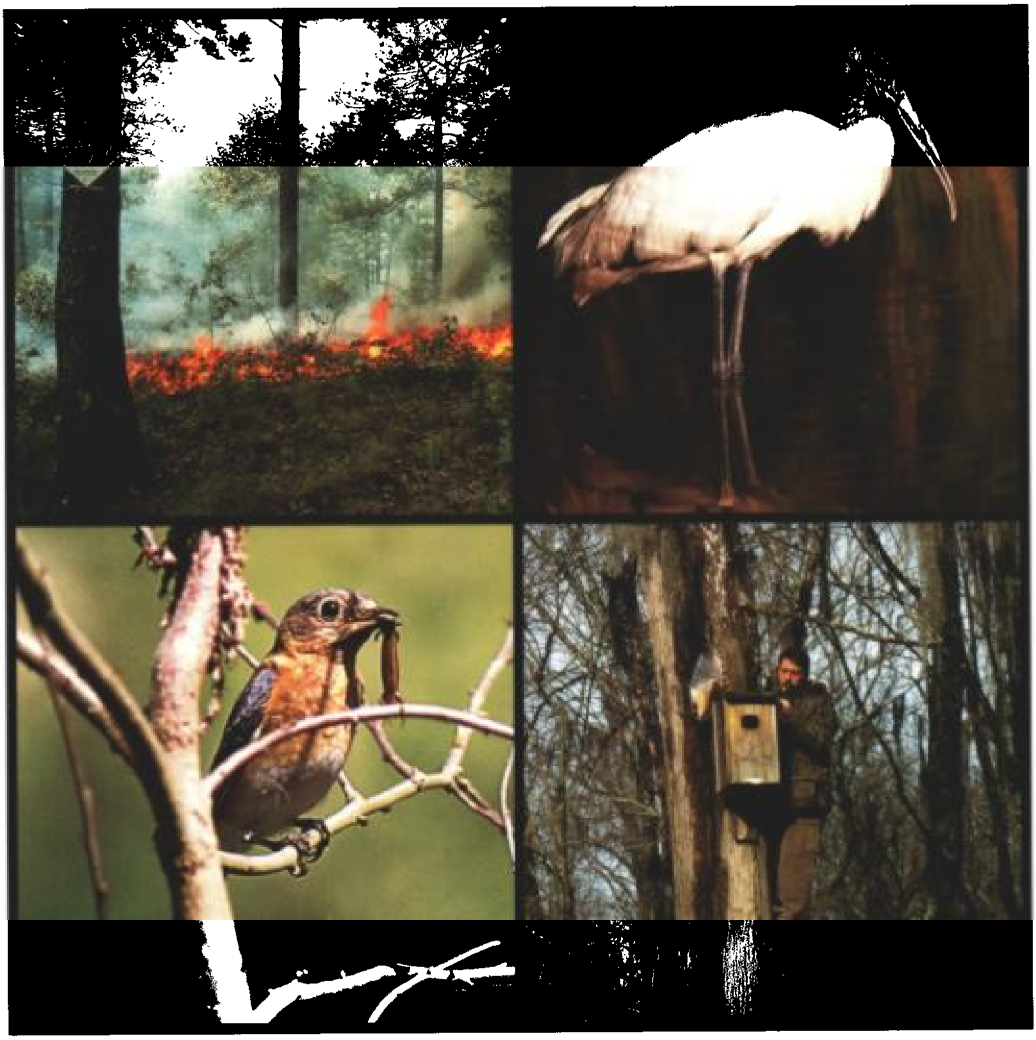
AVIAN RESEARCH AT THE SAVANNAH RIVER SITE: A MODEL FOR INTEGRATING BASIC RESEARCH AND LONG-TERM MANAGEMENT

JOHN B. DUNNING, JR. AND JOHN C. KILGO, EDITORS



Studies in Avian Biology No. 21
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AVIAN RESEARCH AT THE SAVANNAH RIVER SITE: A MODEL FOR INTEGRATING BASIC RESEARCH AND LONG-TERM MANAGEMENT

John B. Dunning, Jr. and John C. Kilgo, editors

Sponsored by the U.S.D.A. Forest Service

Savannah River Institute

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Cover photos (clockwise from upper left): prescribed burn for Red-cockaded Woodpecker (*Picoides borealis*) habitat management (file photo, USDA Forest Service, Savannah River); Wood Stork (*Mycteria americana*; photo by David E. Scott); researcher checking Wood Duck (*Aix sponsa*) nest box (photo by Robert A. Kennamer); Eastern Bluebird (*Sialia sialis*; photo by David E. Scott).

