Spatial and Temporal Patterns of Tree Mortality in Two Mixed Hardwood Forests of the New Jersey Highlands

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Introduction

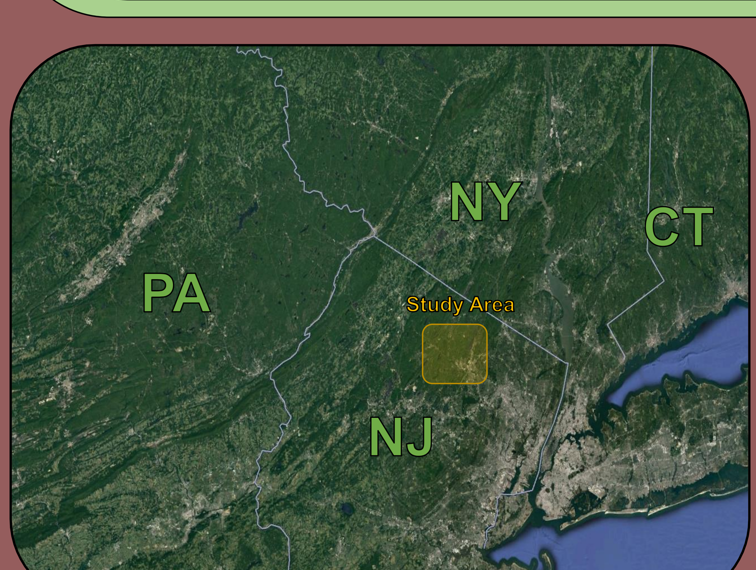
- A variety of mortality agents (e.g., invasive insects, diseases, severe weather) have led to increased rates of mortality for numerous tree species in northeastern U. S. forests (Lovett *et al* 2006).
- Depending on the tree species composition of any given forest, the dynamics of tree mortality could vary dramatically over both space and time. Such spatial and temporal variation in tree mortality can have significant implications for small-scale disturbance ecology within these forests.
- The purpose of this study was to examine the spatial and temporal dynamics of tree mortality over the past 16 years at each of two forest sites in the New Jersey Highlands.

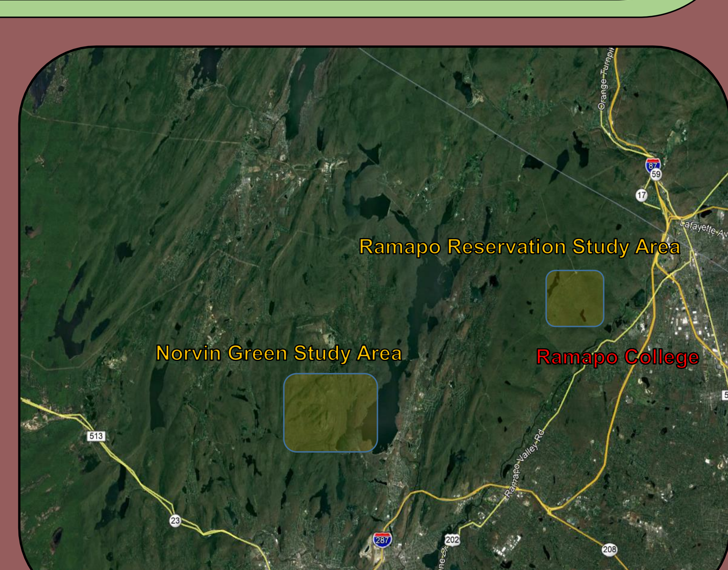
Objectives

- The overall approach of this study was to create spatial maps of canopy and subcanopy trees that died within each of the four most recent 4-year intervals within two different forest tracts. Specific objectives were to:
  - track spatial patterns of overall tree mortality over time, and examine how different mortality agents influence the spatial and temporal dynamics;
  - compare the relative densities of dead trees versus live trees in order to predict any possible shifts in tree species composition over time.

