Evaluating Extreme Drought-induced Tree Mortality and Biomass Loss in East Texas Using Forest Inventory and Analysis (FIA) Data

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Introduction

- Tree mortality and biomass loss caused by rising temperature and increased drought have been increasingly documented in last two decades[1,2,3].
- Drought induced extensive tree die-off could impact regional forest structure, timber productivity, ecosystem service, carbon (C) budgets, reducing ecosystem potential to sequester C and increasing loss of C through soil respiration rates[3].
- Forests in the east Texas which encompass more than 90% of productive forests of Texas are strongly influenced by various disturbance events including hurricanes, wildfires, insect outbreaks and increased droughts.
- Texas has been experiencing significant droughts since 1950s, most recently severe drought occurred in the 2011.
- We examined tree mortality, biomass loss and the carbon implications of forest disturbance by drought in the East Texas region during last 14 years.

Questions

- Have annual tree mortality rate changed in recent decade due to drought?
- What are the trends in annual proportion of biomass loss?

Patterns of Drought

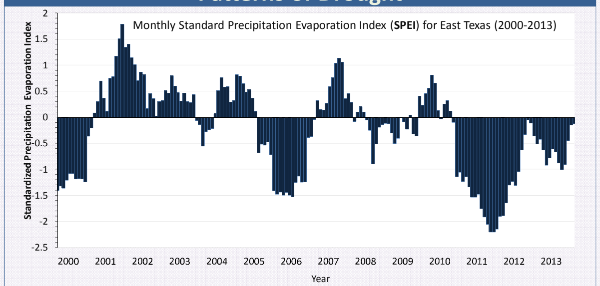

Fig.1. Temporal distribution of 12 month average Standard Precipitation Evaporation Index (**SPEI**) value for the period of 2000-2013. Positive values (> 0.5) indicate wet conditions; negative values (<-0.5) indicate drought conditions. The more negative the value, the more severe the drought conditions.

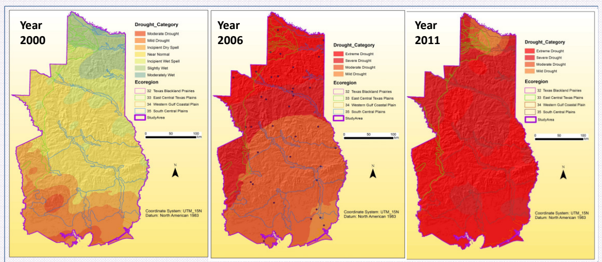

Fig.2. Spatiotemporal distribution of Palmer Drought Index (**PDSI**) values for the three drought periods (Year of 2000 , 2006, 2011) from left to right, respectively.

Methods and Materials

Study area: The east Texas (**Fig.3**), which includes 43 counties covering an area of around 9 million square Kilometer.

Climate data: 34 years of monthly climatic variables for the Upper Coast (Climate Division 8) and East Texas (Climate Division 4) were obtained from the National Oceanic and Atmospheric Administration (NOAA)[4]. Palmar Drought Severity Index (**PDSI**)[6] and Standard Precipitation Evaporation Index (**SPEI**)[7] were calculated and interpolated (Ordinary kriging) at 1 km grid.

FIA data: Forest Inventory and Analysis (FIA) data with 2013 inventory were downloaded from the United States Forest Services (USFS) website[5]. Plots inventoried three times were extracted. Plots experienced moderate droughts (SPEI<-0.75) for at least 6 years were utilized in the analysis. The drought data were then geo-spatially linked to each plot.

Analyses: Annual proportions of biomass lost to mortality (**apbm** referred as tree mortality rates) were estimated by annual compounding over the census interval length. Linear mixed models (**LMM**) were utilized to understand trends in tree mortality and biomass loss[8].

Results

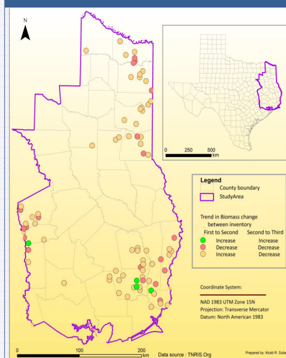

Fig.3. Locations of the selected plots. Green circle indicate plots increased in biomass, Corral color represents plots decreased biomass, Sand color circle represents increasing biomass between Ist to 2nd but decreasing between 2nd to 3rd inventory.

