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THE SAVANNAH RIVER SITE: SITE DESCRIPTION, LAND USE AND MANAGEMENT HISTORY

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Abstract. The 78,000-ha Savannah River Site, which is located in the upper Coastal Plain of South Carolina along the Savannah River, was established as a nuclear production facility in 1951 by the Atomic Energy Commission. The site's physical and vegetative characteristics, land use history, and the impacts of management and operations are described. Aboriginal and early European settlement was primarily along streams, where much of the farming and timber cutting have occurred. Woodland grazing occurred in the uplands and lowlands. Land use intensity increased after the Civil War and peaked in the 1920s. Impacts from production of cotton and corn, naval stores, fuelwood, and timber left only scattered patches of relatively untouched land and, coupled with grazing and less-frequent fire, severely reduced the extent of longleaf pine (*Pinus palustrus*) ecosystems. After 1951, the USDA Forest Service, under the direction of the Atomic Energy Commission, initiated a large-scale reforestation effort and continued to manage the site's forests. Over the last decade, forest management efforts have shifted to recovering the Red-cockaded Woodpecker (*Picoides borealis*) and restoring longleaf pine habitat. A research set-aside program was established in the 1950s and is now administered by the Savannah River Ecology Laboratory. Impacts from thermal effluents, fly-ash runoff, construction of radioactive waste facilities, and release of low-level radionuclides and certain metals have been assessed by the Savannah River Ecology Laboratory and other researchers.

Key Words: Department of Energy, ecological impacts, land use history, longleaf pine, presettlement, Red-cockaded Woodpecker, Savannah River Ecology Laboratory, Savannah River Institute, Savannah River Site, set-asides.

Creation of the 78,000-ha Savannah River Site (SRS) by the Atomic Energy Commission (AEC) in 1951 resulted in the relocation of 6,000 people from seven towns and set the stage for a dramatic change in land use. Construction of nuclear production facilities and the reforestation and management of abandoned farmland and cut-over forests profoundly affected SRS ecosystems, both positively and negatively. Because it was protected from the prevailing land uses outside its boundaries, the site became, in part, a large biological reserve, especially rare for the Sandhills/Upper Coastal Plain of the Carolinas and Georgia. The construction and operation of nuclear facilities directly impacted 3,000 ha of land, created almost 2,000 ha of cooling reservoirs, and released thermal effluent in all but one SRS stream. Nuclear facilities now on the site include five deactivated nuclear reactors, as well as facilities for nuclear materials processing, tritium extraction and purification, waste management, solid waste disposal, and power plants for steam generation and production of electric power (Noah 1995).

The SRS has become a major site for both applied and basic scientific research. The University of Georgia's Savannah River Ecology Laboratory, and the USDA Forest Service Savannah River Natural Resource Management and Research Institute (SRI), as well as other institutions, have contributed significantly to the research programs supported by the U.S. Department of Energy and to the management of the site as a National Environmental Research Park (NERP).

SITE DESCRIPTION

PHYSICAL

The Savannah River Site is located on the upper Atlantic Coastal Plain, south of Aiken, South Carolina, 32 km southeast of the Piedmont Plateau (Dukes 1984), and borders the Savannah River for 30 km (Fig. 1). Most of the SRS is drained by five tributaries of the Savannah River with small streams feeding each so that no SRS location is very far from flowing water (Dukes 1984). Upper Three Runs is the least disturbed blackwater stream in the area and the only one that has not received thermal effluent. Twenty percent of the site is covered by wetlands, including bottomland and swamp forests, two large cooling reservoirs, creeks, streams, and upland depressions and Carolina bays (Lide 1994, Wike 1994). Water is retained intermittently in wetlands and in more than 200 natural basins and Carolina bays as well as 3,800 ha of Savannah River swamp. Carolina Bays are ovoid- or elliptical-shaped, natural shallow depressions found on the Coastal Plain of SC and NC. The 194 Carolina Bays within the SRS occur at elevations between 36–104 m with surface areas ranging between 0.1 and 50 ha, many of which have been cleared and drained for agriculture (Schalles et al. 1989). Bays in the area were also used extensively by Native Americans during the early Holocene (Brooks et al. 1996).

