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Cover photo: Typical scene in a bottomland hardwood forest of the Albemarle Sound region. (photo courtesy of Daniel White, The Nature Conservancy)

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Abstract

The Albemarle Sound, a 6-million-acre watershed, contains some of the largest areas of bottomland hardwood habitat in the Eastern United States. Using close to 30 years of data from the Forest Inventory and Analysis Program, a study of the current status and trends in the Albemarle Sound's bottomland forest system was conducted. In 2012, bottomlands totaled approximately 800,000 acres and were composed of mainly swamps/bogs and floodplains. Swamps/bogs were dominated by tupelo (*Nyssa*) species and cypress (*Taxodium distichum*), while floodplains were dominated by tupelo, red maple (*Acer rubrum*), and a diverse mixture of hardwood species. Just over half of bottomland acreage was <60 years old, and younger forest had less tupelo and cypress than did older forest, but more loblolly pine. Over the last 30 years, the acreage of bottomland forest has not changed. Periods of overharvesting have occurred; the growth-to-removals ratio from the mid-1980s through the early 2000s was never higher than 1.2, and has since varied from 0.3 to 3.4. The net result is that total live-tree volume declined by 8 percent from its peak in 2002. The changes in growth and harvesting are reasonable when put in context with the region's recent history, both economic and ecologic.

Keywords: Bottomland hardwoods, FIA, forest inventory and analysis, growth, harvesting, removals.

INTRODUCTION

Among the myriad of freshwater estuaries found along the Atlantic, the Albemarle Sound, draining from southeast Virginia into northeast North Carolina, is the largest. This 6-million-acre watershed contains some of the largest areas of bottomland hardwood habitat in the Eastern United States. The Roanoke River, the largest tributary to Albemarle Sound, supports large stands of baldcypress-tupelo (*Taxodium-Nyssa*) swamps that are interspersed with centuries-old trees.

The Sound's bottomlands have long served as a fiber basket for a robust forest products industry while also providing valuable wildlife habitat and a source of drinking water for several large cities, including Norfolk and Virginia Beach. In a variety of ways, both nature and people rely on the services provided by Albemarle Sound's extensive floodplain forests. For that reason, many government agencies and nongovernmental organizations, including The Nature Conservancy, have worked to conserve hundreds of thousands of acres within Albemarle Sound over the last several decades.

This paper uses the Forest Inventory and Analysis (FIA) Database to describe the current state of bottomland forests in and near the Sound and to showcase trends related to the continued sustainability of that resource. While much has been written about Albemarle Sound's most famous landmark, the 112,000-acre Great Dismal Swamp (Carter and others 1994, Dabel and Day 1977, Day and others 1998, Simpson 1998), a U.S. Fish and Wildlife Service National Wildlife Refuge, the rest of the bottomland ecosystem has not been extensively studied. Despite the importance of these floodplain forests, the amount of published forest inventory information about this system is limited. Past Forest Service, U.S. Department of Agriculture publications have covered portions of the Albemarle Sound region (Conner 2003, Rose 2007, Rose 2009) but have not focused specifically on the Albemarle Sound floodplain forests. Below, we seek to address this information gap on the condition and extent of this critical resource.

METHODS

Study Area

The data for this study were collected in Virginia and North Carolina within a circle centered on latitude 36.46° N. by longitude 77.20° W. with a radius of 70 miles (fig. 1). This circle encompasses a majority of the Albemarle Sound's watershed and associated bottomland hardwood forests, excepting that portion of the Roanoke River that is located upstream of the hydroelectric dam at Roanoke Rapids, VA. The western portion of the Sound's watershed consists of "brownwater" or "red" river systems (Kellison and Young 1997) such as the Roanoke, Meherrin, and Nottoway Rivers. These rivers originate in the Piedmont and cross into the Coastal Plain at the Atlantic Seaboard Fall Line. They are swifter moving and carry more nutrient-rich sediment derived from uplands than river systems that fall entirely within the Coastal Plain. Coastal Plain rivers are classified as "blackwater" systems and are slower moving, inherently less fertile, and typified by muck swamp communities. Numerous blackwater rivers discharge into the Coastal Plain reaches of the Sound's brownwater rivers.

Forests within this area consist of a variety of species, including red maple (*Acer rubrum*), sweetgum (*Liquidambar styraciflua*), baldcypress (*Taxodium distichum*), swamp tupelo (*Nyssa biflora*), and green ash (*Fraxinus pennsylvanica*).

