Supplementary Methods

Inventory Data Collected in 1951 and 2001 (Measured Variables)

A complete forest inventory of what is now the U.S. Department of Energy's Savannah River Site was conducted in 1951 by the United States Army Corps of Engineers after the land was acquired by the US government. The sampling design is unknown, but was probably a 100% survey, because volumes were extremely low as a result of extensive harvesting removal immediately prior to government land acquisition. The inventory included records of land use and timber volumes by product classes for each of the 1,334 ownership parcels, which ranged in size from 0.04 to 2,424.3 ha [1]. About 45% of the ownership parcels contained no woodland area, with pasture and cropland accounting for 32,279.4 ha. Forested woodlands accounted for 48,714.5 ha and were classified as predominately pine (naturally regenerated), planted pine, hardwood, or swamp. The inventory combined the area of farm homes, other structures, and farm roads in the agricultural or woodland area estimates and therefore overestimated area of forest or cropland; however, most housing units were small, and most roads were narrow dirt tracts. All structures were demolished and removed after acquisition. These areas became part of the subsequent forest through natural regeneration or planting, if they were not converted into industrial facilities or other permanent infrastructure. The shallow depressional wetlands, Carolina bays, were either farmed or covered by trees and therefore became either cropland or forest woodland. The approximate area of forest woodland and agricultural land was confirmed within 1-2% of the inventory estimates based on a subsequent object-oriented classification analysis of the ortho-rectified mosaic of aerial photos from 1951 [2,3].

There was no direct correspondence between the woodland classification (i.e. pine, pine-plantation, hardwoods, or swamp) for each parcel and the volumes reported for the parcel. Only the total volume by product class (sawtimber, pulpwood, or fuelwood) was reported for each parcel. For sawtimber, the nominal species were listed as pine, gum, poplar, miscellaneous hardwoods, and cypress; for pulp, either pine or hardwood; and fuelwood was designated as mixed species. To link volume to woodland area, we assigned all pine volume and half fuelwood volume to the area classified as pine and pine plantation, and we assigned all hardwood and cypress volume and half fuelwood volume to the area classified as hardwood or swamp. Commercial wood volume or growing stock for all parcels could then be associated with woodland classification area to approximate biomass density. Growing stock was the volume of a tree from a 0.3 m stump height to a 10 cm top calculated on all trees ≥12.7 cm DBH to a 10 cm top diameter. We considered this approach reasonable based on the ecological history and land management to that time. Uplands were originally pine savanna with small inclusions of xeric and mesic hardwood species, and the hardwoods and cypress forests were concentrated in the stream drainages, bottomlands, and Savannah River swamp. All parcels with woodland area, but no associated volume (3.6%) were maintained separate for estimation of vegetation biomass. Almost all non-stocked woodland was in the pine and pine-plantation classifications.

Wood volume was reported as board-feet for sawtimber and as cords for pulp and fuelwood. Based on the inventoried DBH (diameter at breast height) ranges, the product class DBH limits for saw timber, pulp, and fuelwood were similar to current nominal dimensions for commercial growing stock [4]. It is uncertain if top wood on sawtimber size trees was included in the inventory data, but we believe it was because estimation tables were available [5]. The latter is the merchantable volume between the upper diameter limit for sawtimber (15.3 cm for pines and 20.3 cm for hardwoods) and the 10 cm top limit. This material would be classified either as pulp or fuelwood.

The 2001 forest inventory was completed between March 1999 and January 2002. Plot design and analysis methods for growing stock volume were similar to the US Southern Region National Forest Inventory and Analysis (FIA) methods in the 1980's and 1990's. Plots were established on a 1,000 by 1,000 m grid over the entire land base, which resulted in approximately one sample plot per every 100 ha of forest, but only 629 plots were sampled due to various constraints. Each plot was assigned to a forest type based on species composition [6] and consolidated into seven nominal forest groups to facilitate analysis; 1) loblolly, 2) longleaf, and 3) slash pine (pine plantations); 4) mixed pine-hardwood (pine basal area ≥50% but <80%); 5) mixed hardwood-pine (pine basal area ≥20% but <50%); 6) hardwood (pine basal area <20%); and 7) cypress-tupelo. Each plot consisted of a cluster of five subplots spaced 21.34 m apart. Each sub-plot was a variable-radius plot where an 8.61 basal area factor (m^2 ha^{-1}) prism was used to sample trees. For live and dead trees, DBH, species, and height were measured [2,7]. In-between the five subplots, four planar transects were used to measure forest floor litter depth, duff depth, and down woody material according to standard size classes representing moisture time lags, and live vegetation (grasses, forbs, shrubs, vines and small trees ≤2.54 cm) was measured with the FIA vegetation profile method [8].

