Hindawi Publishing Corporation
International Journal of Forestry Research
Volume 2010, Article ID 401951, 10 pages
doi:10.1155/2010/401951

Research Article

Documentation of Significant Losses in *Cornus florida* L. Populations throughout the Appalachian Ecoregion

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Received 17 June 2009; Revised 15 October 2009; Accepted 19 January 2010

Academic Editor: Terry L. Sharik

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Over the last three decades the fungus *Discula destructiva* Redlin has severely impacted *Cornus florida* L. (flowering dogwood—hereafter "dogwood") populations throughout its range. This study estimates historical and current dogwood populations (number of trees) across the Appalachian ecoregion. Objectives were to (1) quantify current dogwood populations in the Appalachian ecoregion, (2) quantify change over time in dogwood populations, and (3) identify trends in dogwood population shifts. Data from the USDA Forest Service Forest Inventory and Analysis (FIA) database were compiled from 41 FIA units in 13 states for county-level estimates of the total number of all live dogwood trees on timberland within the Appalachian ecoregion. Analysis of covariance, comparing historical and current county-level dogwood population estimates with average change in forest density as the covariate, was used to identify significant changes within FIA units. Losses ranging from 25 to 100 percent of the sample population ($P < .05$) were observed in 33 of the 41 (80 percent) sampled FIA units. These results indicate that an important component of the eastern deciduous forest has experienced serious losses throughout the Appalachians and support localized empirical results and landscape-scale anecdotal evidence.

1. Introduction

Cornus florida L. (flowering dogwood—hereafter referred to as "dogwood") is widely distributed across the eastern United States (U.S.), including the Appalachian ecoregion. Dogwood is one of the most common understory trees in North America and is an important member of the Eastern deciduous forest that has been and is currently threatened by an imported fungus [1, 2]. Extensive dogwood mortality throughout the east and particularly the Appalachian ecoregion has been attributed to the fungus *Discula destructiva* Redlin (Dogwood anthracnose) [3–5].

Botanical surveys conducted throughout the twentieth century have documented the abundance of dogwood in the eastern U.S. [6]. Measures of high relative density and elevated importance values prior to *Discula destructiva* infestation were reported by Hannah [7] in North Carolina, Quarterman et al. [8] in Tennessee, Muller [9] in Kentucky, Carr and Banas [10] in Virginia, and Sherald et al. [11] in Maryland. Dogwood is also a common component of second-growth hardwood stands [12, 13], an important understory component of old-growth forests [14, 15], and an important source of calcium, in the form of leaf litter, in the surface horizons of some forest soils [16, 17].

Discula destructiva was identified as the causal agent for dogwood anthracnose in 1991 [4]. This fungus is thought to have originated from Asia and was introduced into the United States through infected *Cornus kousa* L. (kousa dogwood) stock [18]. While symptoms of *D. destructiva* were first observed in 1977 on native *Cornus nuttallii* (Pacific dogwood) in southern Washington, similar symptoms were observed in the eastern U.S. in 1979 throughout southeastern New York and southwestern Connecticut [19]. By 1989 *D. destructiva* had spread through the Appalachian Mountains as far south as Alabama [19]. Although smaller stems appear more susceptible, *D. destructiva* attacks aboveground portions of trees of any size [3]. Mortality results from either repeated defoliation or girdling from cankers [18].

Dogwood mortality is extensive following local colonization by *D. destructiva* [1, 6, 20–22]. While many studies have quantified local losses of dogwood [6, 10, 11, 20–22] specifically attributed to *D. destructiva*, few, if any, studies have quantified large-scale losses across entire ecoregions. These studies have been important for filling knowledge gaps about the impacts of *Discula destructiva* on dogwood populations. However, large-scale assessments are lacking. Both remote-sensing products and field-based large-scale forest inventories, such as implemented by the U.S. Department of Agriculture Forest Service Forest Inventory and Analysis (FIA) program, provide important data for monitoring forest attributes, including tree species population shifts, across large regions. Remote-sensing products are not suited for identifying individual species over large swaths of forests; therefore large-scale inventories must be relied on. Here we estimate natural dogwood populations (number of trees) for the Appalachian ecoregion for two periods, 1984–1993 (time 1) and 2004–2006 (time 2). Estimates are based on state-level forest land inventories conducted by FIA. Changes from time 1 to time 2 are quantified at the county, FIA unit (geopolitical boundaries routinely used by FIA for analysis and reporting), and ecoregion scale, and significant losses or gains are identified. Specific objectives were to (1) quantify current dogwood populations in the Appalachian ecoregion, (2) quantify changes in dogwood populations from the mid 1980's to 2006 and (3) identify trends in dogwood population shifts for the same period. Our hypothesis is that significant losses are widespread throughout the Appalachian ecoregion. While *D. destructiva* is known to reduce dogwood populations, we do not identify the one or most culpable agent of loss. The primary objective is to quantify large-scale changes, through comparisons of large-scale forest inventories, to the population of a tree species known to be experiencing localized losses due to a pathogen with a large geographical distribution.