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PREFACE

JOHN B. DUNNING, JR., AND JOHN C. KILGO

The Savannah River Site (SRS) is a 78,000-ha tract in western South Carolina operated by the U. S. Department of Energy (DOE). It is designated as a DOE National Environmental Research Park. Although the primary mission of Savannah River Site was the production of nuclear weapons materials, the site has a long history of environmental stewardship, restoration, and ecological research. Natural resources have been managed since the inception of the federal facility by the U.S. Forest Service (Savannah River Institute, SRI) according to Department of Energy policies. The natural resource programs have evolved from an initial goal of reforestation of abandoned farmland to sustainable management, restoration, and stewardship. Ecological research at SRS has been conducted by several organizations, including the Savannah River Ecology Laboratory (SREL), the U.S. Forest Service Southern Research Station, Westinghouse Savannah River Company, the Philadelphia Academy of Sciences, and many cooperating universities. This research has focused on everything from radiological impacts of facilities to the effects of forest management.

Researchers on the Savannah River Site have always been conscious of the competing mandates present in the operation of the facility. On the one hand, fundamental ecological research has been conducted on the plant and animal communities, both terrestrial and aquatic, from the first years of federal management. On the other hand, the primary functions of the nuclear program required that research be directed towards answering pressing questions posed by the management planners. Also, research activities could be and were often constrained by competing activities and land-use needs involving other workers and programs on the site. Thus, SRS researchers have worked within an atmosphere where research and management must be cooperative in logistical planning, strategic planning, and on-site implementation. Because improved integration of research and management is increasingly seen as a worthwhile goal for both the scientific community and land management agencies, experiences on the Savannah River Site may be instructive in helping others to attain this integration.

As described by Meyers and Odum (*this volume*), some of the earliest ecological research at SRS was conducted on birds. Dr. Eugene P. Odum, founder of SREL, initiated studies of the birds found in abandoned farmland even before the Savannah River Site was officially designated. SREL researchers have continued their ornithological research to the present, covering many issues but focusing largely on radiological and endangered species impacts of the SRS program, especially in wetland ecosystems. In the late 1980s, the Department of Energy initiated a Biodiversity Program to fund ecological research designed to meet specific information needs of SRS land managers. J. G. Irwin, SRI Forest Manager at the time, was responsible for identifying the need for the research-management collaboration underlying the Biodiversity Program. Ornithological work conducted under the SRI Biodiversity Program has been done primarily by scientists associated with the Southern Research Station and various universities, including the University of Georgia, Clemson University, the University of Florida, Purdue University, and Virginia Polytechnic Institute.

The papers presented herein arose from a workshop held at the Savannah River Site in 1996 sponsored by the Savannah River Institute. As the volume of ornithological work conducted at SRS increased, programmatic review indicated that a synthesizing workshop was warranted. John I. Blake, Research Manager of the Savannah River Institute, initiated discussion with J. B. Dunning and the idea of the workshop was born. In addition to introducing the participants to the range of avian research being conducted on the SRS, a goal of the workshop was to explore the interaction of researchers and managers within the multidisciplinary program of the Savannah River Site, identifying successful aspects of the collaboration as well as lessons for improvement. The workshop was one of a series of similar workshops held during the early to mid 1990s intended to summarize available information on topics of interest to SRS land managers, such as spatially explicit population models, the importance of coarse woody debris to the biodiversity of Southern forests, ecological restoration, and the ecological legacy of historical land use.

In organizing the workshop, an attempt was made to represent as much of the ornithological research conducted at SRS as possible. Participants included biologists from SRI and researchers from the Southern Research Station, SREL, Westinghouse Savannah River Company, and several of the universities mentioned above. Biologists with the South Carolina Department of Natural Resources, non-governmental organizations such as the National Audubon Society, and regional ornithologists who did not work specifically at the SRS also were invited to provide a wider range of opinions on the material presented in workshop talks. The resulting discussions improved our collective understanding of the research/management interaction, and eventually resulted in the papers published in this volume of *Studies in Avian Biology.*