Estimates of Forest Biomass (Conversion of Measured Variables)

We used two methods (hereafter, Method A & B) to determine aboveground tree biomass, carbon (C), and Net Biome Production (NBP) in 1951 and 2001. Both methods were designed to convert growing stock volume-density to biomass, and can be applied to both inventories. We calculated the growing stock volume and biomass density separately for softwoods, including cypress, and hardwoods in 1951. To convert commercial growing stock volumes in English units, board feet, and cords to cubic volumes of wood, we used applicable historic conversion factors of 0.181 ft^3 per board-foot for saw timber and 76.0 ft^3per cord for pulp and fuelwood [5]. We assigned these volumes to either the combined pine or hardwood woodland classification areas as previously determined. To determine the live tree growing stock volume in 2001, we used standard FIA equations applicable to the region to convert individual tree dimensions [9]. We applied tree factors based on DBH and the prism factor to expand tree data to an area basis and summed across the plot to calculate total growing stock volume for each plot. Plot means for each forest group and associated area totals could then be calculated.

Method A uses simple expansion factors developed for each region in the U.S. for softwoods and hardwoods [10] to convert the growing stock volume to total aboveground tree biomass. The biomass includes non-merchantable crown and stem portions, small trees, and dead trees. Method A assumes a simple linear relationship between growing stock volume and tree biomass. We used expansion factors to convert softwood (including cypress; 1.408) and hardwood (1.793) growing stock to total aboveground tree volume [10, Table 1.1]. We converted softwood (0.523) and hardwood (0.580) volume to total aboveground mass [10, Table 1.2]. Volume to mass conversion factors were identified as specific gravity and not as wood density; however, these values are often very similar when aggregated for large scale estimates. All plots in 2001 and all parcels in 1951 with woodland area listed, but with no growing stock volume, were assigned a growing stock of 0.0 m^3 ha^{-1} and therefore, a biomass of 0.0 Mg ha^{-1}. There were several hundred parcels totaling 1,628 ha with no associated volume in 1951, but only 6 plots in 2001.

Method B relates FIA plot growing stock volume to the plot total tree aboveground biomass within each region, major forest ownership, and species classification using a series of non-linear regressions [11]. Method B estimates biomass using equations for live softwood and hardwood separately, and a composite equation for all live trees. These allometric equations [derived from 12] provide a reference standard to estimate total live tree aboveground biomass. Dead tree biomass was estimated using the composite equation. We used the same growing stock estimates from Method A for softwoods and hardwoods as inputs. We converted growing stock volume on the combined woodland areas in 1951, or plot-based forest group areas in 2001, to total aboveground live and dead tree biomass [11, Tables 9 & 10 for live trees and Table 6 for dead trees]. Each plot (2001) or combined area (1951) was assigned to one of Smith's ownership and species classes for the respective region. We created a crosswalk between the seven SRS forest groups in 2001 and the two combined woodland forest classification areas in 1951 and Smith's ownership and species classes using FIA descriptors

(Supplementary Table 2). When applying Method B to the parcels or plots with no growing stock volume, a non-zero biomass was predicted because equations have a non-zero intercept [11]. The latter can be interpreted as small trees below merchantable limits, cull trees and dead trees that are present.

To provide a direct estimate of live and dead aboveground tree biomass and C stocks in 2001, without the assumptions involved in Method A or B, we used updated allometric equations [13] for total aboveground live tree biomass, but developed a separate procedure to estimate mass of standing dead trees. Total aboveground biomass for each live tree was estimated by assigning a national biomass allometric equation to each tree in the inventory [13]. We created a crosswalk for all trees ≥2.54 cm DBH and calculated the biomass for each tree in the prism plot (Supplementary Table 3). We expanded tree data to an area basis as before and summed across the plot to give total live tree aboveground biomass. To estimate the aboveground mass of a dead standing tree, we first estimated the aboveground biomass by species and DBH as described above with live trees. We then computed the ratios for stem wood and bark and applied those to the aboveground biomass to obtain the stem wood plus bark biomass [12]. Foliage and branch masses were excluded on the assumption that there was no foliage and most branch mass had been lost. To correct for wood decay, we applied results from two previous studies on the survival age of snags at SRS and changes in wood density in decaying trees at SRS. The average reported half-life of snags ranged between 2 and 4 years depending upon DBH [14], so we assumed an average of 3 years and used the predicted percentage of the remaining mass in dead trees (0.62) [15]. This percentage was multiplied by the stem wood plus bark mass computed for each tree. During the inventory, only about one-third of the dead trees had either one or two large branches. By the third year following tree death, about 30% of the standing stem volume was lost from breakage [16]; however, because inventory data did not provide a diameter at the break-point, we could not adjust for this loss.