2. Materials and Methods

The forest inventory conducted by FIA is a year-round effort to collect and disseminate information and statistics on the extent, condition, status, and trends of forest resources across all ownerships [23]. In the late 1990s, FIA began a transition from irregular and asynchronous periodic inventories to annual inventories [24]. Before 2000, most inventories were periodic; after 2000 most states have been inventoried annually. FIA applies a nationally consistent sampling protocol using a quasisystematic design covering all ownerships in the entire nation [24]. For this study, data were collected from 41 FIA units in 13 states (Figure 1). Fixed-area plots were installed in locations that have accessible forest land cover [24]. Field crews collect data on more than 300 variables, including land ownership, forest type, tree species, tree size, tree condition, and other site attributes (e.g., slope, aspect, disturbance, land use) [25, 26]. Plot intensity for field-collected data is approximately one plot for every 2,400 hectares (6,000 acres) of land. Briefly, the plot design for FIA inventory plots consists of four 7.3-meter (24-ft.) fixed-radius subplots spaced 36.6 meters (120 ft.) apart in a triangular arrangement with one subplot in the center [24]. All trees with a diameter at breast height (dbh) of at least 12.7 cm (5 in.) are inventoried on forested subplots. Within each subplot, a 2.1-meter (6.8 ft.) radius microplot is established wherein all live tree saplings (dbh $\geq$2.54 cm and <12.7 cm) are tallied according to species.

The public Forest Inventory and Analysis (FIA) database (FIADB) contains both current and historical inventory data [27]. Forest Inventory Mapmaker 3.0 [28] was used to access the FIADB and capture county-level estimates of the total number of all live trees $\geq$2.54 cm for dogwood and total volume and number of all live trees for all species on timberland (forest land not administratively withdrawn from timber production (e.g., wilderness areas or "reserved" forest land)) within a broad definition of the Appalachian ecoregion. We included data from FIA units that intersected any one of the seven level-III EPA Ecoregions [29] that comprise the Appalachian region. The Level III Ecoregions are the Ridge and Valley, Blue Ridge, Central Appalachians, Southwestern Appalachians, North Central Appalachians, Northern Appalachian Plateau and Uplands, and the Western Allegheny Plateau.

County-level estimates of natural dogwood populations and the number and volume of all live trees for all species were generated for two periods in time and labeled time 1 and time 2 (Table 1). Perfect alignment of inventory dates was not possible due to the nature of past periodic inventories and variability in transition times between periodic and annual inventory designs [24]. The data labeled "time 1" ranged from 1984 in Virginia to 1993 in New York (Table 1) and represents a time period early in the spread of the disease. The dates for the data labeled "time 2" ranged from 2003 to 2006. Individual counties were assigned to FIA units that correspond to both political and ecological boundaries. Average county-level absolute change and relative change were calculated for each county. Average annual change was calculated by dividing the difference between times 1 and 2 for each county by the remeasurement period.

Simple linear regression (PROC REG) in SAS [30], relating dogwood population change to changes in all live volume (trees greater than 12.7 cm dbh), was used to determine the amount of change that may be attributed to changes in stand structure. An analysis of covariance (ANCOVA) Type III test of fixed effects (PROC GLM) was used to identify significant changes in dogwood tree populations within FIA units between times 1 and 2. Change in volume of all live trees greater than 12.7 cm dbh (a proxy for changes in forest density) for each county was included in the analysis as a covariate. Average annual change and relative change was then mapped according to FIA unit for visual interpretation.

3. Results

The dogwood population in the Appalachian ecoregion decreased approximately 57 percent between times 1 and 2 and losses occurred in all dogwood diameter classes (Figure 2). The current dogwood population estimate in the Appalachian ecoregion is 2.215 billion individuals, down from an estimated 5.162 billion. Considerable variation