The U. S. Department of Energy, the Savannah River Institute, the workshop participants, and the authors are to be commended for making this volume possible. In addition to the authors, we thank the other invited workshop participants who contributed to planning and discussions. These include Amanda Beheler, Keith Bildstein, John Cely, Jeff Christie, Daniel Connelly, Karen Gaines, Carol Eldridge, Larry Eldridge, Michael Guzy, William Jarvis, Dennis Forsythe, Gary Hepp, Brad Seaman, Jonathan Stober, and Craig Watson. Reviewers of manuscripts and workshop proposals include participants in the workshop and Frank Golley, Scott Pearson, Jeff Price, Kimberly Smith, Joel Snodgrass, and Jeffrey Walters. We thank personnel of SRI (particularly Ed Olson), SREL, and the Southern Research Station of the U.S. Forest Service for assistance in the workshop itself and the development of this volume. The workshop was funded by a grant from the SRI Biodiversity Program, which also subsidized the publication of this *Studies in Avian Biology* volume. Laura Janecek and David Scott of SREL aided in the production of the cover.

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INTRODUCTION

JOHN B. DUNNING, JR. AND JOHN C. KILGO

Land managers and ecological researchers have long had an uneasy relationship. Ideally, land management and research should be intimately intertwined: managers need a solid scientific basis for their planning and strategies (Perry 1998), and researchers need a context for their research that demonstrates its relevance in solving today's conservation problems (Lubchenco 1998). In short, managers need answers to questions, and researchers need support for answering questions. In an ideal world, these two needs would provide a synergistic effect allowing managers and researchers to work together closely.

The real world is not always ideal. Although in some places land managers and researchers have a long history of working together closely and effectively, in many other situations tension exists between the two groups. While the value of both research and management to each other should be apparent, there exist many reasons why research and management do not mesh well. For instance, the scientific basis of a proposed management action is only one of several factors that must be woven into the development of an overall strategic land management plan (Johnson et al. 1999). Similarly, while the management relevance of a scientific question may be one motivation to encourage scientists to investigate the question, for many researchers this motivation may be less important than publishability, funding, and an intrinsic curiosity to investigate the question.

In an era of limited funding for research and increased scrutiny of land management, it is imperative that the tension between research and planning be reduced whenever possible (Huenneke 1995). To this end, examination of the research-management interaction at places where the two groups collaborate can be instructive. In November 1996, we gathered together a group of avian ecologists working on long-term projects at the Savannah River Site, a U.S. Department of Energy facility in South Carolina. The purposes of the workshop were varied, but an important theme was to examine how research and management interacted at this facility whose primary mission was not natural resource management.

The Savannah River Site hosts a wide variety of research ranging from ecology to environmental science to nuclear physics. Biological researchers included scientists with the U.S. Forest Service, university faculty and students, and other individuals with various research facilities located on the site. Managers of the Savannah River Site include professionals with the U.S. Forest Service, Department of Energy, and private companies such as Westinghouse that run the daily operations.

In part the workshop was held to introduce the participants to the wide range of avian research being conducted on the SRS. As pointed out previously by Huenneke (1995), such personal contact between and among researchers and managers is a crucial step in fostering collaboration. A major additional goal was to explore how researchers worked with the land-management structure of the SRS to accomplish the researchers' plans and meet the strategic goals of the Department of Energy, as those goals apply to natural resource management. We discovered many examples of positive collaboration between research and management, including programs in environmental recovery from anthropogenic stress, monitoring of sensitive species, mitigation for human development, landscape ecology, and the accumulation of a tremendous amount of new ecological knowledge. We also discovered many strong opinions on how researchers and managers should or should not interact.

Following the conclusion of the two-day workshop, participants agreed to produce a series of papers summarizing their experiences and thoughts on working in a research/management framework. The current collection of papers is the result of this agreement. Not all participants were able to submit papers for publication, and we also solicited manuscripts from people invited to the workshop who were unable to attend. The result is a broad-ranging collection of papers demonstrating how some people have been able to exploit the combined interests of basic and applied research foci successfully. The papers in this collection also include some essays on how collaborative initiatives between researchers and managers can be implemented, and why doing so is important. We hope that the publication of these papers can further the discussion that is in progress on this important topic.

WHY ARE THERE PROBLEMS BETWEEN LAND MANAGERS AND ECOLOGICAL RESEARCHERS?

