Modeling the Historical Disturbance Regimes of NYC

Historical Disturbance Regimes

scale and frequency of various natural and human disturbances in the North Eastern US (Lorimer 1980, Foster et al. 1998, Pan et al. (2011), Lorimer and White 2003)

Characterization of human influence on the landscape (Day 1953, Russell 1997, 1997, Krech III 1999, Patterson and Sassaman (1988))

Fire

Custom Fuel Models

Fuel parameters for hardwood forest types are based on USFS model 9 (hardwood litter), which is used to simulate fires in long leaf pine and hardwood stands, especially oak-hickory types (Anderson 1982, Scott and Burgan 2005). Where average loads for 1 hr, 10 hr, and 100 hr fuels were available for northeastern forest types the values were substituted into the custom fuel model (Reinhardt and Crookston 2015) (section 4.13.9). The remaining fuel attributes were carried over from the base model. The USFS FIA community types were cross-walked to the NY State Heritage community classification so fuels could be assigned for our landscape.

[cross walk table]

Fuel Moisture Content

Region specific fuel moisture classes were used as start conditions in FARSITE (Reinhardt and Crookston 2015) (section 4.14.6). All freshwater wetland communities (marshes, shrub-swamps and forested wetlands) were initialized with a wet fuel profile, all other communities with burnable fuel types were initialized with a moist fuel profile.

Size Class	Very Dry	Dry	Moist	Wet
1 hr	5	7	10	19
10 hr	8	9	13	29
100 hr	12	14	17	22
Live woody	89	105	135	140
Liver herbaceous	60	82	116	120

Table XX. Four predefined moisture values(%) which alter fire intensity and consumption (from (Reinhardt and Crookston 2015))

Initial Conditions - Forest Age

The initial age of forest type communities randomly assigned using a truncated normal distribution ($\mu = 65$, minimum=0, max=200)(Loewenstein et al. 2000, Pan et al. 2011). All other community types were initialized with a forest age of zero.

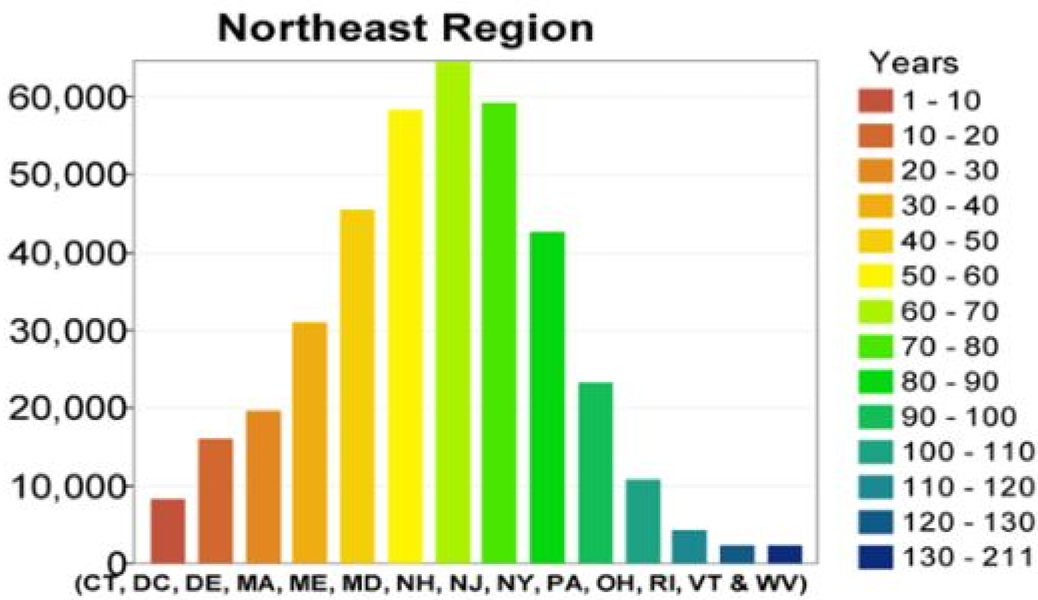

Figure 1: age class distribution

Initial Conditions - Canopy

Communities were initialized with their maximum canopy values as defined in the community table (needs reference/rational).

fire size and frequency literature

effects of fires on temperate forests (Kozlowski 2012) power law(Reed and McKelvey 2002, Stephens 2005, Cui and Perera 2008)

Modeling Expected Frequencies

A Poisson distribution is used to model annual forest fire events (Johnson 2001, Yang et al. 2008). We created distributions for trail fires, garden fires and lightning fires.