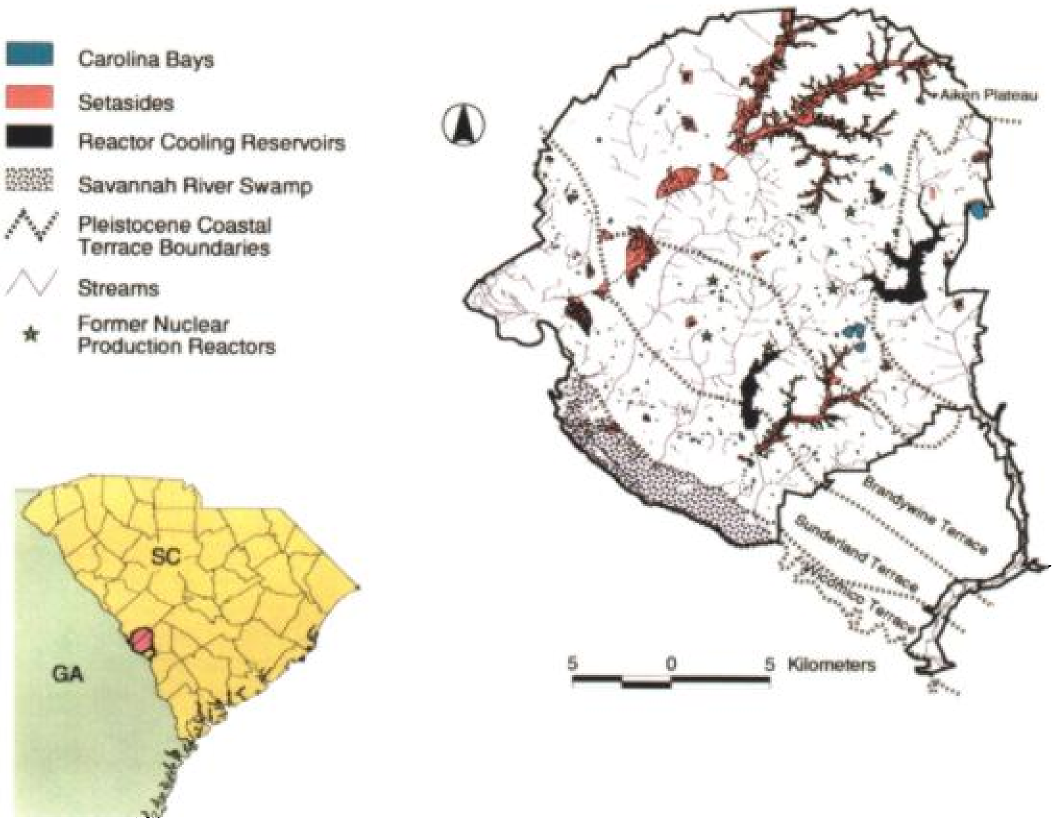

FIGURE 1. Map of the Savannah River Site, showing general location in the region, physiography, streams, research set-asides, and Department of Energy facilities.

The vegetation associated with Carolina Bays varies along a complex gradient related to depth of the depression, hydroperiod, substrate, and accessibility to fire (Schalles et al.1989, Kirkman 1992).

Physiographic provinces of the SRS include the Sandhills or Aiken Plateau, the Atlantic Southern Loam Hills (Sunderlands and Brandywine Terraces), and the Wicomico Terrace (Langley and Marter 1973, Imm 1997; Fig. 1). Elevation ranges from 115 m on the Aiken plateau, 50–80 m on the Brandywine Terrace, 30–50 m on the Sunderland Terrace, and 30 m or less on the Wicomico Terrace. The age of Aiken Plateau soils ranges from 10–50 million years while those of the three Pleistocene terraces range from 10,000 to 1,000,000 years (Langley and Marter 1973). Seven soil associations are represented within the SRS (Rogers 1990). Generally, sandy soils occupy the uplands and ridges and are less fertile than the loamy-clayey soils of the stream terraces and floodplains. Just over 15% of the area is considered prime farmland (Rogers 1990).

Precipitation in the area is some of the lowest in the State, averaging 120 cm (Workman and McLeod 1990). The generally mild climate averages 240 frost-free days per yr. Average temperature in winter is 9 C and in summer 26 C. Hurricanes are uncommon but tornadoes occur occasionally in the spring (Langley and Marter 1973).

Vegetation

For the past 10,000 years, oak (*Quercus*) and pine (*Pinus*) forests have dominated the Central Savannah River Area (CSRA in this paper refers to Aiken, Barnwell, Edgefield and Orangeburg Counties, SC, and prior to the formation of Aiken County in 1871, only the latter three), with the southern yellow pine species group increasing in importance after 8,000 years bp. Pine species probably have dominated the uplands of the CSRA for the past 4,000–5,000 years (Watts 1971, 1980; Delcourt and Delcourt 1987). Views of pre- or early settlement forests in the CSRA from the 1700s (Cordle 1939; Bartram 1942, 1958; Drayton 1996) and 1800s (Mills 1826,

TABLE 1. PRESETTLEMENT VEGETATION TYPES OF THE SRS, FROM FROST 1997

Presettlement vegetation type	Percent of SRS area
Xeric longleaf pine and longleaf pine-turkey oak	3.8
Dry-mesic and mesic longleaf pine savanna	51.7
Longleaf pine-pyrophytic woodland complex	3.7
Pyrophytic hardwood woodland	10.0
Mixed mesic hardwood forest	3.5
Wetland pyromosaic—sandy or mucky soils[a]	9.3
Wetland pyromosaic—silty or clayey soils[b]	2.9
Bottomland hardwoods, levee forests, oak flats	2.7
Swamp forests	6.1
Carolina bays, upland depressions	1.0
Udorthents	3.6
Surface water (aquatic communities)	1.7

[a] Canebrake, pocosin, pond pine forest, loblolly pine and non-pyrophytic bottomland hardwoods, baldcypress, and *Nyssa biflora*.
[b] Bottomland hardwoods, hardwood/canebrake, baldcypress, and *Nyssa biflora*.

Lieber 1860) as well as descriptions of other areas of the SC Coastal Plain from the early 1700s (Von Reck 1733, Lawson 1967) through the 1800s (Michaux 1805, Mills 1826, Sargent 1884), help characterize the distribution of plant communities in the region. Generally, the uplands were dominated by longleaf pine (*Pinus palustris*) while the "clay land" and terraces and flood plains were dominated by hardwoods, ranging from oak-hickory to cypress-tupelo forests (*Taxodium distichum-Nyssa aquatica*). Cane brakes (*Arundinaria gigantea*) in adjacent regions (Logan 1858, Lawson 1967) and the existence of remnant patches within the SRS suggest these communities were common.