Forest Inventories

The measurements for this study were based on five inventories conducted by the Forest Service FIA Program. While FIA data have been collected in North Carolina and

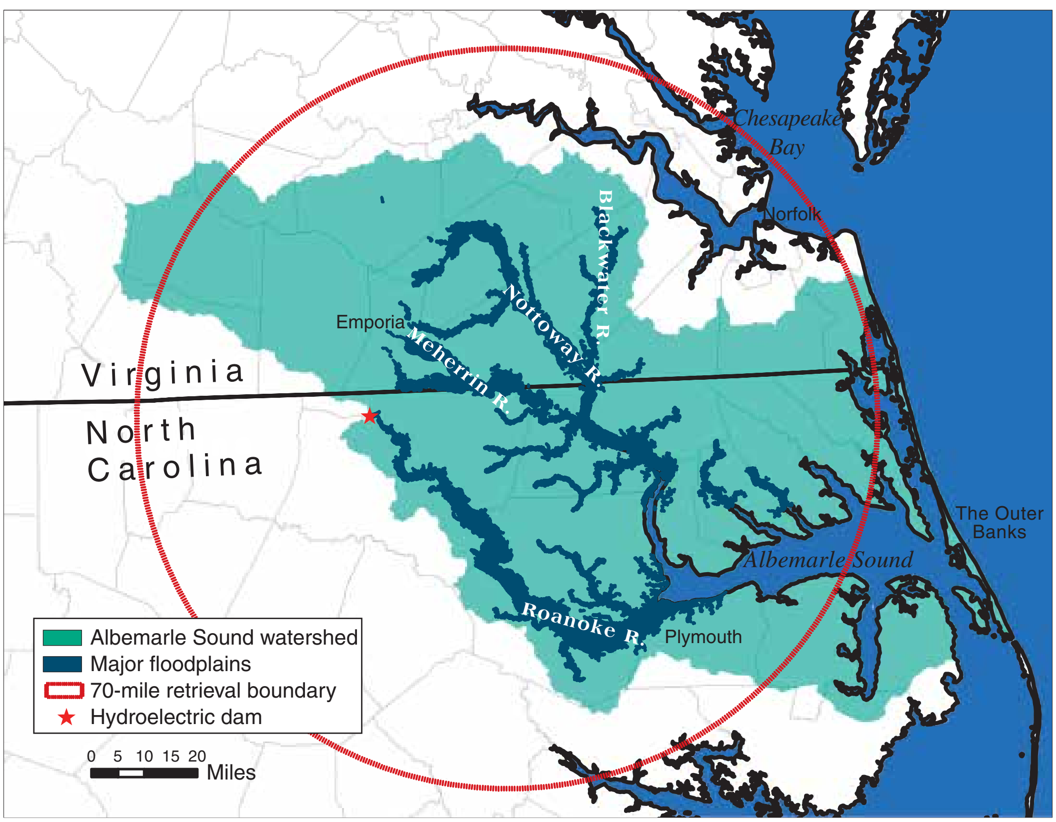

Figure 1—Map of the area of interest, centered on the Albemarle Sound watershed in Virginia and North Carolina.

Virginia for several decades, these two States implemented sampling regimes at slightly different times. This resulted in inventory dates not coinciding exactly. We obtained summarized data from FIA's online tool EVALIDator (Miles 2015). The data were selected as follows:

North Carolina	Virginia	Data set name (for this report)	Number of plots
1984	1985	1985	306
1990	1992	1992	297
2002	2001	2002	171
2007	2007	2007	181
2012	2012	2012	189

Data Collection

The first two inventories (1985, 1992) were completed in 1 to 2 years using a variable radius sampling design. At each forested location, a sample cluster of five satellite points was installed. At each sampling point, trees ≥5.0 inches diameter at breast height (d.b.h.) were selected using a 37.5-square-foot basal area factor prism. All following surveys (2001 and later) used an annualized fixed-plot sample design with 20 percent of the plots being measured each year over a 5-year period. After all plots were measured, the cycle started again. This sample design consisted of four 24-foot-radius subplots 120 feet apart where all trees ≥5.0 inches d.b.h. were measured. Trees 1.0 to 4.9 inches d.b.h. were measured on 6.8-foot-radius microplots. Growth and removal estimates were based on remeasured plots only and are, by nature of the current sample design, based upon measurements spread across a 10-year period. For example, removals for the 2012 survey were based upon changes between time one (plots measured from 2003 through 2007—the 2007 survey) and time two (plots measured from 2008 through 2012—the 2012 survey). More detailed information on the current FIA sample design can be found in Bechtold and Patterson (2005). Further discussion and comparison of the two sample designs can be found in Rose (2007).

Data Analysis

At close to 1 million acres of bottomland forest, the area of interest was large enough to generate results that had reasonable sample error rates (<15 percent). However, further restricting sample sizes by creating many categories of an attribute (e.g. forest type) resulted in much larger errors for each metric analyzed. Therefore, results were reported in fewer, more broad categories (e.g., all hardwood forest types) instead of finer categories (e.g. red oak-hickory or yellow-poplar-sweetgum). Error rates were noted generally for a table but also for specific attributes in some instances. FIA confidence intervals are based on one standard deviation (68.27 percent). Using that protocol, the estimate would cover the true mean 68.27 percent of the time. Tree species nomenclature is based on Little (1979).