Lightning Frequencies

Description of extent and impact of lightning caused forest fires (Loope and Anderton 1998)

The expected frequency (*lambda*) of lighting caused fires are based on areal frequencies from region 9 (U.S. Northeast) USFS wildfire records between 1940 and 2000 (Stephens 2005). These values were converted from the given units (frequency/400000 ha)/yr to (frequency/km^2)/yr.

Region	Lightning		Human	
	Ha burned	No. fires	Ha burned	No. fires
9	11.840	2.170	327.990	39.950

	Lightning		Human	
	Area burned	No. Fires	Area burned	No. Fires
1 hectare	0.0000296	0.000005425	0.000819975	0.000099875
per km^2	0.00296	0.0005425	0.0819975	0.0099875

Human Caused Fire and Frequency Scenarios

The extent and effect of human caused fires on the landscape prior to European settlement is debated. Theorized fire regimes range from biannual burns over large areas with a significant impact on under-story structure (Day 1953, Patterson and Sassaman 1988), to frequencies only marginally above lightning caused fires with minimal effect on vegetation structure (Russell 1983). Disagreement stems from the lack of empirical evidence in the ecological record, most observable signs of fire disturbance has been erased by land use change. Because of this our understanding of these processes are primarily based on the historical record. Early travelers during the 16th and 17th century made note of fire as a land management tool in the North Eastern US by Native Americans, but these accounts generally lack quantitative description. Those accounts including estimates of burn frequency are often annual or semi-annual (Russell 1983). We have proposed two frequency scenarios, which bound what we believe are the upper and lower limits of human caused fire disturbance in this region.

Welikia Fire Frequency Scenarios

source	no human fire	Russell (1983)	Day (1953)
trail	0	???	???
garden	0	???	???
hunting	0	???	???

Fire Frequency Tables

Ignition Points

Native Americans used fire for a variety of land management purposes, our model accounts for three potential sources of human caused ignition. Human fires can be started along trails, horticultural sites, and on hunting grounds.

The number of ignitions in a given year is determined randomly using a Poisson distribution for each source . Ignition points can occur on any trail, garden or hunting site pixel that is coincident with a burnable fuel type. Non-burnable fuels include various types of bare-earth and open water. These points are randomly placed on cells that meet the selection criteria.

Seasonality and Duration and Weather Conditions

Climate year equivalence

Each year in the modeled time-frame (1409-1609) has a Palmer's Drought Index derived from [tree ring data??]. Using the drought index we select an equivalent climate year between 1876-2006, for which we a have daily weather records [National Weather Service].

weather data is reported with following fields:

Precipitation: is the daily rain amount specified in hundredths of an inch or millimeters (integer).

Hour1: corresponds to the hour at which the minimum temperature was recorded (0-2400).

Hour2: corresponds to the hour at which the maximum temperature was recorded (0-2400).

Temperatures: (Temp1 is minimum; Temp2 is maximum) are in degrees Fahrenheit or Celsius (integer).

Humidities: (Humid1 is maximum; Humid2 is minimum) are in percent, 0 to 99 (integer).

Elevation: is in feet or meters above sea level. NOTE: these units (feet or meters) do not have to be the same as the landscape elevation theme (integer).

(The wtr files formated for FARSITE are copied over from the Mannahatta project, I am not aware of any documentation describing the reformatting process or of the original NOAA data (This data is online at the NOAA website, but I was only able to find a portal to access daily records for past 2 months, and did not see a way to download many daily records at once. It worth checking to make sure this field has been properly converted and the measurement system header is correct (ENGLISH/METRIC)).

Duration

FARSITE requires specific start and end dates for fire events. The disturbance model has a defined window, or *fire season*, in which start dates can be selected. This selection is made randomly from the subset of dates with no precipitation. Historical records suggest that fires typically occurred in the fall and spring. As a default we have defined the start date window occurring between 3/1-5/31, though this can be changed in the disturbance configuration file (FIRE_SEASON_START/FIRE_SEASON_END, scenario_settings.py). The end date of the actual fire simulation is selected by finding the nearest following date in which precipitation exceeds the critical rainfall threshold (CRITICAL_RAINFALL, scenario_settings.py). The end date may extend beyond the end date of the fire season.