Root biomass for all three methods was estimated by applying a simple coefficient based on the assumption that, on average, root biomass is equal to 23% of aboveground tree biomass [17,18]. To estimate live and dead understory biomass, including forest floor, fallen branches, logs, grasses, and forbs, and all live woody plants <2.54 cm DBH, we used two methods. The values for southeastern US from various ecological studies [10, Table 1.4] were applied to the woodland areas in 1951 because the actual forest understory conditions were unknown. To this end, we constructed a crosswalk between the combined woodland classification areas in 1951, including the non-stocked areas (Supplementary Table 1). Because most forest land in 1951 was cutover immediately prior to SRS establishment, we assumed forest understory biomass was equivalent to average conditions of uncut forests in which the ecological studies were conducted. To estimate forest floor and understory in 2001, we used measurements obtained during the 2001 inventory for six forest groups [8, Table 3] and unpublished data on the cypress-tupelo plots. We excluded small tree biomass between 2.54 cm and 10.7 cm DBH that was reported as available wildland fire fuels, as the latter is included when growing stock is converted to total aboveground tree biomass. We used the area weighted means for loblolly, longleaf, and slash pine stands to represent pine plantations.

Estimates of Non-forest Biomass (Conversion of Measured Variables)

To estimate the biomass in the abandoned crop and pasture lands in 1951, we used the comprehensive studies of abandoned agricultural field succession and development done at the SRS in the early 1950's [19]. These studies measured net primary productivity (above- and belowground) and litter accumulation for 7 years on a wide range of former agricultural lands. We calculated the average biomass as 5.6 Mg ha^{-1} for both crop and pasture [19, Figure 10]. The area of crop and pasture land was provided directly from the 1951 land inventory. For 2001, we estimated the area of the SRS in open conditions, primarily grass and herbaceous cover along major roads and the herbicide-maintained powerline rights-of-way from spatially explicit land records. In these open areas, above- and belowground biomass was assumed to be the same as the value estimated for 1951 crop and pasture lands. Therefore, the total biomass change is a result of the change in area of open land. These areas are maintained as free of arborescent vegetation as possible.

Estimates of Annual Biomass Fluxes and Life-Cycle Residues (Measured Variables and Conversion of Measured Variables)

The principal C fluxes on SRS, exclusive of industrial operations, are removals associated with harvested wood products, losses associated with forest fires, and stream export. Forest harvest activities on the SRS have been carried out since 1955 [20]. Annual harvest data covering the period 1955 to 2000 (measured variables) were provided by the United States Forest Service Savannah River. The data consisted of annual forest harvest removals as either softwood or hardwood, and two size classes: small round wood, which is material based on dimensions that was expected to be converted to wood pulp; and large round wood, which was material expected to be converted to solid wood products. The biomass removed was calculated as the wood volume multiplied by the species average wood plus bark density (green volume to dry mass) when only the wood volume was known [21, Table 1B]. For softwood volumes, we used the average density of the three major pines (0.577 Mg m^3), and for hardwoods, we used the average density of the two major hardwood species (0.591 Mg m^3) harvested, sweetgum (*Liquidambar styraciflua*) and water oak (*Quercus nigra*). About 1,400 ha of pine straw sales occurred over a 10-year period from 1991-2001. Based on average amounts removed (~2.25 Mg ha^{-1}), we elected to not include this amount in the analysis.

Prescribed fire was used for a variety of purposes at SRS, including: site preparation for planting (8.6%); fuel load reduction (50%); treatment of fuels along the railroad rights-of-way (1.8%); wildlife habitat maintenance (33%); and other purposes (6.6%) [20]. The total area burned by wildfire was small relative to that burned by prescribed fire (~3.1%) during the period, but these areas were also included in the C flux estimate. The annual total area of prescribed and wildfire (measured variable) was used to calculate annual C flux. A meta-analysis of many fuel consumption studies at SRS during prescribed fires was used to estimate biomass consumption [22]. Since individual prescribed burns range in size from <10 ha to >1,000 ha, and frequently cover numerous forest and non-forest conditions, the average biomass consumption (7.2 Mg ha^{-1}) was used to convert annual burn area to C flux.