Since the focus of this analysis was resource sustainability, only land available for timber production (timberland) was selected. U.S. Fish and Wildlife Service National Wildlife Refuges were omitted from this timberland classification due to their lack of active timber management. We decided to investigate privately owned timberland for this analysis to ensure that only available timber was included.

For age-based analyses, age classes were delineated based upon stand development ecology. Young forest (0 to 20 years) represented those years prior to full utilization of the site's resources, loosely modeled on the stem initiation phase of forest succession (Oliver and Larson 1990). Saplings and small poletimber were the dominant size classes in this age group. Maturing forest (21 to 60 years) represented stands in the stem exclusion phase of forest succession. This was defined as rapidly growing stands with some competition-induced mortality that are still somewhat biologically immature. Poletimber and small sawtimber-sized trees were dominant in this age group. Mature forest (61+ years) represented stands that had reached biological maturity as well as, in many cases, economic maturity. Sawtimber-sized trees were dominant in this age group.

Only a subset of live-tree data was used for analyses of relative volume or density within age classes, defined by a diameter threshold. Those stems that best reflected the true nature of the age class were included. For young forest (0 to 20 years), only stems ≤8.9 inches d.b.h. were included. While some volume and density of stems fell above this threshold, these larger stems were likely not part of the stand's regeneration following disturbance; they were likely uncut or surviving residuals. For maturing and mature forest, only stems ≥9.0 inches d.b.h. were included. This threshold captured a large majority of the volume in each age class (>80 percent), likely leaving out only a small number of suppressed or midstory trees.

RESULTS

Current Conditions of Bottomland Forest

The region's bottomland forests covered approximately 800,000 acres and consisted of roughly equal parts of swamps/bogs, broad floodplains and bottomlands, and narrow floodplains and bottomlands (table 1). Most forests were in the oak-gum-cypress forest-type group (*Quercus-Nyssa-Taxodium*), followed by the elm-ash-cottonwood group (*Ulmus-Fraxinus-Populus*). For the remainder of this analysis, broad and narrow floodplains were combined, due both to compositional similarities and the resultant reduction in error rates.

Sixty-one tree species were present, and as measured by overall relative volume, hydric species like baldcypress, water tupelo (*Nyssa aquatica*), and swamp tupelo were the most dominant (table 2). Red maple was also prevalent, as were oak (*Quercus*) species, sweetgum, and ash species. Cypress and tupelo accounted for 66 percent of the total volume in swamps/bogs versus only 33 percent in floodplains. As a group, more mesic species like oaks, ashes, sweetgum, yellow-poplar (*Liriodendron tulipifera*), loblolly pine (*Pinus taeda*), and soft maples (e.g., red maple) accounted for 53 percent of total volume in the floodplains versus 31 percent in swamps/bogs.

The two major physiographic classes had a similar distribution of age classes (fig. 2). In swamps/bogs, approximately 48 percent of acreage was in mature forests (61+ years old), 35 percent in maturing forests (21 to 60 years old) and 17 percent in young forests (0 to 20 years old). In floodplains and bottomlands, approximately 42 percent of acreage was in mature forests (61+ years old), 42 percent in maturing forests (21 to 60 years old) and 16 percent in young forests (0 to 20 years old).

When all bottomland physiographic classes were combined, some differences in species composition were noted between the young and mature age classes. The maturing age class usually contained values between the other two (table 3). Given the larger error rates for species groups, only differences that seem likely to be significant are reported here. For relative volume, young forests had a lower proportion of cypress (2 percent versus 11 percent), a lower proportion of ash (1 percent versus 7 percent) and a greater proportion of loblolly and shortleaf pine (34 percent versus 2 percent) than did mature forests. While results also indicate that younger forests had a lower proportion of tupelo and blackgum than mature forests (15 percent versus 39 percent), the difference in the margin of error for both age classes makes this result inconclusive. The remaining species groups, including soft maple, sweetgum, and the oaks, had similar proportions of species groups in all age classes.

Table 1—Area of private timberland by forest-type group and bottomland physiographic class in the Albemarle Sound region, 2012

		Physiographic class			
Forest-type group	All classes	Narrow floodplains/ bottomlands	Broad floodplains/ bottomlands	Swamps/ bogs	All other[a]
			acres		
Loblolly-shortleaf pine	24,788	4,579	8,379	5,725	6,105
Oak-pine	26,656	11,509	5,796	3,324	6,028
Oak-hickory	61,418	34,102	—	—	27,316
Oak-gum-cypress	507,490	172,255	106,474	198,523	30,237
Elm-ash-cottonwood	176,408	67,515	52,894	35,422	20,578
Nonstocked	8,624	7,154	—	—	1,470
All groups	805,384	297,114	173,542	242,994	91,734

— = no sample for the cell.