Composition and distribution of 11 presettlement vegetation types were recently described by Frost (1997) (Table 1). Community types were defined from soils, historical data, and remnant vegetation. Longleaf pine was dominant on 63% of SRS forests (80% of non-wetland areas). Swamps, bottomland, and bay forests occupied 22% of the site. Estimates of fire return intervals ranged from 1–3 years on the Aiken Plateau to 7–12 on more fire sheltered sites; it was variable on other areas. The vegetation associated with beaver pond areas, especially along smaller tributaries adjacent to the pine uplands, is not well known. These areas would have represented wetland habitat for many plant and animal species common before settlement.

Various vegetation classifications have been developed for use in the SRS (Jones et al. 1981, Workman and McLeod 1990, Frost 1997, Imm 1997). A description of current vegetation by age class, derived from the SRI's Continuous Inventory of Stand Conditions (CISC) database, is shown in Table 2. Loblolly pine (*Pinus taeda*), longleaf pine, and bottomland hardwood forest types comprise 35%, 23%, and 20% of the total forested area, respectively. About half of the area in pine dominated types is in 30 to 50 yr-old stands, whereas 76% of the hardwood area is in stands >50 years. Longleaf and loblolly pine comprised 49% and 47% of the < 10 yr age class, respectively.

LAND USE BEFORE 1950

PRESETTLEMENT THROUGH 1865

Aboriginal people entered the SRS area about 11,500 years bp. Hunting, plant gathering, and fishing were the predominant land use activities. Corn cultivation did not become widespread until approximately 850 years bp (Sassaman et al. 1990). As with the Europeans that came after them, aboriginal people primarily settled along streams. Native Americans used fire extensively in the South for hunting and land clearing. Generally, cultivation and burning by Native Americans were regarded as having minimal impact on soils (Herndon 1967; Trimble 1974:28–33).

TABLE 2. CURRENT VEGETATION DISTRIBUTION BY FOREST TYPE AND AGE CLASS (AREA IN HA)

	Age class				
Forest type[a]	0–10	10–30	30–50	>50	Total
Longleaf pine	4390	876	8843	2454	16563
Slash pine	30	153	7981	504	8668
Loblolly pine	4266	8687	9783	3011	25747
Longleaf-scrub oak	1	0	152	58	211
Mesic pine-hardwood	40	249	951	1283	2523
Upland hardwood	49	15	633	1777	2475
Bottomland hardwood	221	1811	1251	11032	14315
Cypress tupelo	27	0	85	2558	2670
Total	9026	11790	29681	22677	73174

[a] Derived from either single or combined forest types used by the USDA Forest Service. Area estimates are derived from 1997 Continuous Inventory of Stand Conditions (CISC) data from the SRI.

A significant portion of the aboriginal population is thought to have abandoned the CSRA in the mid 1400s, largely as a result of interactions between three complex chiefdoms that occupied the South Atlantic area (Anderson 1994, Sassaman et al. 1990). Population declines would have had some impact on fire dynamics, the area cleared for cultivation, and the level of hunting pressure, but the degree of impact is not known.

Prior to settlement in the 1760s, the SRS was inhabited by herdsmen raising cattle (Brown 1894, Meriwether 1940, Brooks 1988). An increase in hunting and trapping associated with the nearby trading post at Savannah Town (5–6 km downstream from Augusta, GA; 20 km northwest of the SRS boundary) may have affected the area as early as 1700, but impacts of the peltry trade are not well known. The predominant land use before 1780 was woodland cattle grazing and scattered small-scale farming. Both Brown (1894) and Bartram (1942) describe "cowpens" in or near the SRS area in the 1700s. Cowpens were mostly 40- to 160-ha cleared areas, with enclosures for cattle, horses, and hogs. They also contained a garden tract and a few buildings for the cowpen keepers (Dunbar 1961). Cattle grazed the upland forests, bays, and bottomlands along streams. They used savannas in summer and cane swamps in winter. Likely impacts from cattle were on (1) competing grazers (white-tailed deer, *Odocoileus virginianus,* and buffalo, *Bison bison*), (2) the abundance of cane and other forage species, (3) other plant and animal species from trampling and soil compaction, and (4) soil erosion and water quality localized along streams and near cowpens. Hog abundance was high in the region (Schoepf 1911, Frost 1993), but their abundance in the CSRA was not known until 1825 (Mills 1826).

Livestock density peaked in 1850 where there were over 15 hogs and 8 cattle/km^2. Hogs grazed heavily on seeds and seedling roots of longleaf pine (Schoepf 1911), as well as hardwood mast. This, in turn, affected longleaf pine and, possibly, mast-dependent species like the Passenger Pigeon (*Ectopistes migratorius*; Frost 1993). By 1860, the demise of the SRS longleaf pine forests was underway.

Crop cultivation and timber cutting prior to 1780 was limited and occurred primarily along streams and terraces (Brown 1894). Although rice and indigo were grown in the area, the extent of cultivation is not known. Rice would have been grown mostly in the lowland areas where periodic flooding could have been created, whereas indigo was probably planted in the uplands.