While the reasons for a lack of collaboration between individual researchers and land managers are probably as varied as the individuals themselves, we offer a few reasons why such collaborations can be difficult to establish and maintain smoothly.

- Some managers do not see the need for supporting basic research directly on their lands, viewing it as superfluous and generally not directly related to the strategic goals of their operation.
- Some researchers work on arcane topics of little immediate obvious value to conservation and management.
- Research on management questions may be viewed as too site-specific, species-specific or limited in applicability to interest researchers (and their publication outlets) in general (Huenneke 1995).
- Researchers hesitate to link their results directly to recommendations for specific land-use decisions, preferring the safer "more research needed" approach when asked to respond to specific management questions (Pouyat 1999).
- Managers must meet short-term goals and annual quotas, and research results may suggest actions that are inconsistent with these short-term goals.
- Researchers demand long-term funding to allow their research to unfold, while managers demand quick answers to specific questions that may not be the main focus of the research.
- Researchers dislike working with managers who do not value scientific information, or who misuse such information and cite it out of context (Mills et al. 1998).
- Managers dislike working with researchers who refuse to get involved in decision making processes, but who then criticize decisions from a distance (Mills et al. 1998).

BASIC DICHOTOMIES

Part of the separation between researchers and managers stems from application of inaccurate labels onto the work that people do, labels that tend to support separation (Huenneke 1995). A dichotomy exists between managers and researchers, but within the research ranks, further divisions exist that tend to increase confusion. Basic research is viewed as distinct from applied research, and university (or academic) research is viewed as distinct from that conducted by government agencies or private research firms. Furthermore, these dichotomies themselves can be confused. University research is not always basic, and agency research is not always applied. Much applied research is conducted in natural resource departments within universities, for example.

Often, certain stereotypes are applied to researchers—both by managers and by other researchers—based solely on their professional affiliation. For instance, ecology has long been considered one of the "basic" sciences conducted to increase the general knowledge in the field, while resource management has been labeled an "applied" science, conducted to address a particular goal set by society. Using these labels, university ecologists from a field station or ecology department are generally assumed to be interested mostly in basic science approaches, whereas researchers with a management agency such as the U.S. Forest Service are generally assumed to be applied scientists.

These dichotomies were probably never very accurate, and certainly do not apply to the kinds of research conducted on the Savannah River Site. University-based ecologists are finding it crucial to make their research relevant to solving problems of interest to the general public—to make their research more easily applied, in other words. Some (but not all) researchers in the Forest Service and other agencies have always conducted pure, basic research. In spite of this, we have observed a tendency for some scientists in academia to lump all personnel in land-management agencies as "applied scientists" (or even less accurately, "managers," which assumes no research is being done), while some agency managers lump all academic scientists as "basic researchers" whose work is irrelevant to any real-world problems. A major goal of the Savannah River workshop was to get people from all these arenas together and break down some of the barriers that labels can build.

WHY SHOULD THESE PROBLEMS BE OVERCOME?

In spite of all these potential problems, it is critical for all interests to work together if valuable research is to be conducted. The need for management/research collaboration may be easiest to see in the case of long-term research programs, and the papers presented in this collection emphasize long-term studies. To generate answers to some important questions, research programs may need to outlive the typical lifespan of a single research grant, the graduate career of a single student, or even the working career of a single researcher. Long-term research therefore needs consistent support. Similarly, management planning is shifting from short-term goals that dominated the past to long-term ecological management and sustainability (Christensen et al. 1996, Johnson et al. 1999). Thus, managers need research results that guide them in making long-term plans. For both research and management, then, the benefits of collaboration should make the problems worth overcoming (Nygren 1999).

LONG-TERM RESEARCH FROM THE ORNITHOLOGISTS' PERSPECTIVE

Ornithologists have long realized the value of long-term research. The importance of continued research efforts has been seen in the study of lifetime reproductive success in many birds (Newton 1989), in the teasing apart of genealogies and inter-individual relationships (e.g., Brown 1987), and in the tracking of population dynamics (e.g., Grant and Grant 1989). The value of continuous research on specific topics or ecosystems can be seen in the National Science Foundation's funding of Long-Term Ecological Research sites (Bildstein and Brisbin 1990).