Note: Error rates for the total of each physiographic class (excluding "All other") averaged 15 percent and ranged from 13 to18 percent.

Note: Error rates for the total of each forest-type group (excluding "Nonstocked") averaged 28 percent and ranged from 10 to 45 percent.

[a] Small drains, bays and wet pocosins, beaver ponds, and other hydric.

Table 2—Net volume of live trees (≥5.0 inches d.b.h.) on private timberland by species group and major bottomland physiographic class in the Albemarle Sound region, 2012

		Major physiographic class	
Species group	All classes	Floodplains and bottomlands	Swamps/ bogs
		million cubic feet	
Miscellaneous species[a]	90.9	81.2	9.7
Other eastern soft hardwoods[b]	122.9	108.8	14.1
Lobolly and shortleaf pine	67.9	55.9	11.9
Ash	150.9	126.2	24.8
Sweetgum	178.7	158.7	20.0
Yellow-poplar	79.1	60.4	18.7
All oaks[c]	191.1	141.0	50.1
Soft maple (red maple)	249.4	185.9	63.5
Cypress (baldcypress)	174.3	61.1	113.2
Tupelo and blackgum	693.7	401.4	292.4
All groups	1,998.9	1,380.5	618.4

d.b.h. = diameter at breast height.

Note: Error rates for species group totals averaged 22 percent and ranged from 13 to 26 percent.

Note: Error rates for species group within each physiographic class averaged 33 percent, and ranged from 16 percent (soft maple in floodplains) to 84 percent (loblolly in swamps).

[a]Miscellaneous species: primarily American beech, eastern cottonwood, American holly, Atlantic white-cedar, musclewood, and 30 other species.

[b]Other eastern soft hardwoods: primarily American sycamore, river birch, hackberry, black willow, slippery elm, and eight other species.

[c]All oaks: primarily willow oak, laurel oak, white oak, swamp chestnut oak, cherrybark oak, and seven other species.

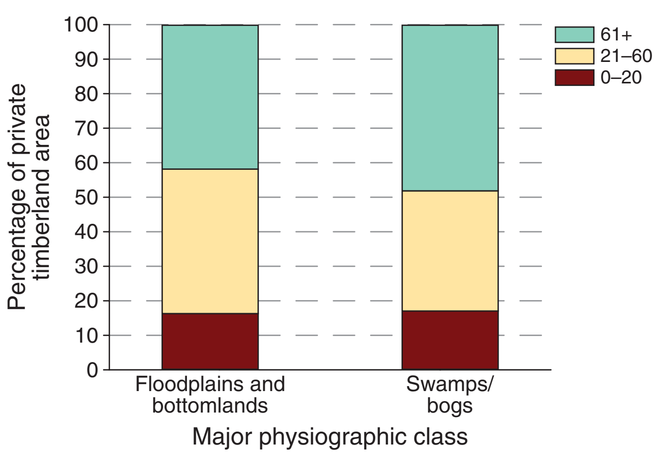

Figure 2—Distribution of private timberland by stand-age class (years) and major physiographic class in the Albemarle Sound region, 2012. Error rates for all age/physiographic combinations averaged 32 percent and ranged from 21 to 51 percent.

Table 3—Relative volume[a] of live trees (≥5.0 inches d.b.h.) on private timberland by species group and age class in the Albemarle Sound region, 2012 (all bottomland physiographic classes combined)

	Age class (years)		
Species group	0–20	21–60	61+
		percent	
Miscellaneous species[b]	10	5	4
Other eastern soft hardwoods[c]	12	7	6
Loblolly and shortleaf pine	34	7	2
Ash	1	6	7
Yellow-poplar	6	11	3
Sweetgum	10	10	8
All oaks[d]	4	13	11
Soft maple	7	13	10
Cypress	2	4	11
Tupelo and blackgum	15	24	39
All groups	100	100	100

d.b.h. = diameter at breast height.

Note: Error rates for species groups within an age class averaged 51 percent for the 0–20 age class, 29 percent for the 21–60 age class, and 31 percent for the 61+ age class.

[a]Volume is based on stems between 5.0 inches and 8.9 inches d.b.h. for the 0–20 age class and stems ≥9.0 inches d.b.h. for the 21–60 and 61+ age classes.

[b]Miscellaneous species: primarily American beech, eastern cottonwood, American holly, Atlantic white-cedar, musclewood, and 30 other species.

[c]Other eastern soft hardwoods: primarily American sycamore, river birch, hackberry, black willow, slippery elm, and eight other species.

[d]All oaks: primarily willow oak, laurel oak, white oak, swamp chestnut oak, cherrybark oak, and seven other species.

