | | | | | | | | | 0.79 | 0.44 | 0.73 | 0.46 |
| C no dist | | | | | | | | | | | | | | | | | -1.35 | 0.21 |

N: North, C: Central, S: South, * Light grey: Statistical significant

the north area of the study, who concluded that it was not apparent relationship in vegetation and climatic gradients. It is important to note that the speed of 29 mph for both Tornadoes Chris and Floyd (NOOA, 2016) was very low, compared with 121 mph reached for the Great Hurricane of 1938 that devastated many of the forests in Central MA (Grossi, 2008).

When the Jaccard index for the plots close to the tornadoes were compared with other groups, it was found statistically significant difference between them and the plots that suffered insect attack, stand improvement, harvest and with plots that did not present any disturbance or intervention (table 6). This statistical significant differences should be looked carefully in relation to the regional location of the plots and the difference between north and south regardless the occurrence of disturbances or interventions.

For this reason, in table 6, the statistically significant differences that can be attributed as a response to an event or disturbance, are those between the groups snow/ice storm and insect attacks, with the groups located in the same area, in this case in the north (stand improvement, plots with no disturbance and between them).

Statistical comparison with Jaccard index among the state parks (table 7), showed significant differences between Templeton Park to Oakham, Spencer, Sutton, Wachusset Mountain, Wells, and Upton; Sutton to Otter, and to Spencer; Upton to Otter, and Hubbardston to Petersham.

Table 7: Statistics for comparison of Jaccard index between State parks with significant difference

| Parks | Templeton (N) | | Otter (N) | | Petersham (N) | | Spencer (S)) | |
|---|---|---|---|---|---|---|---|---|
| | t | p | t | p | t | p | t | p |
| Oakham ( C ) | -3.2 | 0.01 | | | | | | |
| Spencer (S) | -2.53 | 0.03 | | | | | | |
| Sutton (S) | -3.59 | 0.02 | -2.32 | 0.05 | | | -2.36 | 0.05 |
| Wachusset Mtn. (N) | -2.69 | 0.02 | | | | | | |
| Wells (S) | -3.18 | 0.01 | | | | | | |
| Upton (S) | -3.51 | 0.001 | -2.33 | 0.03 | | | | |
| Hubbardston (N) | | | | | 2.42 | 0.04 | | |

Five of this parks are located at the north, fourth at the south and one in the central area of the county, then according with the statistically significant difference already found between north and south, the most important differences to highlight are among parks within the same region. These comparisons are Templeton to Wachusset Mountain, Petersham to Hubbardston, and Spencer to Sutton.

## CHAPTER 4. CONCLUSIONS

Statistically significant differences in diversity were not found in 34 years period in Worcester County.  However as measure by Jaccard index significant difference in similarity were found between north and south areas of the county. The north showed greater dynamism, reflected in some units of study with Jaccard index values below 0.5 and changes in species composition, as well population size for some species.

The most intense dynamics in the northern area, with the central region virtually unchanged, could show the study units, lying in the ecotone of the transition zone between central and northern forest types in which Massachusetts lies (according with De la Crétaz, 2010

The decline of White Spruce and increase of Northern Red Oak, suggest that some interventions in the forest could be favorable to help a greater increase in the latter shade tolerant and hardwood specie.

Red Maple, Northern Red Oak and White Pine, seems to be the species that will increase their number in the future composition of the forest in Worcester County, especially in the North and in the South; Hemlock seems to increase mainly in the north.,

Both, the evidence on forest, and the dynamics with species replacement, offer elements to DCR for forest management in the state parks. Talk more about this.

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