Critical Rainfall

Modeled fire spread stops when it encounters one of the following conditions: (1) a non-flammable type of land cover; (2) boundaries of the region; and (3) when rainfall exceeded a certain critical amount. We assume that a daily precipitation of 0.10" or more would stop a fire, the R Crit in Eq. (2) was estimated as 0.026 (the proportion of total number of days that has daily precipitation of 30 mm or more) from the historical precipitation data of the Edison weather station. (Li 2000)

Tree Allometry

Description	Equation	Reference
Tree Height	$TH = 44 * ln(Age) - 93$	(Bean and Sanderson 2008)
DBH	$DBH = (Age - 34.44)/1.18$	(Loewenstein et al. 2000)
Crown Ratio	$CR = 0.4$	(Bean and Sanderson 2008)
Bark Thickness	$BT = vsp * DBH$	(Reinhardt and Crookston 2015)

Communities to Bark Thickness

Bark thickness multipliers for each community are based on the dominant tree type (Edinger et al. 2014), for communities with co-dominate species we calculated average bark thickness (Reinhardt and Crookston 2015)(section 4.13.4).

community	dominant tree species	vsp scaler
Floodplain forest	avg(sliver maple, sycamore, American elm)	0.032

community	dominant tree species	vsp scaler
Red Maple Hardwood Swamp	red maple	0.028
Coastal Plain Atlantic Cedar Swamp	Atlantic cedar	0.025
Pitch pine - scrub oak barrens	avg(pitch pine, oak spp)	0.045
Chestnut oak forest	avg(American chestnut, oak spp)	0.043
Coastal oak beech forest	avg(oak spp, beech)	0.035
Coastal oak hickory forest	avg(oak spp, hickory spp)	0.045
Oak tulip forest	avg(oak spp, yellow-poplar)	0.038
Appalachian oak pine forest	avg(oak spp, pine spp)	0.038
Hemlock northern hardwood forest	hemlock	0.045
Inland Atlantic Cedar Swamp	Atlantic white cedar	0.025
Red maple black gum swamp	avg(red maple, black gum)	0.034
Red maple sweetgum swamp	avg(red maple, sweetgum)	0.032
Maritime holly forest	holly	0.042
Post oak black jack oak barrens	post oak	0.044
Appalachian oak hickory forest	avg(oak spp, hickory spp)	0.045
Beech maple mesic forest	avg(beech, sugar maple)	0.029
Successional maritime hardwoods	other hardwoods	0.044
Successional hardwood forest	other hardwoods	0.044

Fire Mortality Equations

Scorch Height

[1]

$$SH = 3.1817(FL^{1.4503})$$

(Bean and Sanderson 2008)

Crown Kill

[2]

$$CK = 41.961(100(\ln(\frac{SH - CH)}{CL})) - 89.721$$

(Bean and Sanderson 2008)

Percent Mortality

[3]

$$P_m = \frac{1.0}{1.0 + e^{-1.941+6.316(1.0-e^{-BT})-0.000535CK^2}}$$

(Bean and Sanderson 2008)

Horticulture

Archaeological Evidence for Gardening

Archaeological evidence suggests the American Indian people living in the Hudson Estuary region practiced horticulture and relied partially on domesticated fruit and vegetable to supplement foraged/hunted foods (Kraft 2001, Cantwell and Wall (2001), Benison (1997)).

Ethnohistorical

(Ascher 1860, Danckaerts and Sluyter (1867))

Site Selection

Horticultural fields were modeled at historical sites meeting the following two criteria.

1. historical and archaeological records provide evidence for semi-permanent habitation.
2. site point is located within 250 m of freshwater source

Garden locations are then selected using a suitability model which takes into account proximity to the site center, slope and community type.

Field Size

crop	yield (kg/ha)	calories/100 g	calories/kg	calories/ha
corn	1720	365	3650	6278000
beans (Phaseolus vulgaris)	110	33	330	36300
squash (Indian squash)	80	16	160	12800

Corn-bean-squash poly-culture yields in Tabasco, Mexico (reproduced from (Gliessman et al. 1998) pg 224 table 15.3)

Caloric density of corn beans and squash crops prepared by boiling is reported from the USDA Basic Reports Agricultural Research Services.