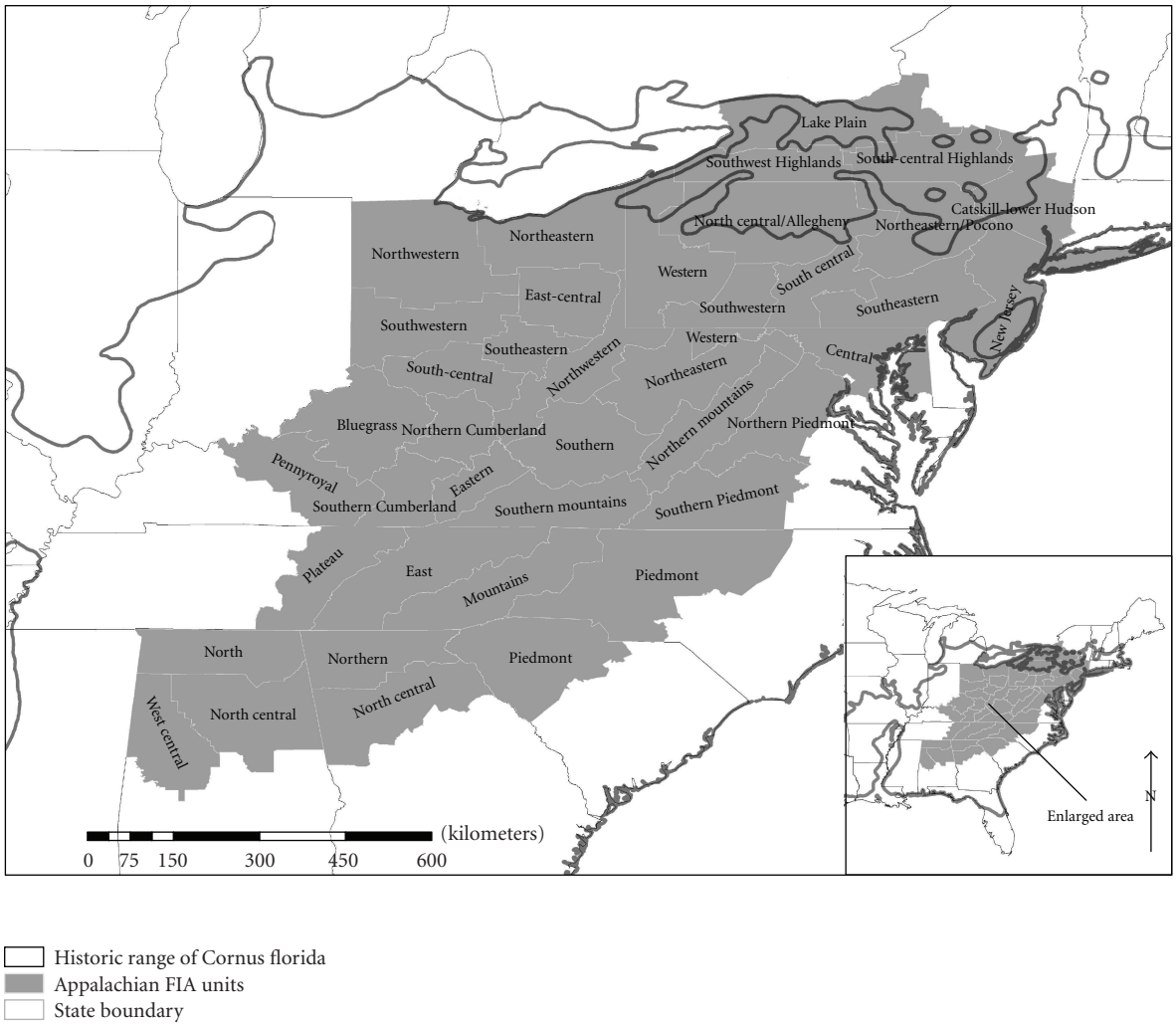


Figure 1: The Appalachian ecoregion and associated FIA unit boundaries.

existed among the estimates of county-level populations within each time period. Time 1 averaged 9.15 million (std. dev. = 8.06 million, max. = 42.02 million, min. = 0) individuals per county while time 2 averaged 3.93 million (std. dev. = 4.26 million, max. = 32.94 million, min. = 0) individuals per county.

Areas in West Virginia, Virginia, Tennessee, Ohio, North Carolina, New York, and Maryland showed the largest losses (Table 1). Sixty-three percent (353) of Appalachian counties experienced dogwood population losses greater than 50 percent while thirty-seven percent exhibited losses of greater than 75 percent.

The regression analysis indicated that a significant relationship existed between county-level dogwood population change and all live-tree volume ($P < .0001$) between times 1 and 2, confirming the decision to use change in all live tree volume as a covariate in the regional analysis by FIA unit. The regional analysis (ANCOVA) showed significant ($\alpha = 0.05$) losses in 33 of the 41 (80 percent) sampled FIA units (Figure 3). While the central and southern portions of the Appalachian ecoregion experienced larger absolute losses (Figure 3(a)) of dogwood, the populations in the northern portions experienced greater proportional losses (Figure 3(b)). FIA units in New York, Ohio, and Pennsylvania experienced severe losses relative to population estimates at time 1. In New York, dogwood populations in FIA units decreased 100, 98, 83, and 56 percent in the South-Central Highlands, Southwest Highlands, Catskill-Lower Hudson, and Lake Plain units, respectively (Table 1). In Ohio, population losses were 85, 82, 77, 77, 72, and 62 percent for the Northwestern, Southwestern, South-Central, Northeastern, Southeastern, and East-Central FIA units, respectively. Populations in Pennsylvania decreased by 76, 75, 75, 67 and 44 percent in the Southwestern, Southeastern, South Central, Western, and Northeast/Pocono units, respectively. While the mean county-level dogwood population increased in the North Central Allegheny unit of Pennsylvania, the increase was not statistically different from 0. The largest absolute mean county-level decrease was a loss of 13.80 million trees per county ($P = .0001$) in the Southern unit of West Virginia. The largest relative loss occurred in the South-Central Highlands unit of New York (100 percent).