Several local (Mills 1826, Brown 1894) and regional references (Ashe 1682, Von Reck 1733, Logan 1858, Chapman 1897, Bartram 1958, Lawson 1967) cite an abundance of wolves (*Canis lupus,* and the red wolf, *C. rufus*), panthers (*Felis concolor*), and wild cats (bobcat, *Lynx rufus*), as well as game species, notably white-tailed deer and Wild Turkey (*Meleagris gallopavo).* Buffalo were also probably abundant based on their abundance above (Logan 1858) and below the SRS (Von Reck 1733). Tarleton Brown (1894), who lived near the SRS in 1769 and later along Lower Three Runs, and Mills (1826) describe the abundance of certain predator and game species and the constant effort to eliminate the former. The dynamic relationship between the decline of the native fauna, the process of settlement, and the extensive peltry trade with Native Americans was well characterized by Logan (1858) for the South Carolina upcountry (Piedmont), much of which is relevant to the SRS area. Buffalo and the large predators were the first species eliminated, largely before 1800. Laws to control or eliminate predators were passed in South Carolina from 1695–1786 (Heaton 1972). White-tailed deer, black bear (*Ursus americanus*), beaver (*Castor canadensis*) and other species were reduced dramatically before 1800. Other species such as the raccoon (*Procyon lotor*), opossum (*Didelphis virginiana*), muskrat (*Ondatra zibethicus*), and squirrel (Logan did not indicate whether he was referring to eastern gray squirrel, *Sciurus carolinensis,* eastern fox squirrel, *S. niger,* or southern flying squirrel, *Glaucomys volans*) suffered declines throughout the 1800s. Prior to 1900, the Carolina Parakeet (*Conuropsis carolinensis*) and the Passenger Pigeon were extinct or near extinction (Salley 1911). South Carolina passed laws between the early 1700s and 1837 to regulate fish traps and to rid streams of obstructions to fish passage and human-related traffic.

There was a dramatic increase in cotton farming from 1780–1865, and grain and sawmills became important in the area in the late 1700s. The amount of cultivated (Mills 1826) or improved land (defined in the 1850 census as "..only such as produces crops, or in some manner adds to the productions of the farmer..") increased from 4% of the total in 1825, to 31% in 1860, at which time about 70% of the land on farms was woodland. In 1825, cotton and lumber were primary staples in the CSRA, although corn and sweet potatoes were also important. Hammond (1883) indicated that river swamps, as well as bays and creek bottoms of the South Carolina Upper Coastal Plain, were rapidly cleared, drained, and cultivated between 1845–1860, only to be abandoned thereafter. Ruffin (1992) describes relatively intact swamp forests along the Savannah River within the SRS, with patchy disturbance in the forms of scattered fields, roads, and paths.

Timber and fuelwood harvest in the upland forests were substantial before 1865. On Upper Three Runs, there were 10 sawmills before 1820 (Brooks and Crass 1991); 5 on the short Four Mile Creek in the 1840s (Ruffin 1992), and 75 throughout the Barnwell district in 1840. Ruffin also indicated that CSRA streams were navigable "very high" (i.e., far upstream from the Savannah River) and had been used to transport rafts of lumber to the Savannah, often by releasing the floodgates at mills. The 1840 census indicates that forests within the Barnwell district were utilized more than those in surrounding counties, as well as many areas of the southeastern United States. Demands on forests included the construction (1833) and operation of the Charleston to Hamburg (North Augusta) Railroad, Savannah River steamboats, and domestic fuelwood use.

1865–1950

Following the Civil War, a cycle of poverty, cotton dependence, and land abuse developed in the South and persisted for most of this period. Increased pressures on the land for production of cotton and other crops, naval stores (tar, pitch, and turpentine), fuelwood, and timber left only scattered patches of relatively untouched land. The CSRA's population increased from about 8 to 19 people/km^2 from 1870 to 1950. A significant shift in settlement towards the upland sandhills and an increasing trend away from watercourses occurred in the SRS after 1865 (Brooks and Crass 1991), corresponding to an increased emphasis on cotton production and a decrease in available farm land. Within the CSRA, land-use intensity peaked in the 1920s with the peak in cotton production and following extensive forest cutting.

Approximately 30% and 45% of Aiken and Barnwell counties, respectively, was improved land (mostly cultivated) during most of the period from 1900 to 1950, with cotton and corn production accounting for the majority of cultivated land. "Shifting agriculture," i.e., the abandonment of "worn out" land for "new land," prevailed in the 19th and 20th centuries. The abandoned land eventually reverted to forest. As a result, estimates of land under cultivation at any point in time mask or underestimate the cumulative impacts of cultivation on the landscape.

The tenant farm era, which began after the Civil War and peaked in 1925, resulted in a greater number of small, dispersed farms at the SRS. Since a greater proportion of land on tenant farms was tilled than on other farms, erosional land use increased with tenancy (Trimble 1974). Mechanization of southern agriculture did not occur until the 1930s and came even later to most of the farms of the SRS (Cabak and Inkrot 1996). While soil erosion increased after 1870, it was probably not extensive until after 1900. Based on local soil descriptions for the SRS area (Carter et al. 1914, Bennett 1928, Rogers 1990), severe erosion was not common, and moderate erosion was not extensive.

The degree of impact of soil erosion and other agricultural activities on SRS streams is not known but increased sediment in streams would have certainly impacted populations of aquatic species. In addition, deposition of sediment along the Savannah River floodplain from soils of the Upper Coastal Plain and Piedmont would have impacted wetland communities. As railroad use increased, use of SRS streams declined, although some were still used to operate mills. The 1890 census shows that Lower Three Runs had a "few corn and sawmills" as well as several abandoned mills, while Upper Three Runs had 12 grist and sawmills, one cotton yarn mill, and six abandoned mills. Drainage and cultivation of upland depressions and bays in Barnwell County was reported by Carter et al. (1914) to be uncommon before 1912 even though some of the bays were probably drained or cultivated prior to 1930 and certainly were after that.