See Speth 1983 for discussion of caloric requirements and diet in temperate hunter gather societies (Speth and Spielmann 1983)

Agricultural Dependency Scenarios

Dependency	calories/person/yr	ha/person	m^2/person
15%	94060.50	0.01	14.87
30%	188121.00	0.03	29.73
60%	376242.00	0.06	59.47
100%	627070.00	0.10	99.11

Complete Horticulture Tables

Create Garden Method

When a new garden is created a starting cell is selected randomly from the set of cells within 500 m of the site that have the highest suitability index. Adjacent cells with the highest suitability are iteratively added in groups around the center. When adding a group of cells would cause the garden to exceed the target area, single cells are added instead, again, choosing cells with highest suitability.

The target area of a new garden is calculated using the population at the site. Each time a new garden is created a value of between -5 and 5 is added to the base number of individuals at the site (which does not change overtime), representing changes in population size and introducing variation in the garden size over the course of the disturbance simulation (see the POPULATION_VARIANCE parameter in scenario_settings.py).

Beaver Ponds

Beaver Populations and Disturbance in the North Eastern United States

Site Selection

Model Parameters

Parameter	Value		Source
abandonment P	0.10		(Logofet et al. 2016)
colony density	0.4	colonies/km^2	(Naiman et al. 1988)
territory	1000	m	Naiman et al. (1988); Allen (1983)]

Create Pond Method

New dam points can only added along mapped streams with a slope of less than 8 degrees, and must be located outside a minimum distance buffer (MINIMUM_DISTANCE, scenario_settings.py) from all existing colonies.

The dam point is an input for the Arc GIS watershed tool, which returns the upstream area that drains into that point. Next, the dam height parameter (DAM_HEIGHT, scenario_settings.py) is added to the elevation at the dam point, all cells in the watershed which have a value lower than the dam height are converted to pond. Watershed and dam hight

Potential for errors and artifacts The shape of beaver ponds is determined by the elevation model. Interpolation artifacts, particularly in areas where there information about the topography was limited and in very flat areas, will produce unrealistic pond geometries.

Wetland Successional Pathways

The freshwater wetland succession sequence has four stages(Allen 1983, Naiman et al. 1988, Johnston and Naiman 1990, *Ecology of Red Maple Swamps in the Glaciated Northeast* 1993, Hay 2010, Logofet et al. 2016).

$$\text{active beaver pond} \rightarrow \text{emergent marsh} \rightarrow \text{shrub swamp} \rightarrow \text{forested wetland}$$

Conversion from non-wetland community to active pond can occur along any perennial streams where the gradient of the stream is equal to or less than 8 degrees (Allen 1983). Due to the temporal scale of our study (200 yrs), forested wetlands are treated as a terminal community in this series (*Ecology of Red Maple Swamps in the Glaciated Northeast* 1993). This rule defines beaver caused disturbance as a one directional change in successional trajectory; A non-wetland community can be converted into a wetland type, but once converted cannot be returned to an upland type.

Analysis

time since fire (Johnson 2001) fire size frequency hist (Malamud et al. 1998, Reed and McKelvey 2002, Cui and Perera 2008)

References

Allen, A. W. 1983. Habitat suitability index models: Beaver. Western Energy; Land Use Team, Division of Biological Service, Research; Development, Fish; Wildlife Service, US Department of the Interior.

Anderson, H. E. 1982. Aids to determining fuel models for estimating fire behavior. The Bark Beetles, Fuels, and Fire Bibliography:143.

Ascher, G. 1860. Henry Hudson the Navigator. Hakluyt Society, London.

Bean, W. T., and E. W. Sanderson. 2008. Using a spatially explicit ecological model to test scenarios of fire use by Native Americans: An example from the Harlem Plains, New York, NY. Ecological Modelling 211:301–308.

Benison, C. 1997. Horticulture and the Maintenance of Social Complexity in Late Woodland Southeastern New England. North American Archaeologist 18:1–17.

Cantwell, A.-M., and D. d. Wall. 2001. Unearthing Gotham: The Archaeology of New York City. Yale University Press, New Haven, CT.

Cui, W., and A. H. Perera. 2008. What do we know about forest fire size distribution, and why is this knowledge useful for forest management? International Journal of Wildland Fire 17:234.

Danckaerts, J., and P. Sluyter. 1867. Journal of a Voyage to New York: And a Tour in Several of the American Colonies in 1679-80. The Long Island Historical Society, Brooklyn.

Day, G. M. 1953. The Indian as an Ecological Factor in the Northeastern Forest. Ecology 34:329–346.