The recognition of the value of long-term research contrasts vividly with the 2–3 year length of a standard research grant. To develop a long-term program, a researcher is usually forced to write a series of proposals, each focusing on short-term goals. Given the shortage of research funds in general, researchers commonly must write many proposals to ensure that enough are funded to support the research. It is not uncommon for researchers to be confronted with gaps in funding, during which research may be suspended or abandoned. It is due to the increasing occurrence of such difficulties that calls for increased support for long-term research have been issued. Direct collaboration with management at a study site offers the possibility of long-term support for research.

This support is not just in terms of money, but also in logistical support. Researchers need to know that their study sites are going not going to be compromised by changes in management during the study. Researchers need long-term access to the study region, ability to use the necessary tools to perform experiments, and a supportive attitude among personnel with whom the research teams must interact. Management agencies can be the source of background data, which indicate how study sites were treated in the past, and planning documents can provide expectations of how site conditions are expected to change in the future. This latter point can shape the entire experiment that is being designed, as researchers use future management actions as the experimental manipulations being studied. Huenneke (1995) argues that research on conservation-related topics, done in collaboration with local managers, is attractive to both undergraduates and graduate students, improving the quality of assistants willing to work on a research project. Thus, researchers can find many benefits in implementing a long-term research program in areas that are under strong land management.

THE VALUE OF LONG-TERM RESEARCH FROM THE MANAGER'S PERSPECTIVE

Given the shifting emphasis from short-term to long-term planning, resource managers increasingly require information on the long-term effects of management practices. Monitoring of population numbers and health is critical for managers to discern trends in populations over time (Holling 1993). Information on whether populations are increasing, decreasing, or remaining stable may dictate whether action is needed to reverse or slow the observed trends. However, monitoring alone is not enough. Long-term research is required to relate temporal and spatial trends in populations to a particular management practice or risk factor. Research also allows managers to understand the processes and causal mechanisms underlying the observed patterns, and to be able to predict trends into the future. This is especially true when dealing with forested ecosystems and timber management plans covering 50–100 years.

Frequently managers are faced with questions whose answers require research conducted over long time periods. Managers and researchers both become frustrated when the pressing issues facing managers change by the time a specific research program is completed. To the manager, the information generated by the research no longer seems important, whereas to the researcher, the utility of the information seems compromised. However, if the questions were clearly developed and the study carefully designed, the results ultimately will still prove useful, since pressing issues in natural resource management rarely disappear completely. Reliable knowledge based on sound ecological principles, as established by careful, long-term research, will always be useful in management.

THE SAVANNAH RIVER SITE AS A CASE STUDY

A major goal of the 1996 workshop was to illustrate how research in a variety of avian ecology fields has been conducted within a management framework at the Savannah River Site. While there have certainly been numerous conflicts between research and management over the years, some ecologists at the workshop have developed important research programs with the assistance of the various agencies, institutes, and laboratories present on the SRS. The following papers outline these successes, and offer thoughts on how such collaborations might be developed further. The organization of the papers in this collection is as follows.

The first set of papers describes the SRS, its early history, and the first attempts at avian research done on the Site. White and Gaines describe the region and the natural habitats contained within the Site, and offer an historical perspective on how the land was used prior to the creation of the Department of Energy facility. As one of the first scientists funded to do ecological research on the Savannah River Site, Eugene Odum has a unique perspective on "long-term" research there. Meyers and Odum summarize the work done in the early 1950s on the bird communities present as the nuclear research facilities were created. An additional historical perspective is provided by McNair and Post, who use old museum specimens to determine if the status of several species in South Carolina has changed over the last century. Although the original specimen collections were not done on what was to become the SRS itself, McNair and Post demonstrate the value of older records in documenting long-term change.