For relative stem density (table 4), many of the trends previously mentioned in the relative volume analysis remain consistent: young and mature forests differed compositionally, and maturing forests contained intermediate combinations of species. Compared to mature forests, young forests had a larger proportion of loblolly-shortleaf pine than did mature forests (22 percent versus 1 percent) and a smaller proportion of cypress (1 percent versus 8 percent). The tupelo-blackgum species group was less important in younger stands using relative stem density (3 percent versus 44 percent).

Table 4—Relative density[a] of live trees (≥1.0 inch d.b.h.) on private timberland by species group and age class in the Albemarle Sound region, 2012 (all bottomland physiographic classes combined)

Species group	Age class (years) 0–20	21–60	61+
	percent		
Miscellaneous species[b]	13	7	4
Other eastern soft hardwoods[c]	14	9	6
Loblolly and shortleaf pine	22	5	1
Ash	6	7	7
Yellow-poplar	6	9	2
Sweetgum	13	12	7
All oaks[d]	4	9	7
Soft maple	18	16	14
Cypress	1	4	8
Tupelo and blackgum	3	23	44
All groups	100	100	100

d.b.h. = diameter at breast height.

Note: Error rates for species groups within an age class averaged 49 percent for the 0–20 age class, 30 percent for the 21–60, and 28 percent for the 61+ age classes.

[a] Density is based on stems between 1.0 inch and 8.9 inches d.b.h. for the 0–20 age class and stems ≥9.0 inches d.b.h. for the 21–60 and 61+ age classes.

[b] Miscellaneous species: primarily American beech, eastern cottonwood, American holly, Atlantic white-cedar, musclewood, and 30 other species.

[c] Other eastern soft hardwoods: primarily American sycamore, river birch, hackberry, black willow, slippery elm, and eight other species.

[d] All oaks: primarily willow oak, laurel oak, white oak, swamp chestnut oak, cherrybark oak, and seven other species.

Trends over Time in Bottomland Forests

The total acreage of bottomland forests in the Albemarle Sound region was relatively consistent between 1985 and 2012 (774,000 to 820,000 acres), with the exception of 2002 (732,000 acres) (table 5). Hardwood forest types accounted for >90 percent of bottomland acreage during all time periods; conversely, pine types represented a small amount (approximately 5 percent) of total acreage during all time periods. Pine type acreage did not increase over time.

The overall volume per acre in bottomland forests fluctuated over the observed time period. Volume was 2,795 cubic feet per acre in 1985, peaked at 2,937 cubic feet per acre in 2002, only to decline to 2,702 cubic feet per acre by 2012. The post-2002 decline of 8.0 percent is equal to the margin of error (fig. 3).

Consistent with the volume-per-acre trend, most species groups declined slightly from 1985 to 2012, typically by 10 to 20 percent. Two notable exceptions were ash and oak, which increased by 41 and 57 percent, respectively.

Average annual mortality, net growth, removals, and the ratio of growth to removals varied dramatically between 1985 and 2012 (table 6). In 1985, the growth-to-removals ratio was 2.3:1.0, where growth was significantly higher than removals at 65.2 million cubic feet per year versus 28.0 million cubic feet per year, respectively. In 1992, the growth-to-removals ratio of 1.2:1.0 was approaching parity; growth and removals were 55.5 million cubic feet per year and 45.4 million cubic feet per year, respectively. In 2002, the growth-to-removals ratio was 1.0:1.0, where growth and removals were essentially even at approximately 36 million cubic feet per year. In 2007, the growth-to-removals ratio was much lower at 0.3:1.0, where growth and removals were 25.9 million cubic feet per year and 76.6 million cubic feet per year, respectively. In 2012, the trend was reversed, and the ratio was 3.4:1.0; growth and removals were 42.6 million cubic feet per year and 12.4 million cubic feet per year, respectively. Mortality increased in 2007 from previous levels but remained a small component of the overall gross stand-growth equation.

In order to look at the trend of net growth over time, growth was normalized by the amount of bottomland acreage existing at each time period. As measured by net growth per acre, growth in bottomlands declined substantially between 1985 and 2012. Net growth per acre was highest in 1985 at 79.6 cubic feet per acre per year, lowest in 2007 at 33.4 cubic feet per acre per year, and recovered to 53.0 cubic feet per acre per year in 2012. Removals per acre were highest in 2007, at 99.0 cubic feet per acre per year, and lowest in 2012, at 15.4 cubic feet per acre per year.