Removal of total organic C (TOC) from SRS in stream water was estimated from literature values as there were few continuous stream flow data coupled to TOC measurements available for SRS, and most of the major SRS streams had large contributing areas off SRS [20, Table 2.7]. A global synthesis, including estimated annual TOC discharge from 17 U.S. watersheds smaller than 10,000 km^2, determined a mean annual discharge of 3.2 g C m^2 yr^{-1} for the temperate forest watersheds without flow adjustment [23, Table 2]. They also computed flow adjusted C discharge for these watersheds [23, Fig. 3]. We used published mean annual precipitation [20, Table 2.1] and runoff ratios for the SRS streams [20, Table 2.7] to estimate a total discharge of 809.15 km^2 from the SRS, including industrial and developed portion (measured variables). Using the entire area was reasonable since most of the TOC is believed to originate in riparian-wetland forests [24]. Based on the estimated discharge, the mean annual TOC exported by SRS streams was 2.5 g C m^2 yr^{-1}.

Principal biomass residues present in 2001, which could not be estimated from 2001 field inventory, were undecayed tree root biomass from prior harvest, undecayed landfill waste, and in-use solid wood products. Root biomass remaining in soil after tree harvests was calculated based on the harvest volume data. We converted annual harvest volume of hardwoods and softwoods (measured variables) to total aboveground tree biomass as described earlier [10, Table 1.1] on the assumption that harvest volume was equal to growing stock volume removed. For consistency with the harvested wood volume and mass data, we used the previous wood volume to mass conversions for softwood and for hardwood [21]. These values are slightly greater than the average specific gravity values from Birdsey [10, Table 1.2]. Root mass remaining during the year of harvest was 23% of total aboveground tree biomass, and residues for each year after harvest were estimated using a decay function [25, k = 0.0534]. In-use or landfill residues of stored C in 2001 from wood harvested for each year beginning in 1955 were determined [26, Table 6] and summed to the year 2001. We assigned the volume of large round wood to the end product of saw logs and small round wood to pulp for hardwood and softwood. We used the mass determined for each year from the annual harvest wood removals.

Land covered with forest vegetation prior to 1951 has since been converted to industrial infrastructure support, including facilities, road surfaces, cooling water lakes, and rights-of-way for power transmission and road buffers (Table 1). Most of this development occurred during the first decades of operations and almost entirely on upland areas. For simplification and because no data exist on C in the facilities' soils, lakes sediments, or beneath road surfaces, we assumed that the C balance was unknown. We included the 1,006 ha of forest land transferred to the Aiken county government for industrial development in the 1970's in the industrial infrastructure land when calculating C in 2001. Only the C in vegetative rights-of-way soils and vegetation were estimated for 2001.

Net Biome C Production between 1951 and 2001 and Total Vegetation C Stored in 2001

We assumed no net change in the total soil organic C (SOC) component as there was no reliable approximation of soil organic matter (SOM) in 1951 across the entire landscape. We used the convention of converting biomass to C by multiplying by 0.5 for all components. NBP was estimated as:

$$NBP = \Delta C_{org} + E + O_x - I$$

where ΔC_{org} is the change in organic C stored in ecosystem pools between 1951 and 2001; E is the organic C exported during that period; O_x is the organic C oxidized during that period; and I is the organic C imported during that period [27]. We estimated the total C stored in 2001 as the C in: 1) aboveground tree biomass [calculated using equations from 13]; 2) root biomass fraction (i.e., 0.23); 3) forest understory dead and live biomass [8]; 4) cumulative residues in root biomass, land-fill, and in-use products; 5) vegetation biomass in the open rights-of-way; and 6) SOC.