Methods

- Study Sites (see maps below):
  - Ramapo Valley County Reservation (RVCR), Mahwah, NJ
    - belt transect (along hiking trails): 5.2 km x 80 m = 41.6 hectares
  - Norvin Green State Forest (NGSF), Bloomingdale, NJ
    - belt transect (along hiking trails): 8.7 km x 80 m = 69.6 hectares
- Tree Surveys:
  - all dead trees $\geq$ 10 cm trunk diameter within 20 equal-sized, adjacent plots at each site
    - Species, trunk diameter, approximate time since death, and GPS coordinates were recorded.
  - all live trees $\geq$ 10 cm trunk diameter within thirty-one 0.1 hectare circular plots (at RVCR only)
    - Species and trunk diameter were recorded.
- Analyses:
  - Nearest Neighbor Analyses were used to determine the spatial dispersion patterns at each site overall and for each time period (2003-2006, 2007-2010, 2011-2014, 2015-2018).
  - Regression analyses were used to compare spatial variation in tree mortality across the four time periods.
  - Wilcoxon Signed Ranks Tests were used to test for shifts in the numbers of trees that died at each site across the four time periods.
  - Chi-squared Analysis was used to compare the number of dead trees of each species to an expected value based on the relative density of living conspecifics.





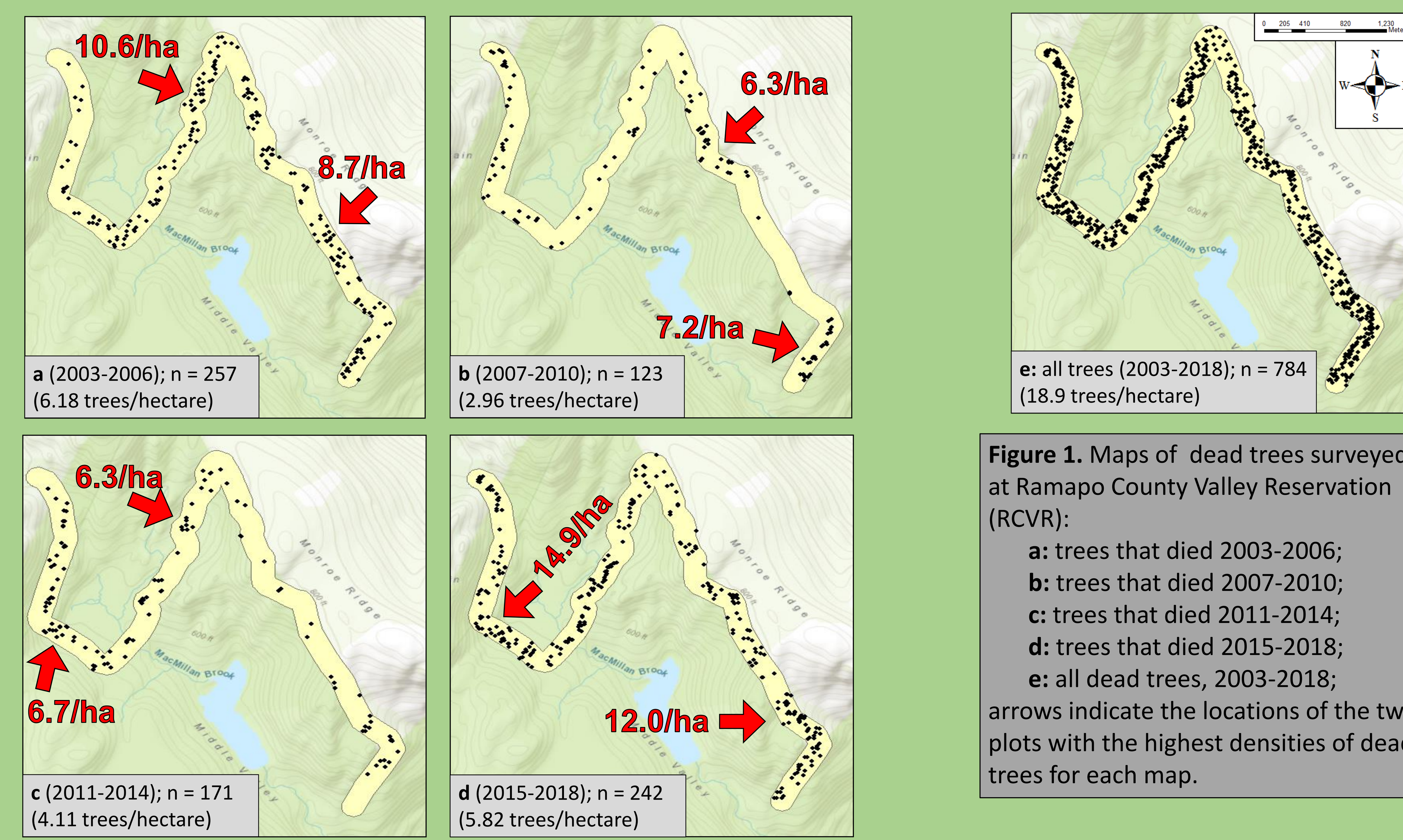


Figure 1. Maps of dead trees surveyed at Ramapo County Valley Reservation (RCVR):
a: trees that died 2003-2006;
b: trees that died 2007-2010;
c: trees that died 2011-2014;
d: trees that died 2015-2018;
e: all dead trees, 2003-2018;
arrows indicate the locations of the two plots with the highest densities of dead trees for each map.