A second set of papers gives examples of long-term avian research conducted on the Savannah River Site. Each paper illustrates a different kind of research, and each set of authors was asked to address how their work benefited, or benefited from, management interactions. Kennamer and Hepp describe their research on Wood Duck (*Aix sponsa*) breeding biology, done in part as monitoring of the ecological systems required by the Department of Energy. Bryan, Coulter, and Brisbin present a summary of their research on Wood Storks (*Mycteria americana*). Their research was initiated as part of a mitigation project required because of the loss of foraging habitat for this endangered species due to a construction project. Brisbin and Kennamer summarize their radioecology studies of the American Coot (*Fulica americana*). Contamination of ecological systems by radioactive elements was an early worry of the operators of the Savannah River Site, and the understanding of how contaminants act in ecological systems has long been a priority research goal. Franzreb and Lloyd describe their studies of the endangered Red-cockaded Woodpecker (*Picoides borealis*), whose habitat needs and population dynamics are strongly affected by forest management. Dunning, Danielson, Watts, Liu, and Krementz outline how the study of habitat needs of Bachman's Sparrow (*Aimophila aestivalis*) evolved into an integrated program of landscape analysis and population modeling to determine the impacts of long-term timber management. Taking a multi-species approach, Kilgo, Franzreb, Gauthreaux, Miller, and Chapman examine the question of how the intensive forest management associated with the establishment of the Savannah River Site has affected the regional assemblage of breeding birds. Finally in this section, McCallum, Leatherman, and Mayer compare the birds studied in Odum's initial studies to those studied in projects undertaken in subsequent decades to determine which species have been inadvertently "falling through the cracks" of scientific coverage and therefore in the understanding of local impacts.

A third set of papers presents a variety of conceptual approaches to merging management and research needs. The workshop stimulated the participants to discuss the implications of the research/management interaction from many different perspectives. In this third section, some authors offer descriptions of research programs that bring some of these perspectives to light. Other contributions address how future research could be conducted to increase the viability of the management/research interaction.

Blake and LeMaster present a manager's perspective on how research might best be designed and conducted to produce information useful to management. Moorman offers advice from a researcher's perspective on how researchers can present proposed work in a way that might ease integration with management systems and goals. Burger offers a variety of reasons why Department of Energy lands offer excellent prospects for long-term avian research and how such research could fit into the strategic goals and futures of these properties. Hamel and Dunning address one of the most difficult aspects of determining how populations have changed long-term—that of reconstructing the past histories of study areas. Their paper makes specific recommendations on how historical data could be retained in management databases to make long-term research easier to accomplish. Pilcher and Dunning offer a review of landscape ecology as one arena where managers and researchers are both aware of the benefits of expanded research and collaboration. Rogers and Heard argue that testing of cutting-edge ecological theory is a research goal not often embraced by land managers, but one that could potentially yield great benefits to all concerned. They use testing of the mesopredator effect as an example of this kind of research that could be accomplished at Savannah River. Kilgo, Miller, and Moore describe how a long-term research program can be created by the integration of a series of short-term projects with specific, yet interwoven research goals. Finally, Odum presents some brief remarks on the 40-year history of ornithological research that he has witnessed at the Savannah River Site.

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The original workshop at the Savannah River Site was funded by a cooperative agreement with the Biodiversity Program of the USDA Forest Service Southern Research Station, with logistical support of the Department of Energy, Savannah River Operations Office. The Savannah River Site is a National Environmental Research Park. We thank all the participants in the workshop for their stimulating discussion and ideas, and thank the patience of the authors of these papers during the long gestation period.

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

David L. White and Karen F. Gaines

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).