Table 1: Estimates of mean county level dogwood populations for times 1 and 2, mean difference, relative mean difference, and result of ANCOVA for each FIA regional unit.

State	FIA Unit Name	$n^{(1)}$	Time 1 Mean[2]	Time 1 SE	Time 2 Mean	Time 2 SE	Difference		ANCOVA[3] Time effect		ANCOVA[3] Covariate effect	
					trees			*percent*	$F_{(1,n)}$	*P-value*	$F_{(1,n)}$	*P-value*
Alabama	West Central	9	20,695,764	3,274,020	10,031,008	2,016,787	−10,664,756	−52	12.29	**.0032**	4.68	**.0472**
(1990–2006)[4]	North Central	15	21,507,327	2,943,946	13,406,251	1,840,435	−8,101,076	−38	9.17	**.0054**	3.31	.0799
	North	10	9,244,358	1,878,898	2,912,652	805,238	−6,331,706	−68	20.47	**.0003**	8.89	**.0084**
Georgia	North Central	32	7,313,091	805,778	4,458,056	577,459	−2,855,035	−39	19.63	**<.0001**	44.85	**<.0001**
(1989–2005)	Northern	21	13,073,967	1,412,887	7,310,997	944,318	−5,762,970	−44	24.93	**<.0001**	29.96	**<.0001**
Kentucky	Eastern	8	10,306,397	1,743,985	6,442,801	1,630,781	−3,863,597	−37	7.01	**.0201**	6.21	**.0270**
(1988–2005)	Northern Cumberland	13	9,990,609	1,275,932	4,001,196	800,892	−5,989,413	−60	18.77	**.0002**	2.21	.1510
	Southern Cumberland	12	13,763,014	2,296,954	7,067,097	938,907	−6,695,917	−49	18.32	**.0003**	10.98	**.0033**
	Bluegrass	23	1,039,546	424,357	974,558	198,036	−64,988	−6	0.40	.5308	1.71	.1981
	Pennyroyal	20	5,654,549	833,179	4,102,760	724,316	−1,551,789	−27	7.07	**.0115**	17.84	**.0002**
Maryland	Central	14	3,056,785	868,256	854,696	355,430	−2,202,089	−72	6.15	**.0202**	0.71	.4081
(1986–2005)	Western	2	6,446,816	4,483,348	2,721,425	2,721,425	−3,725,392	−58	18.82	.1442	18.74	.1445
NewJersey	New Jersey	10	1,988,159	832,293	1,056,032	670,973	−932,127	−47	0.70	.4155	0.02	.8852
(1987–2005)												
NewYork	Lake Plain	4	888,319	647,869	391,994	391,994	−496,325	−56	0.77	.4216	0.73	.4332
(1993–2003)	Southwest Highlands	3	979,608	393,482	21,541	21,541	−958,067	−98	3.03	.1801	0.81	.4347
	South-Central Highlands	6	845,510	262,091	0	0	−845,510	−100	8.41	**.0176**	0.08	.7787
	Catskill-Lower Hudson	7	2,637,366	668,206	446,236	218,787	−2,191,130	−83	8.52	**.0139**	0.00	.9883
NorthCarolina	Piedmont	35	12,946,425	1,185,717	6,299,325	678,232	−6,647,100	−51	46.25	**<.0001**	30.34	**<.0001**
(1984–2005)	Mountains	21	15,561,452	2,239,385	3,889,770	1,055,649	−11,671,681	−75	40.21	**<.0001**	13.74	**.0006**
Ohio	South-Central	10	12,575,259	3,327,952	2,949,358	917,571	−9,625,901	−77	18.20	**.0005**	9.59	**.0065**
(1991–2005)	Southeastern	7	16,271,863	3,664,634	4,594,509	820,116	−11,677,355	−72	12.12	**.0051**	1.88	.1981
	East-Central	11	9,344,192	1,808,647	3,547,333	1,074,389	−5,796,859	−62	9.69	**.0057**	1.91	.1827
	Northeastern	14	2,358,145	635,583	542,080	168,966	−1,816,064	−77	7.47	**.0114**	0.11	.7412
	Southwestern	10	2,640,831	1,469,844	468,895	210,824	−2,171,937	−82	6.54	**.0204**	9.85	**.0060**
	Northwestern	8	1,822,098	797,893	266,995	185,833	−1,555,103	−85	6.53	**.0240**	7.36	**.0177**

Table 1: Continued.