Agricultural chemical use in the SRS area increased significantly in the late 1800s with the dramatic increase in fertilizer use (SCDA 1927). With the arrival of the boll weevil, applications of calcium arsenate were initiated, and by the 1930s most CSRA farmers were "mopping" cotton crops with a mixture of calcium arsenate, water, and molasses (Brunson 1930; South Carolina Extension Service 1940, 1946; Barker 1997, interview). This was the predominant pesticide used in the area until the late 1940s, when farmers began using DDT and other organic pesticides for a variety of cotton pests (Boylston et al. 1948, South Carolina Extension Service 1951).

Forest use, in the form of land clearing, logging, and turpentining, increased dramatically during the period between 1865 and 1950. U.S. Census records and other records (Frothingham and Nelson 1944) suggest that naval stores production peaked in CSRA counties between 1880–1890 after the statewide peak in 1879. Statewide production fell sharply after 1890 but increased again after 1920. In 1936, there were three turpentine stills located within the present-day SRS boundary (Faulks and Spillers 1939). Simulations of 1880s turpentine production (derived from Mohr 1893 and Mattoon 1922), for three hypothetical stills, indicate as much as 10,526 ha of old-growth longleaf may have been abandoned as "worn out turpentine land" over a 10-yr period. For three stills operating in the 1930s and 1940s, 13,360 ha of second-growth longleaf pine may have been abandoned over a 10-yr period.

Longleaf pine was still quite prevalent in CSRA forests in the 1880s (Anonymous 1867, Hammond 1883), and not much of the river swamp was cut until about 1900 (Fetters 1990). Harper (1911) noted that by 1910, much of the longleaf pine lumbering and turpentining had "practically ceased" in the sandhills of Aiken and adjacent counties. Reflecting turn-of-the-century increases in crop production and tree harvesting, farm woodland declined from 65% of farmland in 1880 to 33% in 1925. Between 1910 and the early 1930s, extensive railroad logging occurred within the SRS. The Leigh Banana Case Company had 22 km of rail line in the Savannah River swamp, Kendall Lumber Company had 40 km along Lower Three Runs, and the Schofield Savannah Company logged along Upper Three Runs. Six or more other companies also logged in the area. Seventy percent of the Savannah River swamp had been impacted by logging before 1938, and additional logging occurred between 1938 and 1950 (Mackey and Irwin 1994). In the late 1940s, sawtimber and pulpwood harvests throughout Aiken and Barnwell counties were extensive (McCormack 1948).

Other significant drains on forest resources included harvests for fencing, fuelwood, and the railroad. Nationally and regionally, the railroads impact peaked in the 1880s. Wood demand for construction, maintenance, and fuel was substantial (Williams 1987). After the Civil War, the Port Royal Railroad was built adjacent to the Savannah River swamp within the SRS and, in 1898, an additional line was built from Robbins to Barnwell. Use of yellow pine and other species as fuelwood continued until the 1890s. Initial clearing for construction alone is estimated to have resulted in 3 to 12 ha of cleared line per km of rail (derived from Derrick 1930). The railroads brought increased use of longleaf pine and swamp forests, creating new land for crops and eventually creating settlements and towns, from which many agricultural and timber products flowed.

The rather rapid decline of longleaf pine resulted from a combination of factors, including hogs, destructive wildfires, and naval stores activities (Ashe 1894). Based on hog saturation densities (Frost 1993), Barnwell County had a sufficient number of hogs between 1840 and 1900 to severely impact longleaf pine establishment. Also, after stock laws were passed to keep cattle inside fences in the early 1880s, fire frequency was reduced and competing vegetation increased, further reducing the probability of longleaf pine establishment. Hammond (1883) commented on this condition: "The uplands were covered, as they still are, with a large growth of yellow pine, but a deer might then have been seen, in the vistas made by their smooth stems, a distance of half a mile, where now, since the discontinuance of the spring and autumn fires, it could not be seen fifteen paces for the thick growth of oak and hickory that has taken the lands." After 1880, pressures on the land from agriculture and wood use, coupled with fire suppression efforts of the 1930s, drastically reduced the once extensive longleaf pine forests in the SRS and throughout the rest of the South.

SRS OPERATIONS AND MANAGEMENT

Harvesting and Silviculture Activities

In December 1951, the AEC authorized the USDA Forest Service to manage most of the SRS land and to act as consultant to the AEC and the du Pont Company, the project contractor (Savannah River Operations Office [SROO] 1959, exhibit 4). The benefits of management were described as (1) use of "idle" land, (2) control of erosion and weed growth, (3) monetary return to the government from pulpwood and sawtimber sales, and (4) improvement of existing forests. The 1950 AEC announcement of SRS acquisition resulted in the "sudden removal of thousands of railroad cars of forest products" according to Hatcher (1966). Much of the site had been subjected to repeated cuttings and the timber was of little value. At least 2,000 ha of the plant was in 5 to 15 yr-old pine plantations in 1951, but most of the land was either cut-over second growth or open (Savannah River Project 1968, SROO 1959 exhibit 5; Fig. 2). In a 1951 report (SROO 1974), 34% of SRS was old fields, 15% swamp and stream bottom, and 51% mixed pine and scrub oak (most of the pine was cut-over second growth). Recent analysis of an orthorectified mosaic of 1951 aerial photos estimated that 48% of the area was in forest or heavy vegetation, some of which was young forests growing on abandoned agricultural land. The remaining 52% was considered agricultural land and open areas (Fig. 2).