Ecology of Red Maple Swamps in the Glaciated Northeast: A Community Profile. 1993. U.S. Fish; WIldlife Service.

Foster, D. R., G. Motzkin, and B. Slater. 1998. Land-Use History as Long-Term Broad-Scale Disturbance: Regional Forest Dynamics in Central New England. Ecosystems 1:96–119.

Gliessman, S. R., E. Engles, and R. Krieger. 1998. Agroecology: Ecological Processes in Sustainable Agriculture. CRC Press.

Hay, K. G. 2010. Succession of Beaver Ponds in Colorado 50 Years After Beaver Removal. The Journal of Wildlife Management 74:1732–1736.

Johnson, E. A. 2001. Forest Fires: Behavior and Ecological Effects. Academic Press.

Johnston, C. A., and R. J. Naiman. 1990. The use of a geographic information system to analyze long-term landscape alteration by beaver. Landscape Ecology 4:5–19.

Kozlowski, T. T. 2012. Fire and Ecosystems. Elsevier.

Kraft, H. C. 2001. The Lenape-Delaware Indian heritage: 10,000 B.C.- A.D. 2000. Lenape Books, [S.l.].

Krech III, S. 1999. The Ecological Indian. W.W. Norton & Company, New York.

Li, C. 2000. Reconstruction of natural fire regimes through ecological modelling. Ecological Modelling 134:129–144.

Loewenstein, E. F., P. S. Johnson, and H. E. Garrett. 2000. Age and diameter structure of a managed uneven-aged oak forest. Canadian Journal of Forest Research 30:1060–1070.

Logofet, D. O., O. I. Evstigneev, A. A. Aleinikov, and A. O. Morozova. 2016. Succession caused by beaver (Castor fiber L.) life activity: II. a refined markov model. Biology Bulletin Reviews 6:39–56.

Loope, W. L., and J. B. Anderton. 1998. Human vs. Lightning Ignition of Presettlement Surface Fires in Coastal Pine Forests of the Upper Great Lakes. The American Midland Naturalist 140:206–218.

Lorimer, C. G. 1980. Age Structure and Disturbance History of a Southern Appalachian Virgin Forest.

Ecology 61:1169–1184.

Lorimer, C. G., and A. S. White. 2003. Scale and frequency of natural disturbances in the northeastern US: Implications for early successional forest habitats and regional age distributions. Forest Ecology and Management 185:41–64.

Malamud, B. D., G. Morein, and D. L. Turcotte. 1998. Forest fires: An example of self-organized critical behavior. Science 281:1840–1842.

Naiman, R. J., C. A. Johnston, and J. C. Kelley. 1988. Alteration of North American Streams by Beaver. BioScience 38:753–762.

Pan, Y., J. M. Chen, R. Birdsey, K. McCullough, L. He, and F. Deng. 2011. Age structure and disturbance legacy of North American forests.

Patterson, W. A., and K. E. Sassaman. 1988. Indian Fires in the Prehistory of New England. Pages 107–135 *in* G. P. Nicholas, editor. Holocene Human Ecology in Northeastern North America. Plenum Press, New York.

Reed, W. J., and K. S. McKelvey. 2002. Power-law behaviour and parametric models for the size-distribution of forest fires. Ecological Modelling 150:239–254.

Reinhardt, E. D., and N. L. Crookston. 2015. The fire and fuels extension to the forest vegetation simulator. U.S. Department of Agriculture, Forest Service.

Russell, E. 1983. Indian-set fires in the forests of the northeastern United States. Ecology 64:78–88.

Russell, E. W. B. 1997. People and the land through time: Linking ecology and history. Yale University Press, New Haven, Conn.

Scott, J. H., and R. E. ;. Burgan. 2005. Standard fire behavior fuel models: A comprehensive set for use with Rothermel's surface fire spread model.

Speth, J. D., and K. A. Spielmann. 1983. Energy source, protein metabolism, and hunter-gatherer subsistence strategies. Journal of Anthropological Archaeology 2:1–31.

Stephens, S. L. 2005. Forest fire causes and extent on United States Forest Service lands. International Journal of Wildland Fire 14:213–222.

Yang, J., H. S. He, and S. R. Shifley. 2008. Spatial Controls of Occurrence and Spread of Wildfires in the Missouri Ozark Highlands on JSTOR. Ecological Applications 18:1212–1225.