Table 5—Area of private timberland by forest-type group and survey year in the Albemarle Sound region (all bottomland physiographic classes combined)

Forest-type group	Survey year 1985	1992	2002	2007	2012
			acres		
Loblolly-shortleaf pine	38,567	30,630	37,813	25,271	24,788
Oak-pine	40,473	28,504	18,477	38,517	26,656
Oak-hickory	49,041	65,980	57,110	55,162	61,418
Oak-gum-cypress	572,101	541,866	468,407	475,182	507,490
Elm-ash-cottonwood	114,528	125,431	147,145	166,183	176,408
Nonstocked	5,363	15,164	2,781	13,716	8,624
All groups	820,073	807,575	731,732	774,032	805,384

Note: Error rates for forest-type groups (excluding nonstocked) within a survey period averaged 24 percent and ranged from 6 to 48 percent.

Note: Error rates for each survey period total averaged 7 percent and ranged from 5 percent to 8 percent.

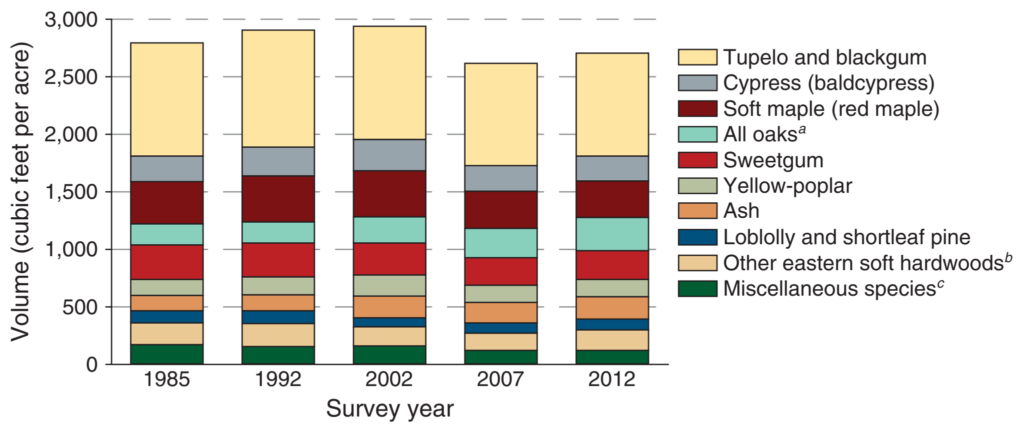

Figure 3—Volume per acre of live trees (≥5.0 inches diameter at breast height) by species group and survey year on private, bottomland timberland in the Albemarle Sound region. All bottomland physiographic classes combined. Error rates for total volume averaged 8 percent. Error rates for total acreage averaged 8 percent. Error rates for species group volume within a survey period averaged 20 percent.

[a] All oaks: primarily willow oak, laurel oak, white oak, swamp chestnut oak, cherrybark oak, and seven other species.

[b] Other eastern soft hardwoods: primarily American sycamore, river birch, hackberry, black willow, slippery elm, and eight other species.

[c] Miscellaneous species: primarily American beech, eastern cottonwood, American holly, Atlantic white-cedar, musclewood, and 30 other species.

Table 6—Statistics for private timberland in the Albemarle Sound region by survey year (all bottomland physiographic classes combined)

Statistic	Survey year 1985	1992	2002	2007	2012
Dates of measurements	1985	1992	1997–2002	2002–07	2007–12
Period represented by growth and removals	1975–85	1985–92	1992–2002	1997–2007	2002–12
Annual mortality (million cubic feet per year)	2.0	2.5	1.4	3.2	3.2
Annual net growth (million cubic feet per year)	65.2	55.5	36.3	25.9	42.6
Annual removals (million cubic feet per year)	28.0	45.4	37.0	76.6	12.4
Growth:removals	2.3:1.0	1.2:1.0	1.0:1.0	0.3:1.0	3.4:1.0
Private timberland (acres)	820,073	807,575	731,732	774,032	805,384
Annual net growth (cubic feet per acre per year)	79.6	68.7	49.6	33.4	53.0
Annual removals (cubic feet per acre per year)	34.2	56.3	50.5	99.0	15.4

Note: Error rates averaged 17 percent for growth, 28 percent for removals, and 8 percent for acreages.

Note: Growth, removals, and mortality are for trees ≥5.0 inches diameter at breast height.

DISCUSSION

Current Conditions and Age Class Comparisons

The compositional differences between floodplains and swamps followed expected ecological patterns. The clearest signature was the greater proportion of tupelo and cypress in swamps/bogs compared to floodplains (table 2). Other, more subtle differences in species composition were difficult to determine, given the high error rates associated with species and class totals. Even so, the trend of mesic species being more dominant on mesic sites was clearly evident in the results. All these differences are consistent with the bottomland classification found in Kellison and Young (1997), in which “muck swamps” and “black river bottoms” (analogous to swamps/bogs) were dominated by cypress and tupelo, while “red river bottoms” and “Piedmont bottomland” (analogous to floodplains) were dominated by mixed hardwoods, including sweetgum and oaks.