The initial focus of management was to reforest abandoned farmland. The largest mechanized tree planting project in the United States was initiated at the SRS in 1952. Almost 24,000 ha had been planted by 1960. Throughout the 1950s, planting of slash pine (*Pinus elliottii*) ex-

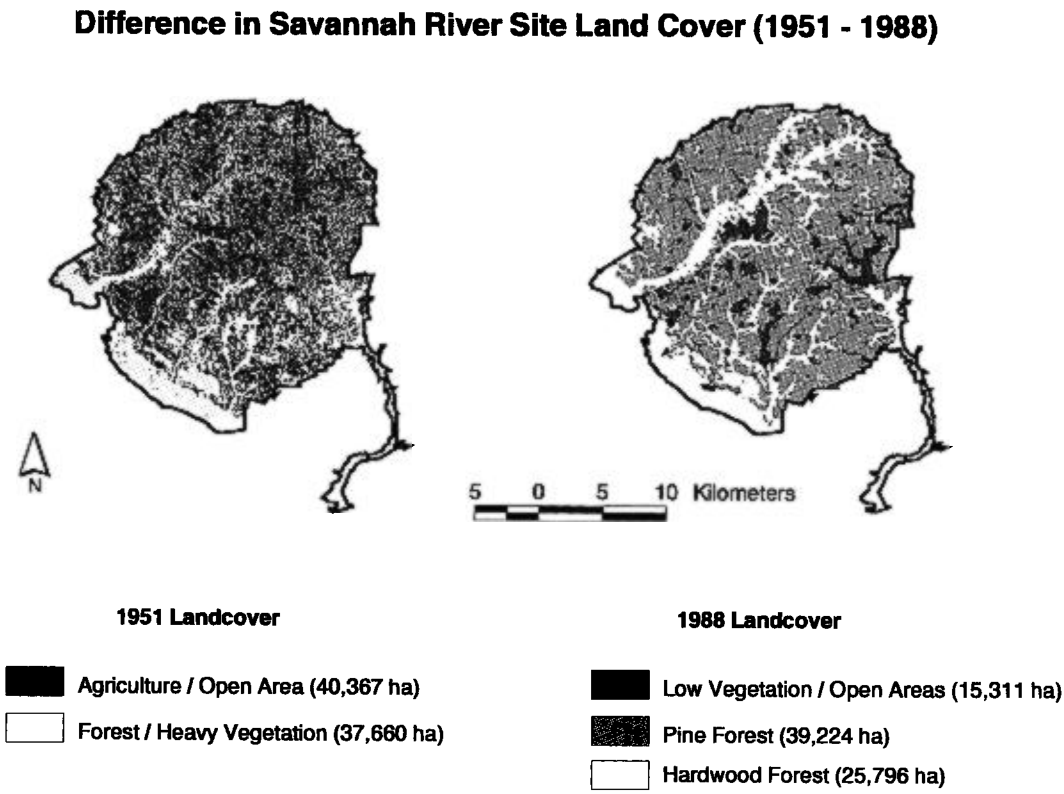

FIGURE 2. Savannah River Site land cover classes, 1951 and 1988 (J. Pinder, unpubl. data). The 1951 map is derived from a USDA Forest Service, orthorectified mosaic of 1951 aerial photos, while the 1988 map was created from a 3-season composite of Landsat TM imagery taken in 1988.

ceeded other species. From 1959–1970, longleaf was the predominant species planted or seeded and was established on over 8,700 ha, much of which was in scrub oak stands (Fig. 3). The only extensive application of insecticides occurred in 1953 when 3,600 ha of newly planted pine stands were sprayed with chlorinated hydrocarbons, to treat an outbreak of *Phyllophage prununculina.*

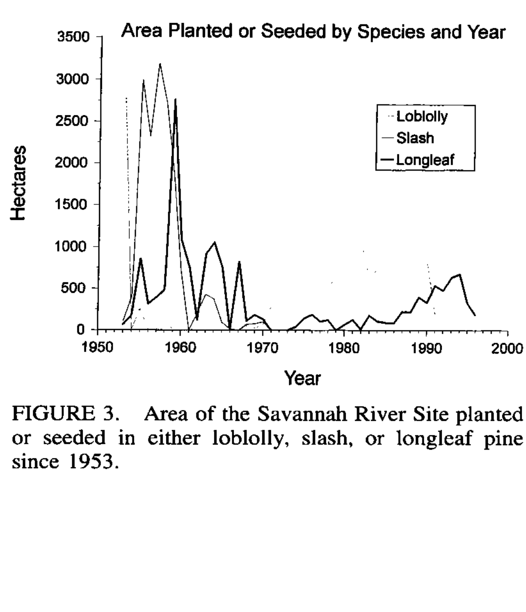

FIGURE 3. Area of the Savannah River Site planted or seeded in either loblolly, slash, or longleaf pine since 1953.

After 1970, slash pine planting ceased and slash pine stands were converted to loblolly. In the 1970s, efforts were made to regenerate relatively pure stands of loblolly and longleaf pine and to convert scrub oak stands to longleaf pine using both mechanical and chemical treatments. From 1970 to 1990, planting of loblolly pine exceeded that of longleaf but thereafter this pattern was reversed (Fig. 3). The reforestation of the SRS is shown dramatically in the comparison of 1951 and 1988 land cover (Fig. 2), where forested land increased from 48% to 81%.