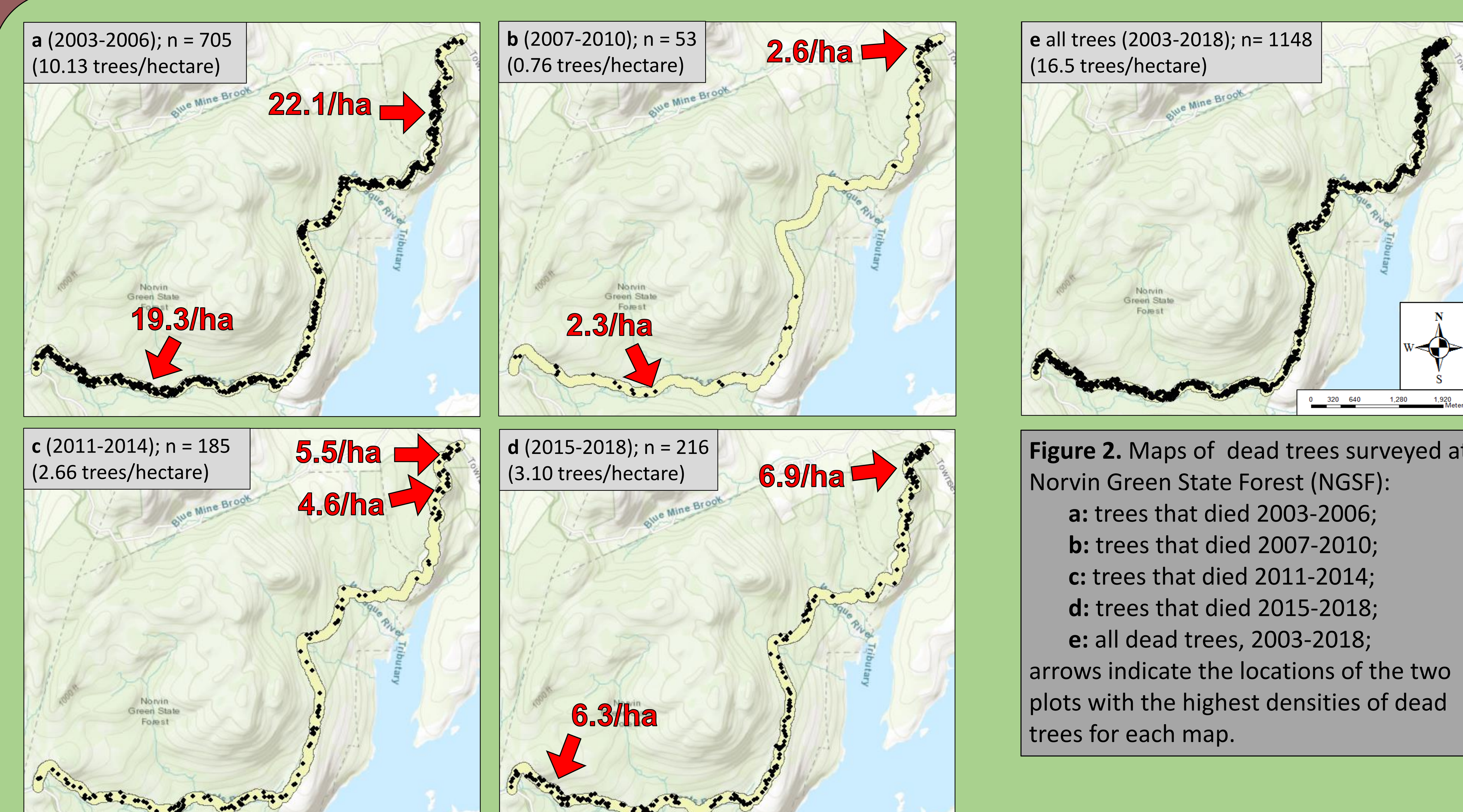


Figure 2. Maps of dead trees surveyed at Norvin Green State Forest (NGSF):
a: trees that died 2003-2006;
b: trees that died 2007-2010;
c: trees that died 2011-2014;
d: trees that died 2015-2018;
e: all dead trees, 2003-2018;
arrows indicate the locations of the two plots with the highest densities of dead trees for each map.