State	FIA Unit Name	$n^{(1)}$	Time 1 Mean[(2)]	Time 1 SE	Time 2 Mean	Time 2 SE	Difference		ANCOVA[(3)] Time effect		ANCOVA[(3)] Covariate effect	
					trees			*percent*	$F_{(1,n)}$	*P-value*	$F_{(1,n)}$	*P-value*
Pennsylvania	South Central	9	4,059,553	803,890	1,012,088	321,546	−3, 047, 465	−75	18.65	**.0006**	4.60	**.0489**
(1989–2004)	Western	11	6,083,886	1,372,618	2,025,858	646,447	−4, 058, 028	−67	9.47	**.0062**	2.71	.1162
	North Central/Allegheny	12	1,530,963	347,328	1,543,194	649,859	12, 231	1	0.11	.7466	1.49	.2358
	Southwestern	5	6,139,095	3,209,492	1,490,563	1,265,416	−4, 648, 532	−76	2.50	.1579	0.80	.4009
	Northeastern/Pocono	11	1,476,173	435,794	831,137	548,256	−645, 036	−44	1.84	.1908	5.77	**.0267**
	Southeastern	11	2,750,142	669,852	681,959	269,232	−2, 068, 183	−75	15.54	**.0009**	11.55	**.0030**
SouthCarolina	Piedmont	18	14,121,375	1,782,213	8,456,840	937,465	−5, 664, 534	−40	12.76	**.0011**	4.68	**.0379**
(1986–2006)												
Tennessee	Plateau	16	14,451,884	2,345,046	4,144,037	510,643	−10, 307, 847	−71	32.60	**<.0001**	10.72	**.0027**
(1989–2005)	East	27	9,121,866	1,349,548	3,603,451	480,197	−5, 518, 414	−60	24.19	**<.0001**	9.10	**.0040**
Virginia	Southern Piedmont	17	14,397,395	1,386,403	8,384,910	677,451	−6, 012, 485	−42	32.03	**<.0001**	15.67	**.0004**
(1984–2006)	Northern Piedmont	17	11,557,137	1,619,409	4,384,169	785,853	−7, 172, 968	−62	45.37	**<.0001**	25.94	**<.0001**
	Northern Mountains	14	12,462,577	1,997,602	2,373,419	576,140	−10, 089, 157	−81	41.67	**<.0001**	13.44	**<.0001**
	Southern mountains	17	9,589,499	853,928	3,115,279	508,146	−6, 474, 220	−68	63.99	**<.0001**	10.33	**<.0001**
WestVirginia	Northeastern	18	7,646,410	1,342,850	2,716,840	942,141	−4, 929, 570	−64	8.85	**.0054**	0.07	.7944
(1989–2005)	Southern	14	15,904,120	1,773,008	2,106,411	696,818	−13, 797, 709	−87	59.06	**<.0001**	3.03	.0940
	Northwestern	19	8,519,707	1,562,666	4,188,189	1,043,101	−4, 331, 518	−51	12.45	**.0012**	20.05	**<.0001**

(1) Number of counties located within the unit.
(2) Mean number of dogwood stems greater than 1-inch diameter in counties located within the unit.
(3) Type III tests comparing time 1 county-level estimates to time 2 county-level estimates with change in stand density as the covariate.
(4) Inventory year associated with each state for both time 1 and time 2.

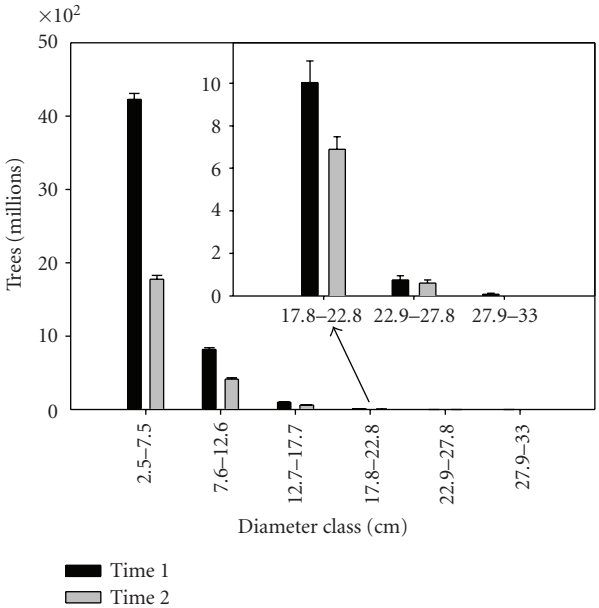


Figure 2: Estimated dogwood populations for the Appalachian ecoregion for times 1 and 2 by diameter class.