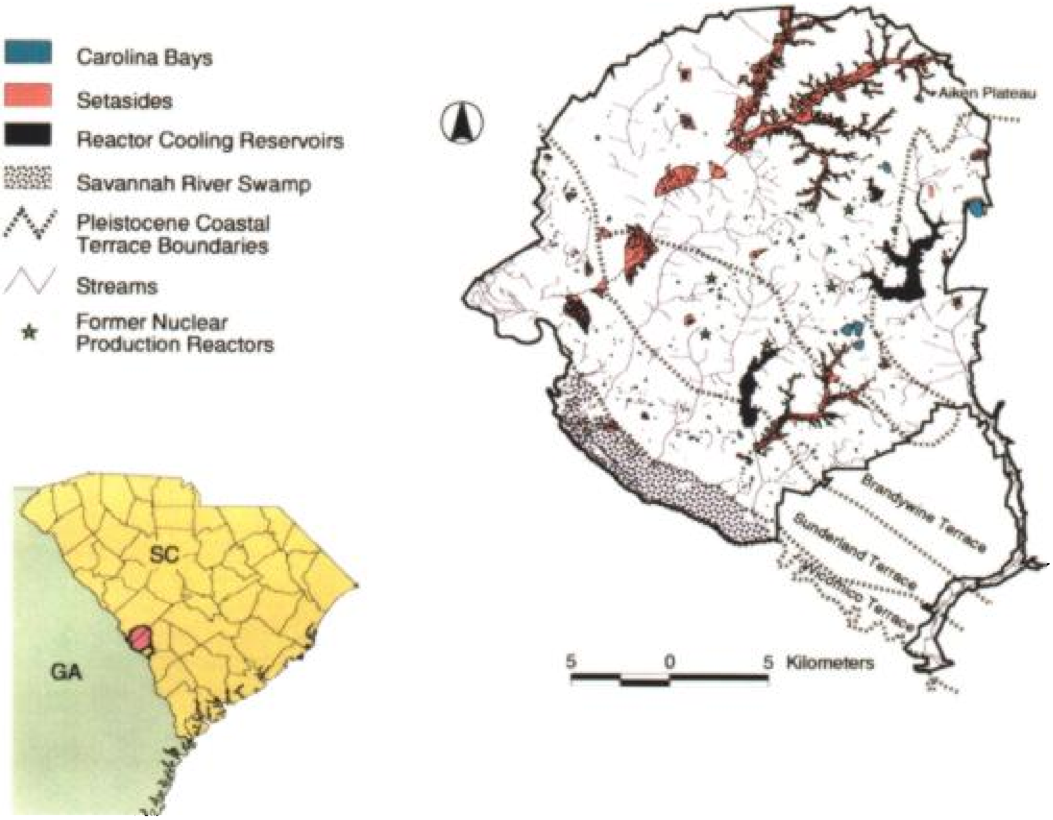

FIGURE 1. Map of the Savannah River Site, showing general location in the region, physiography, streams, research set-asides, and Department of Energy facilities.

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-

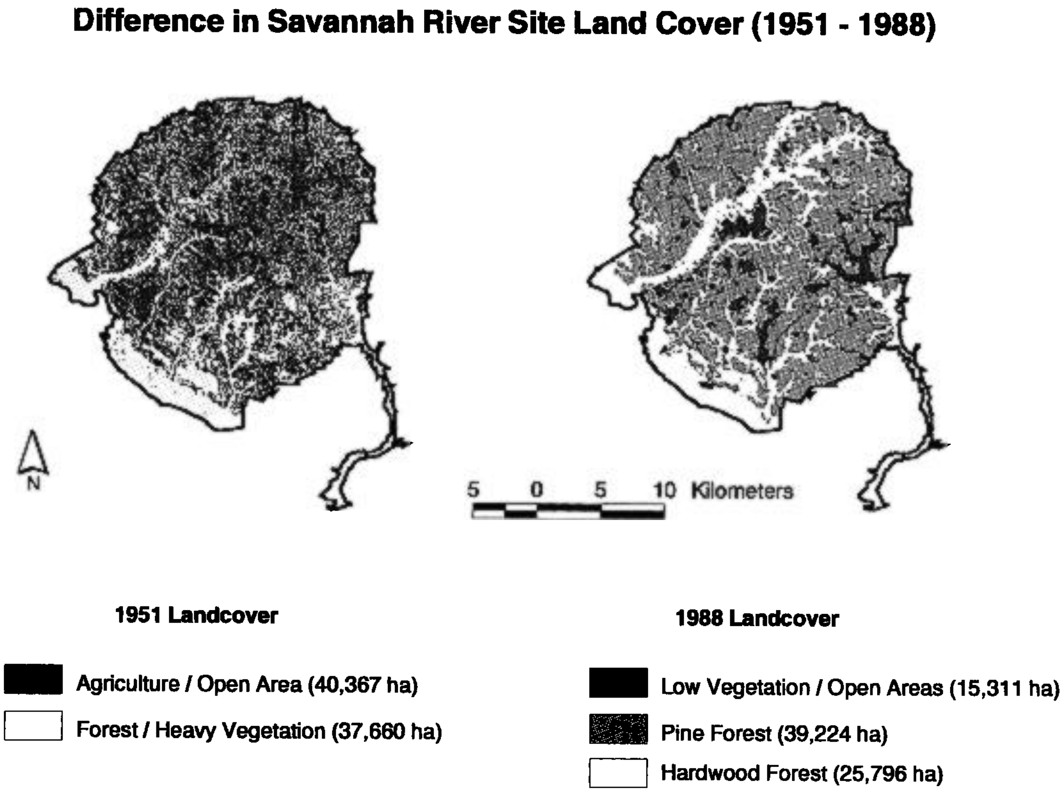

FIGURE 2. Savannah River Site land cover classes, 1951 and 1988 (J. Pinder, unpubl. data). The 1951 map is derived from a USDA Forest Service, orthorectified mosaic of 1951 aerial photos, while the 1988 map was created from a 3-season composite of Landsat TM imagery taken in 1988.