Soil Organic Matter and Carbon

Although SOM content in old farm fields in 1951 and 1980 were reported [28], there was no method for reconstructing SOC for the entire landscape in 1951. We estimated SOC for 2001 based on SRS-wide soil survey made by the Natural Resources Conservation Service (NRCS) [29] and the NRCS databases, which provide values of soil geochemical and physical properties of representative pedons for most series (http://soildatamart.nrcs.usda.gov/). A digital version of the soil survey was used in conjunction with SOM and bulk density data to estimate total SOC in forested areas and open rights-of-way by overlaying the digital mapped layers. The SOC content was calculated to a depth of 1.0 and 1.5 m for each of the soil series. We converted SOM to SOC using a factor of 0.5. Previous recommended conversion values vary and a previous convention of 0.58 had been established until a meta-analysis and theoretical model demonstrated that 0.5 was more accurate under most circumstances [30]. There were 30 mapped soil series (measured variable) with various phases at the SRS for which bulk density and SOM were available. We used the mean SOC content and mean bulk density of each layer. Most series had few measured values of these variables and the general recommendation of a log transformation assumes a large enough sample to have some knowledge of the sample distribution. We also did not adjust for rock content as these soils were generally formed from marine sediments and have only a few rounded coarse pebbles with almost no significant rock content to a depth of 1.5 m [29]. The total SOC in each soil series was multiplied by the area of the soil series occupied by forest and open rights-of-way. We calculated SOC separately for forested areas with frequently flooded/hydric soils and upland soils separately, since most management activities were conducted on upland sites.

Two previous studies of upland soils on SRS dealing with ecological restoration demonstrated a large deficit in SOC on upland soils when remnant forest patches that had never been tilled were compared to forested areas that had been tilled prior to 1951 [31,32]. To test for potential bias (over-estimation) in using the NRCS database to estimate SOC at SRS, we compared data from soil cores on upland (n = 44) and wetland/flooded sites (n = 50) collected for an environmental baseline study in the 1980's at the SRS [33,34]. The SOC content, determined by combustion, of the soil layers in these studies were reported to almost 3 m. From the coordinates of the sample, we determined the soil series and calculated mean SOC to 1.5 m depth in the same manner as with NRCS data and used mean bulk density for each soil series to convert SOC to Mg ha^{-1}. We compared the mean SOC content in NRCS and SRS populations representing eleven (11) soil series for the uplands and eleven (11) soil series for the wetland/flooded soils separately using a one-tailed Wilcoxon Signed Rank Test using the univariate procedure (PROC UNIVARIATE v.9.1.3; SAS Inc., Cary, NC, USA). The one-tailed, non-parametric test avoided issues with unknown sample distributions [35,36] and allowed us to test the hypothesis that the measured SRS values were less than NRCS values as suggested by previous studies.

Supplementary Tables

Supplementary Table S1. Crosswalk between source and values of understory dead and live biomass [10, Table 1.4] for combined woodland class areas in 1951, including non-stocked areas.

Understory biomass	**Combined woodland classification (1951)**
Pine (20.0 Mg ha^{-1})	Pine and pine plantations
Bottomland hardwoods (11.5 Mg ha^{-1})	Hardwood and swamp

Supplementary Table S2. Crosswalk between woodland classification in 1951 or forest groups in 2001 for applying equations to convert growing stock volume to aboveground live and dead tree biomass. Equation names refer to ownership and vegetation names for the SE Region [11, Tables 6, 9, & 10]. .

Woodland Class (1951)	**Equation**	**Forest Groups (2001)**	**Equation**
Hardwood and swamp	Hardwood (private)	Hardwood and cypress-tupelo	Hardwood (public)
Pine and Pine plantation	Natural Pine (private)	Loblolly, longleaf and Slash pine	Planted pine
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Supplementary Table S3. Relationship between aboveground biomass taxa equations [13, Table 5] and species based on species assignments [37, Table 2] and numerical codes for species [12, Appendix A]. .

Aboveground biomass taxa equation	Species assignments
Pine > 0.45 specific gravity	107, 110, 111, 121, 128, 131
Cupressaceae ≥ 0.40 specific gravity	60, 221, 222
Aceraceae < 0.50 specific gravity	313, 316
Betulaceae 0.40 –0.49 specific gravity	370, 373
Betulaceae ≥ 0.60 specific gravity	701
Cornaceae/Ericaceae/Lauraceae/Platanaceae/ Rosaceae/Ulmaceae	391, 460, 461, 491, 521, 591, 660, 680, 682, 691, 692, 693, 694, 711, 721, 722, 731, 760, 761, 762, 763, 931, 970, 971, 972, 999
Fabaceae/Juglandaceae, Carya	400, 401, 402, 403, 405, 407, 409, 602
Fabaceae/Juglandaceae, other	901
Fagaceae, deciduous	531, 800, 802, 806, 807, 808, 809, 812, 813, 819, 822, 824, 825, 827, 831, 832, 835, 837, 840, 841
Fagaceae, evergreen	820, 838, 850
Hamamelidaceae	611
Magnoliaceae	555, 621, 650, 652, 653, 661
Oleaceae < 0.55 specific gravity	540, 543, 544
Salicaceae ≥ 0.35 specific gravity	920, 975

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