Average annual losses were the largest in the Southern unit of West Virginia (Figure 3(a)) which lost an average of approximately 0.86 million trees per year (Table 2). The smallest average annual loss of 3,800 trees per year was found in the Bluegrass unit of Kentucky. However, this unit is one of the least forested sections of Kentucky. The only positive mean annual change was in the North Central unit of Pennsylvania.

While all species experienced losses in the smallest diameter classes (likely a result of forest maturation), dogwood appeared to suffer disproportionate losses (Figure 4). With the exception of a complete loss of the largest diameter class of dogwood (27.94–33.01 cm), the relative loss decreased with increasing size class. That is, the largest losses were in the smaller diameter classes. All diameter classes experienced relative losses of at least 20 percent. Conversely, for all tree species relative gains were found in all diameter classes larger than 17.78 cm, and no diameter class experienced a loss of greater than 12 percent (Figure 4).

4. Discussion

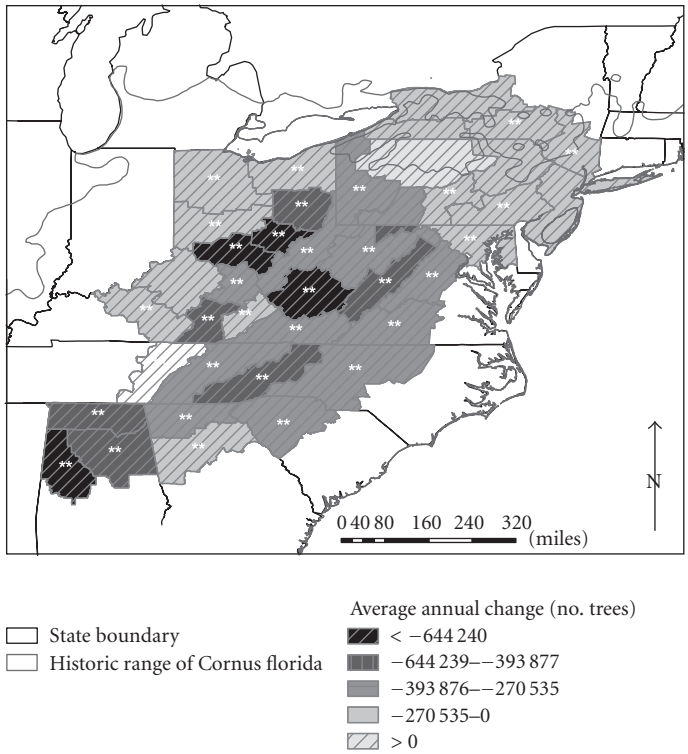
Dogwood populations decreased considerably across the Appalachian ecoregion during the period studied. Proportional losses were greater in the north than in the south. Williams and Moriarty [21] indicated that dogwood is a relatively minor component of many forest types near the northern periphery of its range and therefore considerable losses may have been realized in relatively small initial populations. However, symptoms of what was once labeled as "lower branch dieback" [31] and eventually attributed to *D. destructiva* [4] were first recognized in New York in the spring of 1979 [19]. Therefore, many stems could have succumbed to *D. destructiva* prior to sampling in the Northern FIA inventories during the late 1980s. While the Southern FIA inventories could have been impacted, the lag time that resulted from the movement of *D. destructiva* southward may have resulted in fewer stems counted because of the shorter period between infestation and inventory dates. In contrast to proportional changes in dogwood populations, absolute losses were greater in the south than in the north.

Despite the detection of significant losses in this study, our estimates of change were generally less than many documented studies at much smaller scales. For example, we found a 60-percent decline in the dogwood population in east Tennessee and 71 percent on the Cumberland Plateau; Hiers and Evans [6] reported dogwood losses of approximately 98 percent compared to population estimates first reported by McGee [32] in Tennessee. Myers et al. [33] also observed a significant decrease in dogwood on the Cumberland Plateau in Tennessee and documented the species complete disappearance from the subcanopy on their study site. Though we found smaller relative changes on the Cumberland Plateau in Tennessee than those noted by Myers et al. [33], losses were still substantial and averaged more than 10 million stems per county (Table 1). Dogwood populations were reduced by approximately 165 million trees, total, on the Cumberland Plateau over the time period studied.