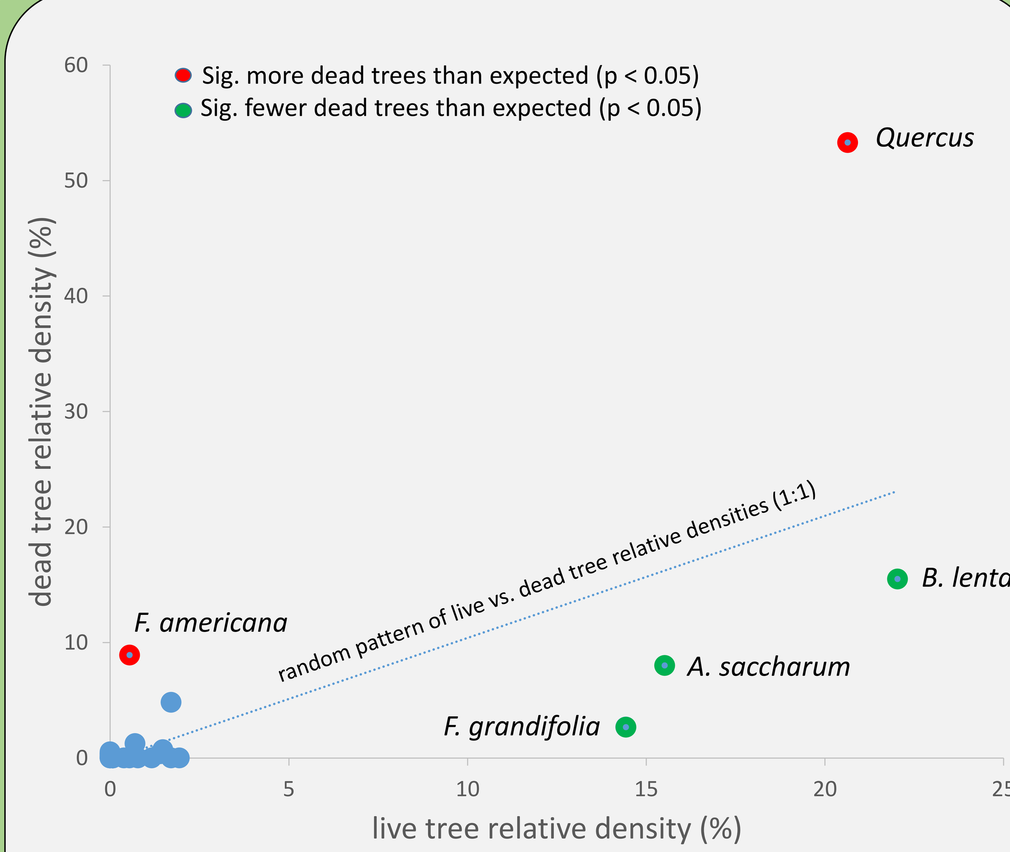


Figure 3: Scatter plot of the relative densities of dead trees for each species versus the relative densities of living conspecifics observed in a total of thirty-one 0.1 ha survey plots at RVCR. Red circles indicate significantly more dead trees than expected. Green circles indicate significantly fewer dead trees than expected.