The use of mechanical and chemical means to prepare sites for planting or to release desired trees from competition (timber stand improvement or TSI) is summarized in Table 3. TSI was begun in 1954; by 1966, 8,000 ha had been mechanically or chemically treated (Hatcher 1966). During the 1950s, most TSI work was done in the uplands and in areas above and adjacent to stream drainages (SROO 1959, TSI map); in the

TABLE 3. SELECTED SILVICULTURAL ACTIVITIES 1953–1996 (AVERAGE HA/YR)

Time period	Prescribed fire	Release from competition	Site preparation[a] Mechanical	Site preparation[a] Chemical
1953–1960	121	992	na	na
1961–1973	1550	462	na	na
1974–1985	3376	130	141	252
1986–1996	4608	234	255	797

[a] Seventy-three and 43% of chemical site preparation was tree injection for 1974–1985 and 1986–1996, respectively.

TABLE 4. SAWTIMBER AND PULPWOOD HARVESTS, 1953–1996 (AVERAGE VOLUME HARVESTED PER YR IN CUBIC METERS[a])

Time period	Sawtimber Pine	Sawtimber Hardwood	Pulpwood Pine	Pulpwood Hardwood	Total combined
1955–1960	5148	0	2613	0	7762
1961–1973	11377	0	46903	0	58281
1974–1985	22570	1606	66093	1537	91805
1986–1996	47081	1434	53185	2950	104650

[a] Volume conversions from board feet (bf), cunits and cords to cubic meters from Husch et al. 1982; specific correction factors used include: 1 cunit = 1.54 cords; 1 ft^3 = 6 bf.

1960s, much of it was done in scrub oak stands that had been regenerated to longleaf pine (Hatcher 1966). TSI work included mechanical and chemical removal of undesirable species in pine stands. Most of the spraying at SRS has been done with mist blowers pulled by tractors. The use of V-blades on planters or seeders to make furrows for enhancing tree survival has been a common practice at SRS since the 1950s. Shearing and raking were used to prepare areas for planting or seeding through the mid-1980s (especially in scrub-oak to pine conversions), but were stopped in the late 1980s because of the intensity of soil disturbance. Other, less-intensive site preparation techniques included drum chopping, chainsaw felling, stem injections, and prescribed burning. Predominant practices in the 1990s are burning and herbicide-and-burn in pine stands, and mechanical treatments where hardwoods have been planted.

Sales of sawtimber and pulpwood began in 1955 but were not extensive until after 1960, increasing significantly as more pine attained merchantable size (Table 4). Pine harvests exceeded hardwoods dramatically. Early harvests were in the area inundated by Par Pond, as well as creek bottoms and existing pine plantations. In the 1970s, clearcutting was used to create a more balanced age distribution, because so much of the site had been planted at the same time. Even-aged management has predominated at SRS and is currently used in areas not managed for the Red-cockaded Woodpecker (*Picoides borealis*). Over the past 10 years, the site has been on a sustained harvest of about 100,000 m^3/yr. Since 1990, 53% of timber volume harvested has been from thinnings with the remainder from clearcuts. Standing timber increased from $2 million in 1952 to over $500 million in 1995. The total area in longleaf pine peaked in 1967 at 18,000 ha, declined to 10,000 ha by the late 1980s, and had increased again to 16,000 ha by 1996. The combined loblolly and slash pine area peaked at 43,000 ha in the late 1980s. In 1996, there were 26,000 ha of loblolly.

Prescribed fire was not used extensively in the 1950s, in part due to operational difficulties, but its use increased thereafter (Table 3). It was not until the early 1970s that the responsibility for wildland fire suppression shifted from the du Pont Company to the SRI, resulting in an increased use of prescribed fire. Use of fire peaked in 1979–81 and then declined drastically due to smoke management regulations. It peaked again in 1990 and remained high after 1991, as needed to recover the Red-cockaded Woodpecker and restore pine savanna. Prescribed burning was first done to reduce fuel accumulation and later to improve game habitat and reduce logging slash and hardwood competition.

The extensive SRS forests that were once rural farmland now serve as important wildlife habitat in the region, especially when considering the degree of fragmentation of forests by urbanization and agriculture in the surrounding Upper Coastal Plain (Kilgo et al. *this volume*; J. Pinder, unpubl. manuscript). This shift in land use has resulted in population increases for many animal species (Beavers et al. 1972). Efforts to control deer, hogs, and beaver populations were begun in the 1960s. Currently, annual deer and hog hunts are conducted by Westinghouse Savannah River Company (WSRC). In addition, on a portion of the site called the Crackerneck Wildlife Management Area, the South Carolina Department of Natural Resources (SCDNR) conducts hunts for white-tailed deer, hogs, Wild Turkey, waterfowl and small game. Additionally, SCDNR and SRI conduct habitat enhancement for Wild Turkey and Northern Bobwhite (*Colinus virginianus*; Davis and Janecek 1997).

A decline in the Red-cockaded Woodpecker population from about 26 birds in 1978 to 4 in 1985 was attributed to a shortage of suitable cavity trees, interspecific competition for cavities, and encroachment by midstory hardwoods (Jackson 1990). In cooperation with the SRI, the Department of Energy (DOE) began a recovery program in 1985 that involved habitat enhancement, extensive monitoring, and population augmentation (DeFazio and Lennartz 1987). Since that time, midstory hardwood removal, prescribed fire, and longleaf pine planting have increased and the Red-cockaded Woodpecker population has increased to 114 individuals. Since 1991, 60% of the forested acres has been managed as potential Red-cockaded Woodpecker habitat in long-rotation longleaf (120 years) and loblolly pine (80 years) stands while the remaining 40% is managed on 50-yr rotations.