It is well documented that timber harvesting in eastern upland forests can precipitate a significant shift in species composition of the regenerating forest (Dey and others 2010). Similar concerns have been raised regarding bottomland hardwoods, focused on the decline of commercially valuable species like certain oaks and baldcypress (Keim and others 2006, Stanturf and others 2004). In the Albemarle Sound’s bottomlands, young forests resulting from timber harvesting indeed had notable compositional differences from mature forests. For example, young forest had a greater relative volume of loblolly-shortleaf pine and lesser relative volumes of cypress, tupelo-blackgum, and ash. Oak, as a group, appeared unchanged between young and mature forests.

Some of these differences can perhaps be explained by successional ecology: a small number of canopy-capable species like baldcypress are surrounded by fast-growing, early-successional species like cottonwood (*Populus deltoides*) and river birch (*Betula nigra*). Over time, the canopy species can outgrow their early-successional neighbors, achieving a greater level of dominance (Evans and others 2013, Johnson and Krinard 1988). Additionally, in flood-prone bottomlands, flood-tolerant species like baldcypress can be favored over time (Young and others 1995). Therefore, it is possible that the species differences observed here are temporary, and that the young forest will grow into the mature forest described here despite the initial differences in composition. However, the small amount of cypress in young stands (tables 3 and 4) warrants continued monitoring, as Greis and others (2012) found that cypress was relatively stable across its range but warned the overall trend could mask local declines. In addition, the low relative density of tupelo in young forest is surprising given tupelo’s ability to sprout prolifically from cut stumps (Burns and Honkala 1990).

The post-harvest decline of oak importance noted throughout eastern forests was not observed in this study. The oaks, consisting of 13 species of varying commercial value, were present in similar amounts in young stands and mature stands. It is possible that individual oak species are fluctuating in importance, but a closer examination of this sort was beyond the scope of the data set. Examination of the quality of oak growing stock would shed more light on the adequacy of the oak resource in Albemarle Sound.

Apart from the natural successional dynamics of hardwoods, the other notable trend in species composition involved loblolly pine. Even after accounting for large error rates, the relative volume and relative density of loblolly was substantially larger in young stands than in mature stands. This increase could be the result of recent efforts at converting bottomland hardwoods to pine plantations. However, loblolly-shortleaf pine forest-type group acreage did not increase from 1985 to 2012 (table 5). Given these confounding patterns, it is not possible to determine whether loblolly pine is actually increasing in importance. One possible explanation is an increase in natural loblolly pines following recent harvesting, but not enough to warrant assigning the loblolly forest type at each location. This scenario would result in increased loblolly volume without a commensurate increase in loblolly forest-type acreage.

Trends across Survey Periods

Comparing growth and removals over time can address the question of whether or not overharvesting has taken place in the region's bottomlands. When an area's growth-to-removals ratio (G:R) approaches or falls below 1.0:1.0 for long periods of time, harvesting has likely occurred at unsustainable rates. By that guideline, harvesting in the Albemarle Sound's bottomlands appears to have been sustainable during the first two survey periods considered for this report (1985 and 1992) (table 6). Then, harvesting increased to 1.0:1.0 during the 2002 survey period. The 2007 survey period showed clear evidence of overharvesting, when over three times as much timber was cut as was grown (G:R = 0.3:1.0), signifying an unsustainable rate of harvesting. However, that period was followed by a much more sustainable rate of harvesting (G:R = 3.4:1.0).

That the G:R ratio varied by an order of magnitude is quite remarkable, but the pattern makes sense when put in context of the region's overall economy. In the economically productive 1990s and early 2000s, demand was high for large quantities of Albemarle Sound's forest products, while beginning around 2008, during the financial crisis of 2007–08, demand for forest and timber products declined sharply. Other assessments of the region's forest products industry corroborated the pattern of decreased output after 2008 (Cooper and others 2011a, Cooper and others 2011b, compared to Johnson and Becker 2007, Johnson and Brown 1996, Johnson and Mann 2007, Johnson and others 1997). Hurricane Isabel, a devastating Category 3 hurricane that hit the Albemarle Sound region in 2003, also caused tree mortality and subsequent salvage harvesting in the region (Rose 2009), but did not result in mortality rates that significantly impacted this dataset (table 6).

These results are mostly consistent with other published reports based on FIA data from the region. It should be noted that previous FIA papers reported metrics for all hardwood species in a given landscape (e.g. Coastal Plain of Virginia), while this paper focused on all tree species in bottomlands only. Our 1985 G:R ratio of 2.3:1.0 was much higher than comparable research from the time; Brown and Craver (1985) and Davenport (1984) reported G:R ratios of 1.2:1.0 and 1.5:1.0, respectively. Our 1992 G:R ratio of 1.2:1.0 was quite similar to comparable research; Thompson (1990, 1991) reported G:R ratios of approximately 1.0:1.0. Our 2002 G:R ratio of 1.0:1.0 is quite similar to comparable research (Conner 2003, Rose 2007), especially since this report contains geographies from both of the other studies. Reports about the region in the 2000s are fewer, but continue to corroborate our results. Specifically, our 2007 G:R ratio of 0.3:1.0 was similar to Rose (2009), who reported a G:R ratio of 0.8:1.0 for Virginia's Coastal Plain.