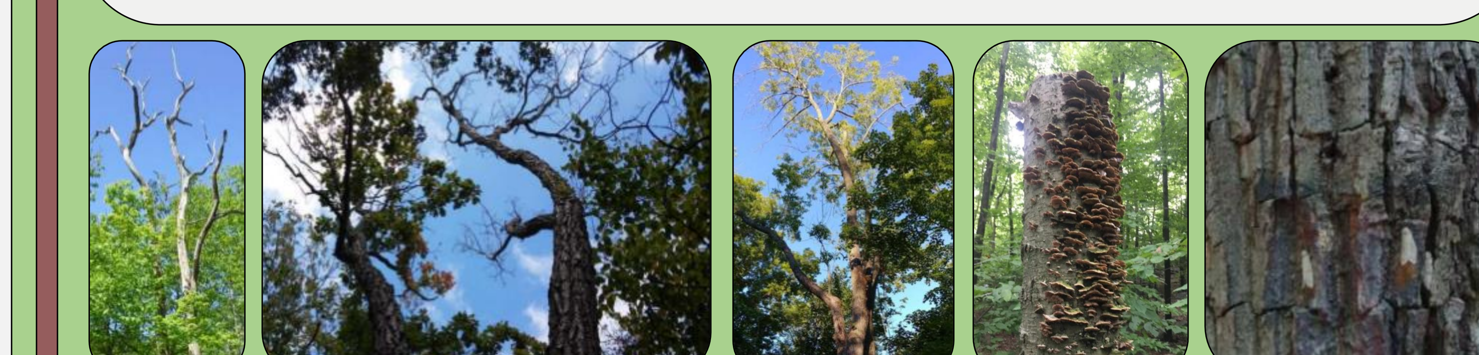
Results of Dead and Living Tree Surveys

Species Name		NGSF		RVCR			
Scientific	Common	Dead Trees	Rel. Density	Dead Trees	Rel. Density	Living Trees	Rel. Density
Acer saccharinum	silver maple	2	0.2	0	0.0	1	0.1
Amelanchier arborea	downy serviceberry	0	0.0	0	0.0	15	1.2
Acer rubrum	red maple	17	1.8	15	2.7	186	14.4
Acer saccharum	sugar maple	35	3.7	45	8.0	200	15.5
Betula alleghaniensis	yellow birch	8	0.8	27	4.8	22	1.7
Betula lenta	black birch	67	7.0	87	15.5	284	22.0
Betula nigra	river birch	2	0.2	2	0.4	0	0.0
Carpinus caroliniana	musclewood	1	0.1	0	0.0	0	0.0
Castanea dentata	American chestnut	0	0.0	0	0.0	1	0.1
Cornus alternifolia	alternate-leafed dogwood	0	0.0	0	0.0	0	0.0
Cornus florida	flowering dogwood	0	0.0	0	0.0	1	0.1
Carya glabra	pignut hickory	1	0.1	0	0.0	7	0.5
Carya laciniosa	shellbark hickory	0	0.0	0	0.0	5	0.4
Carya ovata	shagbark hickory	0	0.0	0	0.0	1	0.1
Carya spp.	unidentified hickory	6	0.6	0	0.0	0	0.0
Carya tomentosa	mockernut hickory	0	0.0	0	0.0	25	1.9
Fagus grandifolia	American beech	7	0.7	15	2.7	186	14.4
Fraxinus americana	white ash	17	1.8	50	8.9	7	0.5
Fraxinus pennsylvanica	green ash	0	0.0	0	0.0	1	0.1
Juglans nigra	black walnut	0	0.0	1	0.2	0	0.0
Juniperus virginiana	Eastern redcedar	4	0.4	3	0.5	0	0.0
Liriodendron tulipifera	tulip tree	10	1.0	4	0.7	19	1.5
Nyssa sylvatica	black gum	0	0.0	2	0.4	18	1.4
Ostrya virginiana	ironwood	0	0.0	0	0.0	22	1.7
Populus deltoides	Eastern cottonwood	0	0.0	0	0.0	1	0.1
Prunus serotina	black cherry	1	0.1	0	0.0	0	0.0
Pinus strobus	Eastern white pine	9	0.9	1	0.2	1	0.1
***Quercus* spp.**	**oak species**	754	78.9	299	53.3	266	20.6
Robinia pseudoacaica	black locust	0	0.0	1	0.2	0	0.0
Sassafras albidum	sassafras	2	0.2	7	1.2	9	0.7
Tilia americana	American basswood	0	0.0	0	0.0	10	0.8
Tsuga canadensis	Eastern hemlock	13	1.4	2	0.4	0	0.0
Ulmus americana	American elm	0	0.0	0	0.0	1	0.1
	TOTAL	**956**	**100**	**561**	**100**	**1289**	**100**