Research Set-Asides

In 1951, the AEC-SROO invited the universities of Georgia and South Carolina (Davis and Janecek 1997) and the Philadelphia Academy of Sciences (Patrick et al. 1967) to gather baseline data from different habitats on the SRS to monitor ecological impacts of facilities construction and operation. In 1952, the manager of AEC-SROO recommended that 4,856 ha, representing ecologically different land types on the SRS, be set aside from reforestation and used for ecological research projects (letter from C. A. Nelson, Manger, AEC-SROO, to G. H. Giboney, 2 February 1952).

The first two areas that were eventually established as set-asides were identified as representing minimally disturbed forest types and comprised less than 40 ha. Today, a total of 5,668 ha, comprising 7% of the total SRS area, are part of a set-aside program administered by the SREL. Thirty tracts of land, ranging in size from 3 to 2980 ha have been reserved for ecological research and are protected from public access and most routine site operations (Davis and Janecek 1997). The set-asides were established to represent the major plant communities and habitat types indigenous to the SRS. They are used in many long-term ecological studies, and as "control" sites in evaluating potential impacts of operations on other areas of the SRS (Davis and Janecek 1997). In 1972, the AEC designated the SRS as the first of seven National Environmental Research Parks (NERP). The purpose of the NERP program is to provide tracts of land where human effects on the environment can be studied (Davis and Janecek 1997).

Ecological Impacts of DOE Operations

The aquatic and terrestrial environments of the SRS have been affected by a variety of perturbations including thermal effluents, which had ended by 1988 (Wike et al. 1994), fly-ash runoff, construction of facilities for radioactive waste (Dukes 1984), as well as the release of low-level radionuclides, chlorine (as an algicide), and certain metals (Gibbons et al. 1980). Specifically, radiocesium (^{137}Cs) was produced during the operation of the five production reactors. Several hundred curies of ^{137}Cs were released from leaking fuel elements into streams in the late 1950s and 1960s and smaller quantities were released from fuel reprocessing operations. Radiocesium concentration and transport mechanisms for the atmosphere, surface water, and groundwater have been extensively studied by the Savannah River Technology Center (SRTC) and ecological mechanisms have been studied by SREL (Carlton et al. 1992).

Par Pond and L Lake represent the largest in a network of several reservoirs constructed to cool the effluents of two production reactors (Workman and McLeod 1990). Water from the Savannah River has been diverted into the 1069-ha Par Pond since the late 1950s. The 400-ha L Lake was constructed as a flow-through cooling reservoir in 1985.

When the five nuclear production reactors were active, high temperature (>70 C) cooling-water effluents were released into thermal canals that flow into the Par Pond and L-lake reservoir systems, or into the major tributaries of the Savannah River (Gibbons et al. 1980, Yanochko et al. 1997). The Savannah River is at least 19 km from any of the reactors, and at the point of entry the effluent water was seldom elevated more than 2 to 3 C above ambient temperature. However, the intermediate thermal conditions between release from the reactors and entry into the swamp or river systems provided a diversity of aquatic habitats (Sharitz and Gibbons 1979, Gibbons et al. 1980). The aquatic areas that received hot water continuously for 25 years and the post-thermal-recovery areas of different ages have been the focus of several studies examining metabolism, thermal tolerance, genetics, dispersal, species diversity, productivity, growth and development, and the synergistic effects of temperature and other forms of environmental stress (Gibbons et al. 1980).

Major studies of the Par Pond reactor cooling reservoir system have focused on subjects ranging from thermal ecology to radionuclide uptake by free-living organisms. In 1991, Par Pond was drawn down approximately 6 m to allow repair of the retaining dam, which reduced the reservoirs surface area by about 50%. That process killed the aquatic macrophytes, exposing the contaminated mudflats and allowing quick colonization by terrestrial vegetation (Brisbin et al. 1996). Par Pond reservoir refill from rainfall began in August 1994, and in December 1994, active pumping of water from the Savannah River was begun. Full pool was attained by January 1995 (Brisbin et al. 1996). During the drawdown period, research was conducted to determine the effects of radiological contamination on poultry production (Peters et al. 1995), remediation of radionuclide contaminated soils (Seel et al. 1995; D. C. Adriano, unpubl. data), health risks to hypothetical residents of a radioactively contaminated lakebed (Whicker et al. 1993), and potential health risks to the public concerning consumption of Mourning Doves (*Zenaida macroura*; Burger et al. 1997, Kennamer et al. 1998). In addition, during and immediately after the refill period, research was conducted to determine the effects on resident alligator and wintering waterfowl populations (Brisbin et al. 1992; K. F. Gaines, unpubl. data).

Storage of high-level radioactive liquid waste in large underground tanks and solid radioactive waste in SRS Burial Grounds have had impacts on the site as well (Dukes 1984). A coal-fired power plant (the 4 x 10^8 Btu h "400 D Area Plant") discharges sluiced fly and bottom ash into a series of open settling basins. A continuous flow of surface water from a secondary basin enters a 2-ha drainage swamp, which enters a tributary of the Savannah River (Beaver Dam Creek). Past investigations of the D-Area basins, swamp, and Beaver Dam Creek have found enrichment of water, sediments and biota of such elements as Al, As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Se and Zn (Cherry and Gutherie 1977, Evans and Giesy 1978, Cherry et al. 1979, Alberts et al. 1985, Sandhu et al. 1993, McCloskey and Newman 1995, Rowe et al. 1996).

In summary, the SRS provides a unique setting for environmental research. Long- and short-term studies conducted on the 78,000-ha NERP have provided insights into the ecological impacts of management and land use. The following chapters discuss some of the avian studies that have been conducted on the SRS and in surrounding areas. Their focus ranges from life history and population dynamics to endangered species management.

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