Given that overharvesting occurred over a number of years in the recent past, did this region's bottomlands experience any cumulative impacts? We conclude that minor cumulative impacts have indeed occurred based on the fact that the forest's overall growth rate per acre and overall volume have decreased over time. Annual volume growth per acre was 33 percent lower in 2012 than in 1985 (table 6). Total volume per acre was 8 percent lower in 2012 than its value in 2002 (fig. 3). The fact that volume per acre followed an explainable trajectory over time (decreasing only after a very low G:R ratio in the preceding time period) supports our conclusion that the patterns seen here are valid, and that recent harvesting levels have slowly depleted the overall volume of the region's bottomland forests.

The decrease in volume over time was present in most species groups; oak and ash were the only exceptions to this pattern, actually increasing significantly over time (fig. 3). This increase is surprising for oaks, given the widespread regeneration problems of the genus (Dey and others 2010). One possible explanation is that much of the oak volume in this region is in less desirable timber species. Over time, as oak timber is preferentially left standing during harvesting, oak volume continues to increase, while surrounding species experience a decrease.

CONCLUSIONS

Our analysis of close to 30 years of FIA data revealed that while bottomland forest in and around the Albemarle Sound is a resilient and somewhat stable system, it is not immune to the cumulative effects of human and natural disturbance. Bottomland forest acreage has not declined from 1985 levels, indicating that conversion to nonforest was not occurring over the last few decades. However, the harvesting rate in bottomland forests has been at the edge of sustainability since the 1990s, only returning to sustainable levels in the past 5 years. The legacy of this level of harvesting, slightly amplified by Hurricane Isabel in 2003, is a decreased overall volume and a decreased overall annual growth rate.

Looking at site-level impacts, timber harvesting possibly changed subsequent stand development. Important bottomland species like cypress and tupelo were less important in younger stands (i.e., recently cut) than in mature stands, while loblolly pine was more important. All other hardwood species groups remained unchanged. Given the importance of an iconic species like cypress, further research into this pattern seems warranted. It is not known whether loblolly's increase is a result of conversions of bottomland hardwoods, the natural expansion of a native species, or an aberration in the data.

This analysis fits with published FIA reports that document sporadic overharvesting of Coastal Plain hardwoods in Virginia and North Carolina during the last 30 years. When overharvesting did occur, was it due to a strong economic market or was it simply the result of salvage cutting after a natural disaster like Hurricane Isabel? Since both events have occurred regularly in this region, the point may be moot.

While this "boom-and-bust" cycle of timber production has occurred here before, it is not without consequences. This paper documented a small but consistent decrease in the forest's total volume and growth per acre following a "boom" period. The post-2007 "bust," in the form of the financial crisis, seems to have allowed the Albemarle Sound's bottomlands a chance to recover somewhat. As the economy now recovers, a shrunken forest industry will expand again. Indeed, several new forest industry mills and plants have begun production in this region during the last few years. While FIA data indicate that the bottomland forest system has ample resources to meet current demand, care must be taken with the assumption that returning to previous greater harvesting levels is a sustainable endeavor.

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The Albemarle Sound, a 6-million-acre watershed, contains some of the largest areas of bottomland hardwood habitat in the Eastern United States. Using close to 30 years of data from the Forest Inventory and Analysis Program, a study of the current status and trends in the Albemarle Sound's bottomland forest system was conducted. In 2012, bottomlands totaled approximately 800,000 acres and were composed of mainly swamps/bogs and floodplains. Swamps/bogs were dominated by tupelo (*Nyssa*) species and cypress (*Taxodium distichum*), while floodplains were dominated by tupelo, red maple (*Acer rubrum*), and a diverse mixture of hardwood species. Just over half of bottomland acreage was <60 years old, and younger forest had less tupelo and cypress than did older forest, but more loblolly pine. Over the last 30 years, the acreage of bottomland forest has not changed. Periods of overharvesting have occurred; the growth-to-removals ratio from the mid-1980s through the early 2000s was never higher than 1.2, and has since varied wildly from 0.3 to 3.4. The net result is that total live-tree volume declined by 8 percent from its peak in 2002. The changes in growth and harvesting are reasonable when put in context with the region's recent history, both economic and ecologic.

Keywords: Bottomland hardwoods, FIA, forest inventory and analysis, growth, harvesting, removals.