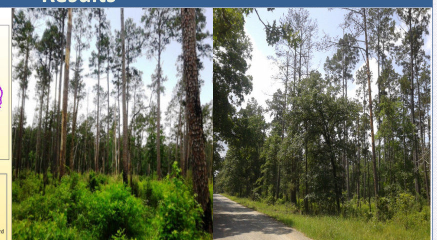

Photo: Drought trigged die-off forest patch and massive tree death in the Sam Houston National Forest, Texas (Subedi, 2015)

Table 1. Trends of **apbm** by species group

Data	Coeff.	Std.Error	p	n
All plots	0.0507	0.0026	<0.001	77
Pine	0.0516	0.0035	<0.001	18
Other conifers	0.0520	0.0058	<0.001	16
Soft hardwood	0.0484	0.0051	<0.001	29
Hard hardwood	0.0518	0.0061	<0.001	14

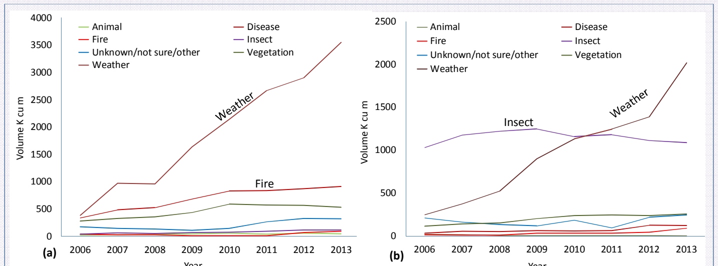

Fig.4. Temporal pattern of volume loss in east Texas forests by disturbance agent types. Calculation was based on all sampled plots in FIA database in east Texas (a) Softwood species (b) Hardwood species.

Results

Table 2. Fixed effect in the linear mixed models describing annual mortality trends (see **Fig.5.** for residual diagnosis)

Model	Data	Coeff.	Std.Error	p
Mortality trends by diameter class	<20 cm	4.873	1.168	<0.001
	20-30 cm	3.827	1.130	0.001
	30-40 cm	3.166	1.192	0.008
Mortality trends by height class	<14 m	1.906	0.785	0.015
	14-16 m	4.255	0.670	<0.001
	16-18 m	3.100	0.673	<0.001
	constant	-7.594	1.158	<0.001

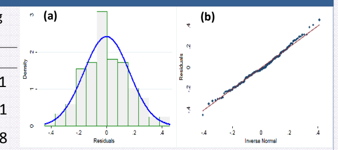

Fig.5. Histogram of residual distribution with normal curve (a), and normal q-q plot (b)

Table 3. Trends in basal area (m^2ha^{-1}) from the linear model

Data	Coeff.	Std.Error	p	n
All plots	-6.841	12.410	0.581	77
Division4	-28.609	14.128	0.043	56
Division8	53.347	23.890	0.026	21
Unit1	33.967	14.055	0.016	51
Unit2	-33.742	22.398	0.132	26

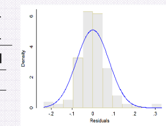

Fig. 6 . Histogram of residual with normal curve for trends in **apbm** by species group

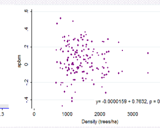

Fig. 7. Annual fractional change in tree mortality rate in individual plots by forest density

Discussion

- Our result indicated that mortality rate was increased in 70% of plots (n= 59). We did not find any difference across the altitudinal gradient.
- Mortality was increased for all sized of diameter and height classes, compared to reference categories (i.e. diameter >40 cm dbh, and height >18 m).
- All major species group showed increased mortality rates (**Table1**). However the higher rate of hard hardwood species could be due to plot wise average rather than specific allocation of species to certain groups.
- Considering all plots together, we did not find statistically significant relationship between predicted mortality and basal area per hectare (**Fig.7. and Table 3**). Forest density declined significantly all plots consider together (p<0.001, LMM).
- The 12 month SPEI showed the directional trend of drought over the census years (LMM b= -0.4431, z=-3.79, p<0.001).

Conclusions

- Drought was the dominant factor, especially in 2011, contributed to increased tree mortality rates and biomass loss.
- 95% of plots experienced increased tree mortality from second to third inventory.
- 23% of the plots experienced consistent mortality after the 2011 drought; only 4 % of the plots were found increase in biomass across forest inventory.
- The spatial variation of the tree mortality and biomass loss were highly correlated with spatial drought distribution patterns.

References

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