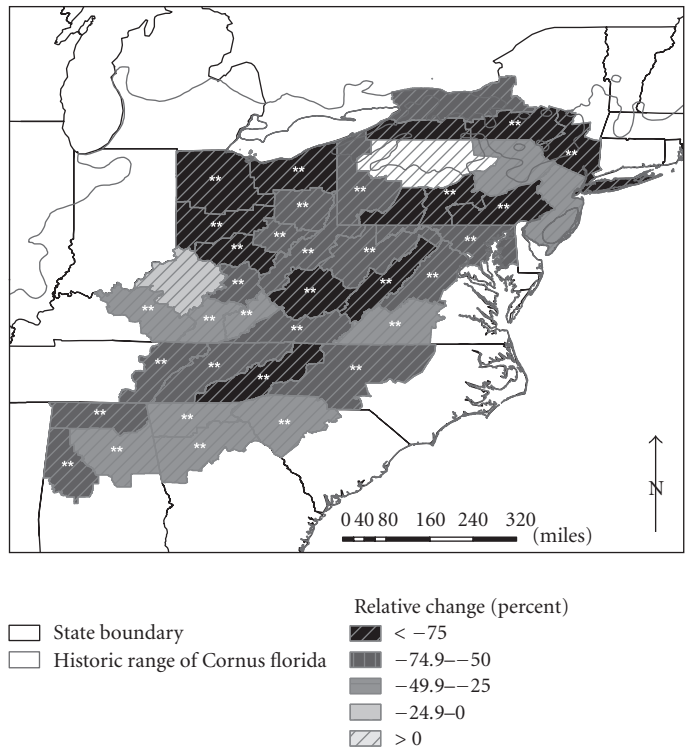
In Maryland, our study noted population declines of 58 and 72 percent in the Central and Western units. Similarly, Sherald et al. [11] documented dogwood mortality at approximately 77 percent between 1976 and 1992. Relative losses of dogwood populations in Pennsylvania FIA units ranged from 44 to 76 percent in this study, with the exception of the North Central Allegheny unit, which experienced no change. Williams and Moriarty [21] reported dogwood mortality between 58 and 68 percent throughout the area corresponding to the North Central Allegheny, Western Allegheny, Southwestern and Southwest Highlands FIA units (Figure 1). The lack of significant change in some units in Pennsylvania could be a result of the lower densities of dogwood [21], or a limited number of counties. For example, the Western unit in Maryland has only 2 counties.

The estimates reported here for time 1 were generated during a time when FIA implemented periodic inventories while time 2 estimates originated from the FIA program's annual inventory design [24]. As a result, some uncertainty is introduced when comparing estimates across time. However, analyses at broad scales, such as the one here, reduce the probability of the additional uncertainty appreciably influencing the results. Fei and Steiner [34] used similar methods (time 1 data were from periodic inventories and ranged from 1980 to 1995 while time 2 data were from annual inventories with a much smaller range) to identify large-scale increases in *Acer rubrum* L. (red maple) populations in eastern forests.

This analysis does not identify causal agents of dogwood mortality. However, given that we controlled for changes in stand structure through the use of changes in all live volume as a proxy for forest density, coupled with losses that correlate



(a)



(b)

Figure 3: Estimates of (a) average annual county-level change and (b) total relative change of dogwood tress for all FIA regional units comprising the Appalachian ecoregion. **Denotes a significant difference between Time 1 and Time 2 (alpha = 0.05). State boundary shapefile is provided by ESRI. FIA Unit boundary shapefile is provided by Joe McCollum, USDA Forest Service, Southern Research Station Forest Inventory & Analysis.

Table 2: Average annual county-level change (AAC), associated sampling error in number of trees and relative AAC of dogwood trees for each FIA unit in the Appalachian ecoregion.

State	FIA Unit Name	Average Annual Change (AAC)		
		trees	*SE*	*percent*
Alabama	West Central	−666,547	197,863	−3.22
	North Central	−506,317	150,897	−2.35
	North	−395,732	76,690	−4.28
Georgia	North Central	−178,440	34,580	−2.44
	Northern	−360,186	68,195	−2.75
Kentucky	Eastern	−227,270	109,481	−2.21
	Northern Cumberland	−352,318	95,554	−3.53
	Southern Cumberland	−393,877	112,491	−2.86
	Bluegrass	−3,823	18,666	−0.37
	Pennyroyal	−91,282	38,283	−1.61
Maryland	Central	−244,677	88,207	−8.00
	Western	−413,932	195,769	−6.42
NewJersey	New Jersey	−51,785	66,824	−2.60
NewYork	Lake Plain	−49,633	84,915	−5.59
	Southwest Highlands	−95,807	41,190	−9.78
	South-Central Highlands	−84,551	26,209	−10.00
	Catskill-Lower Hudson	−219,113	79,132	−8.31
NorthCarolina	Piedmont	−316,529	41,673	−2.44
	Mountains	−555,794	88,388	−3.57
Ohio	South-Central	−687,564	220,690	−5.47
	Southeastern	−834,097	260,894	−5.13
	East-Central	−414,061	130,431	−4.43
	Northeastern	−129,719	41,143	−5.50
	Southwestern	−155,138	99,974	−5.87
	Northwestern	−111,079	48,328	−6.10
Pennsylvania	South Central	−203,164	55,932	−5.00
	Western	−270,535	82,221	−4.45
	North Central/Allegheny	815	47,812	0.05
	Southwestern	−309,902	131,873	−5.05
	Northeastern/Pocono	−43,002	39,767	−2.91
	Southeastern	−137,879	43,230	−5.01
SouthCarolina	Piedmont	−283,227	77,810	−2.01
Tennessee	Plateau	−644,240	135,510	−4.46
	East	−344,901	70,056	−3.78
Virginia	Southern Piedmont	−273,295	63,397	−1.90
	Northern Piedmont	−326,044	49,764	−2.82
	Northern Mountains	−458,598	80,040	−3.68
	Southern mountains	−294,283	37,583	−3.07
WestVirginia	Northeastern	−308,098	57,479	−4.03
	Southern	−862,357	102,240	−5.42
	Northwestern	−270,720	78,845	−3.18