Table 1: The number and relative densities (%) of dead trees surveyed at Norvin Green State Forest (NGSF) and the number and relative densities (%) of dead and living trees surveyed at the Ramapo Valley County Reservation (RVCR).

Results & Discussion

- 784 dead trees (18.9 / hectare) of 20 species were recorded at RVCR, and 1,181 dead trees (17.0 / hectare) of 24 species were recorded at NGSF. 1,289 live trees of 30 species were recorded in the survey of 31 smaller plots at RVCR (Table 1).
- Tree mortality was patchily distributed. Dispersion patterns at both sites were statistically significantly aggregated overall and within each of the four time periods (Figures 1 and 2; Nearest Neighbor Analysis, $p < 0.05$). The density of tree mortality within each site did not tend to be spatially correlated between time periods ($p > 0.05$ for all regression models except 2011-2014 versus 2015-2018 at NGSF), however, suggesting that the specific locations where high versus low levels of disturbance from tree mortality occurred shifted over time (Figures 1 and 2).
- Rates of tree mortality tended to shift among the different time periods. At RVCR, the number of dead trees were consistently greater in 2003-2006 than 2007-2010, and consistently greater in 2015-2018 than 2011-2014 (Wilcoxon Signed ranks test, $p < 0.05$). There was no consistent trend between the 2007-2010 and 2011-2014 periods ($p = 0.628$). At NGSF, the number of dead trees were consistently greater in 2003-2006 than 2007-2010, and consistently fewer in 2007-2010 than 2011-2014 (Wilcoxon Signed ranks test, $p < 0.05$). There was no consistent trend between the 2011-2014 and 2015-2018 periods ($p = 0.066$).
- *Quercus* spp. (oaks) were by far the most common species of trees that died, and they died at a statistically significantly higher rate than expected based on the species composition of living trees. Causes of oak mortality included outbreaks of both native (*Archips semiferanus* (oak leaf roller)) and non-native (*Lymantria dispar* (gypsy moth)) insect species, and high levels of *Q. rubra* toppling during severe storms. The number of dead *F. americana* (white ash) trees were also higher than expected, apparently due to fungal pathogens. (Evidence of *Agrilus planipennis* (Emerald ash borer) has not been observed at the sites.)
- There were fewer dead trees than expected for *B. lenta* (black birch), *A. saccharum* (sugar maple), and *F. grandifolia* (American beech). This trend is likely to change in the near future for *F. grandifolia*, given the high prevalence of beech bark disease at the sites. It is interesting to note that the other two species represent an early successional species (*B. lenta*) and a late successional species (*A. saccharum*).
- Overall, tree mortality tended to be patchy over both space and time. Canopy opening dynamics, therefore, cannot be considered as a simple phenomenon where certain places within the forest experience consistently high or low levels of disturbance. The spatially and temporally dynamic nature of small-scale disturbances caused by the mosaic of shifting patches of mortality of canopy and subcanopy trees likely creates a highly complex context for ecological phenomena such as gap filling via hotspots of tree regeneration, as well as colonization of the forest by light-demanding, invasive plant species where the greatest pulses of disturbance occur. It is also important to recognize that tree mortality is not distributed evenly among the region's tree flora. *Quercus* spp. and *F. americana* have been dying at much higher rates than other species, and their populations may be in severe decline.



Quercus sp. — *Q. montana* defoliated by *Archips semiferanus* — *F. americana* in decline — *Betula lenta* — *Lymantria dispar* on *Q. montana*

Acknowledgements

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