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Assessing changing carbon pool dynamics and species composition in a Pennsylvania broadleaf forest fragment

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Introduction

- Temperate broadleaf forests are pivotal to the global carbon cycle, Representing 37% of the global forest carbon pool (Pan et al 2011).
- Maintaining compositional diversity in temperate broadleaf forests, such as the Gordon Natural Area (GNA) is critical to maintaining ecosystem services, such as carbon sequestration.
- Pressures from native and non-native herbivores threaten the biodiversity of temperate broadleaf forests in the United States (Ghandi et al. 2010). The introduction of non-native insects such as the emerald ash borer (*Argrilus planipennis*), as well as the overpopulation of white-tailed deer (*Odocoileus virginianus*) has led to declines in some tree species.
- Monitoring changes in forest carbon storage and tree species composition through time informs our understanding of forest development and resilience to agents of change.

Research Questions

- How have carbon pools in live and dead wood changed within the GNA from 2018-2023?
- How have tree species composition and species-specific structural attributes changed in the GNA from 2018-2023?

Methods

- The GNA is a 100-year-old deciduous forest fragment in southeastern Pennsylvania.
- Three 0.2 ha plots were censused in 2018 and 2023 to determine species and diameter at breast height (dbh) for all live trees ≥10 cm (Fig. 1).
- All living trees were classified as existing within either the canopy or understory environment.
- Allometric equations (Chojnacky et al. 2014) were used to determine aboveground biomass (AGBM) for live wood in both 2018 and 2023.
- In 2018 and 2023, down and standing dead wood was measured and assigned a decay class to determine carbon storage in these pools.
- Paired t-tests were performed to determine whether AGBM for live and dead wood varied over time.
- The percent difference in stem density, basal area, and AGBM from 2018-2023 was determined for each living tree species.

Figure 1. Measuring tree diameter at breast height.

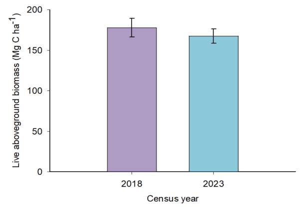

Figure 2. Mean ±1 SE live aboveground biomass (Mg C ha -1) by year (2018 or 2023, $p > 0.05$).

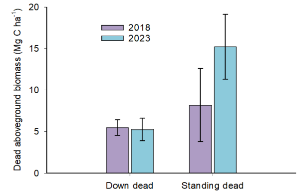

Figure 3. Mean ±1 SE down and standing dead wood aboveground biomass (Mg C ha-1) by year (2018 or 2023). Separate analyses were performed for down ($p > 0.05$) and standing dead wood ($p > 0.05$).

Table 1. Stem density (trees ha^{-1}), basal area ($m^2\ ha^{-1}$), and aboveground biomass (Mg C ha^{-1}) by tree species or genus and census year. Shaded cells represent species with >10% difference between years for each variable where lighter shaded cells represent a >10% decrease and darker shaded cells represent a >10% increase.

Species	Stem density (trees ha^{-1})		Basal area ($m^2\ ha^{-1}$)		AGBM (Mg C ha^{-1})	
	2018	2023	2018	2023	2018	2023
Acer platanoides	52	52	1.32	1.36	3.41	3.55
Acer rubrum	15	15	0.74	0.76	2.18	2.26
***Carya* sp.**	17	13	0.43	0.41	1.46	1.43
Fagus grandifolia	160	152	3.67	4.44	11.2	14.9
Fraxinus americana	8	3	0.93	0.17	3.43	1.17
Liriodendron tulipifera	80	75	23.8	23.3	96.5	95.7
Nyssa sylvatica	2	2	0.03	0.01	0.06	0.03
***Quercus* sp.**	40	32	11.85	9.6	59.2	48.3

Table 2. Percent difference for stem density, basal area, and aboveground biomass by tree species or genus between 2018 and 2023, calculated from data in Table 1. Lighter shaded cells represent a >10% decrease, while darker shaded cells represent a >10% increase.

Percent difference from 2018-2023			
Species	**Stem density**	**Basal area**	**AGBM**
Acer platanoides	0	3	4
Acer rubrum	0	3	3
***Carya* sp.**	-24	-6	-3
Fagus grandifolia	-5	20	33
Fraxinus americana	-63	-81	-66
Liriodendron tulipifera	-6	-2	-1
Nyssa sylvatica	0	-51	-58
***Quercus* sp.**	-20	-19	-18

Results

- Although carbon storage in living wood decreased from 2018 to 2023 (Fig. 2), the change was not significant ($p > 0.05$).
- Carbon storage in down dead and standing dead wood did not vary significantly from 2018 to 2023 ($p > 0.05$). However, a large increase in standing dead wood was observed (Fig. 3). This was not a statistically significant change due to high variance caused by spatial heterogeneity in dead wood distribution among the plots.
- The *Quercus sp.*, *Nyssa sylvatica*, and *Fraxinus americana* experienced >10% declines in basal area and AGBM (Table 1 & 2). The *Carya* sp. and *Liriodendron tulipfera* experienced declines of <10% in basal area and AGBM (Table 1 & 2). Notably, *F. americana* experienced the highest percentage of decline across all structural variables (Table 2).
- *Fagus grandifolia*, *Acer platanoides*, and *Acer rubrum* experienced increased basal area and AGBM (Table 1), with *F. grandifolia* as the only species with a >10% increase (Table 2).
- Stem density declined for all species from 2018 to 2023, with the exception of *A. platanoides, N. sylvatica*, and *A. rubrum* whose stem densities did not change with time (Table 1).
- Overall, trees in the canopy such as the *Quercus* sp. played an important role in AGBM carbon storage (Table 1). However, *Quercus* sp. were largely absent from the understory (*data not shown*).

Discussion

- Though declines in live AGBM were found to be non-significant, this downward trend is contrary to what was observed in the 2013-2018 census interval, where a significant increase in the GNA's live tree carbon storage was documented (Schedlbauer & Polohovich 2018). This demonstrates that a shift in carbon accumulation is occurring in the forest.
- In 2018, low levels of dead wood were observed in the GNA. This observation was consistent with other broadleaf forests with high stem densities of *L. tulipifera*, due to fast decomposition rates in the species (McGarvey et al. 2015). An increased dead wood pool (Fig. 3) in a forest with a high density of *L. tulipifera*, such as the GNA, suggests input via death of canopy trees (McGarvey et al. 2015).
- If current trends persist, the *Quercus* sp. and *F. americana* will disappear entirely from the GNA. These species were absent from the understory environment in 2023 (*data not shown*). This change is likely driven by high levels of deer browse, the presence of the invasive *A. platanoides*, and the presence of emerald ash borer at the site.
- The species with the highest stem density, *F. grandifolia* (Table 1), is at risk in the future due to the newly identified beech leaf disease. It is likely this species will begin to decline in the coming years.
- The diversity of the canopy environment is at risk. Lack of regeneration of trees species that are absent from the understory will lead to a relatively homogenous forest with a greater density of understory and non-native trees. In the future, the GNA will likely become densely populated by *L. tulipifera, A. rubrum*, and *A. platanoides*.
- Ecosystems with higher species richness are more resilient to disturbance (Fotis et al. 2018). Active management will likely be necessary in the GNA, as well as in similar fragmented temperate broadleaf forests to prevent the loss of tree species diversity. Maintaining forest diversity will improve forest ecosystem resilience to disturbance, such as climate change, and prevent future loss of forest carbon storage potential .

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