geographically with the known *D. destructiva* distribution, it can be assumed that *D. destructiva* is a major cause. We assume that a considerable amount of the dogwood loss we observed can be attributed to the impacts of the fungus *D. destructive*; other factors are likely to have played some role. For example, Pierce [35] attributed dogwood mortality in Indiana to competition with *Acer saccharum* Marsh. (sugar maple) mediated by fire suppression activities. In Kentucky, McEwan et al. [22] reported a 36-percent decrease in dogwood density in an old-growth stand prior to *D. destructiva* infestation. While it is possible that *D. destructiva* was present without having been documented,

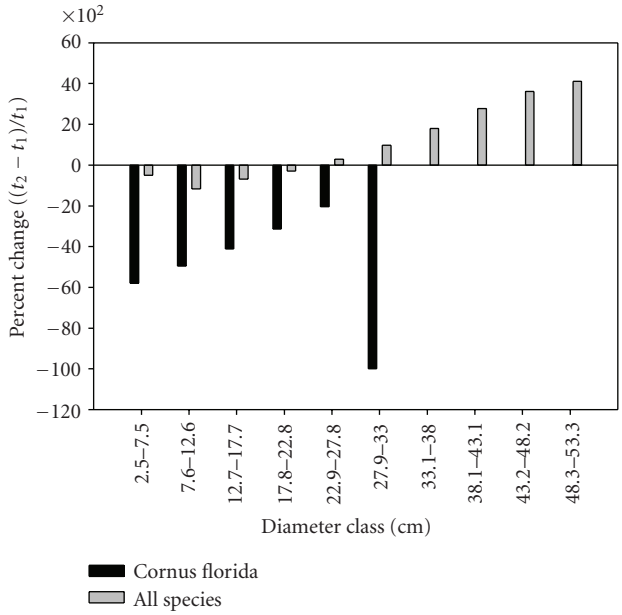


Figure 4: Total relative change of dogwood populations and populations of all species by diameter class.

McEwan et al. [22] suggested that factors such as canopy closure, drought, and natural canopy gap-dynamics may have been an important factor. We support this notion, as changes in dogwood populations were significantly related to changes in all live volume. The well-documented deleterious impacts of *D. destructiva*, however, cannot be ignored. According to reports from Anderson [36] and Knighten and Anderson [37, 38], *D. destructiva*-mediated dogwood mortality increased from 0 to 23 percent in the Appalachians between 1988 and 1993. Concomitantly, the area estimated to be infected with *D. destructiva* increased from 0.5 to 17.3 million acres over the same period [19]. Moreover, Windham et al. [39] reported widespread infection and rapid die-off of dogwood throughout the Great Smoky Mountains National Park in the early 1990's.

Slightly smaller losses in this study compared with other studies are likely an artifact of the data. FIA data are collected over a much larger scale. Therefore, the influence of localized events such as complete mortality in a specific area can be lessened. While small-scale studies with a more limited scope are able to provide specificity, FIA data are able to provide a more holistic ecosystem-wide view of forest changes. Used in combination, large-scale FIA and localized studies can be complementary wherein FIA data are used for hypothesis generation as a precursor to more focused small-scale studies of cause and effect. Or, as in this case, FIA data can be used to validate the findings of multiple small-scale studies at much larger scales.

5. Conclusion

This study empirically explored changes in dogwood populations in the Appalachian ecoregion by comparing estimates from large-scale forest inventories from two different points in time that covered approximately twenty years. Dogwood is an important tree in the Appalachian ecoregion. Its population has declined more than 50 percent in the last 2-3 decades. Decreases were widespread throughout almost all of the FIA units comprising the Appalachian ecoregion. In some areas dogwood populations have decreased to the point where an FIA inventory no longer detects the species. Our results confirm many smaller, localized investigations of dogwood mortality as well as a vast body of anecdotal evidence that has accumulated over time. Such large-scale reductions in dogwood populations, particularly in the midstory of eastern deciduous forests, may result in further expansion of generalist species like red maple as the vacated niche is filled.

Acknowledgments

The author owes Aaron R. Pierce and Christopher W. Woodall and three anonymous reviewers a great deal of gratitude for their suggested improvements for early drafts. This research was funded by the USDA Forest Service Southern Research Station Forest Inventory and Analysis program.

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