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.*

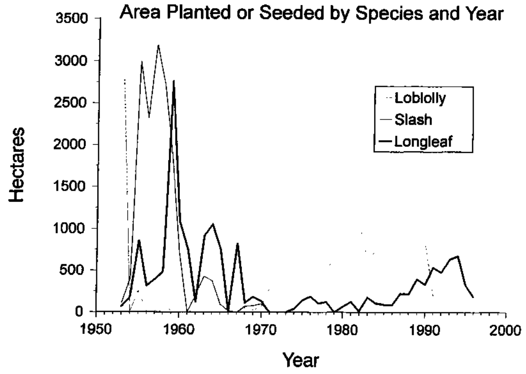

FIGURE 3. Area of the Savannah River Site planted or seeded in either loblolly, slash, or longleaf pine since 1953.

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	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		Pulpwood		Total combined
	Pine	Hardwood	Pine	Hardwood	
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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EARLY AVIAN RESEARCH AT THE SAVANNAH RIVER SITE: HISTORICAL HIGHLIGHTS AND POSSIBILITIES FOR THE FUTURE

J. MICHAEL MEYERS AND EUGENE P. ODUM

Abstract. Avian biology and collection of baseline population data was a major part of the first decade (1951–1961) of field research at the Savannah River Site (SRS). Baseline inventories involving organisms and land-use types were part of the mission in the early contracts between the Atomic Energy Commission (now the Department of Energy) and the University of Georgia prior to the establishment of the Savannah River Ecology Laboratory (SREL) as a National Environmental Research Park Laboratory. About 27% of the SREL publications during this first decade dealt with birds. Since that time, research on the SRS landscape has expanded and broadened with less than 10% of the publications dealing with birds. SRS changed also from an agriculturally dominated area with ca. 40% open areas (fields, crops, pastures) to a timber-managed area with ca. 80% forests, 12% open areas, and 2% open water impoundments. Baseline breeding bird populations of the SRS in the 1950s were typical for the region with avian species richness and density increasing with the age and succession of the vegetation (0–26 species and densities of 0–741 pairs/km^2 for the habitats surveyed). During the first decade at the SRS, the resident game bird population of Northern Bobwhites (*Colinus virginianus*) increased and the Mourning Dove (*Zenaida macroura*) population, a migratory upland game bird, remained stable. Current avian research efforts, as well as new opportunities to reexamine the breeding bird populations and the landscape of SRS, will provide a better understanding of the potential causes of declines of neotropical migratory birds, declines of resident and migratory game birds, and how habitat influences invasions and extinctions of breeding birds in the region. Emphasis for future research and monitoring should be on neotropical migratory bird populations in decline (Yellow-billed Cuckoo, *Coccyzus americanus;* Eastern Wood-Pewee, *Contopus virens*; Wood Thrush, *Hylocichla mustelina*; Prairie Warbler, *Dendroica discolor*; and Painted Bunting, *Passerina ciris*), resident species in decline (e.g., Loggerhead Shrike, *Lanius ludovicianus*), certain species groups (e.g., waterfowl and wading birds), important habitat, and recent invasions and extinctions of breeding species. Old growth forested wetlands should be monitored because of the large number of neotropical migratory birds that depend on this habitat in the southeastern United States. A variety of survey techniques will be needed to determine population trends: line transects, call or song playbacks, roadside point surveys (call counts for game birds), aerial surveys, and presence or absence of species within stratified areas of SRS. The SRS provides opportunity for avian research at the landscape level with the potential to solve problems important to the survival of many bird populations as well as to increase our knowledge on how to manage and conserve our avian natural resources for the future.

Key Words: abundance, bird community, breeding, census, game, habitat, history, landscape, Neotropical migrants, species richness.

In 1951 a proposal for ecological studies on the Savannah River Site (SRS) submitted by Dr. Eugene P. Odum was approved by the U.S. Atomic Energy Commission (AEC). The AEC at that time was in the process of acquiring a 315-mi^2 (780-km^2) tract on the South Carolina side of the Savannah River just below Augusta, Georgia, for the construction of the Savannah River Plant (SRP) to produce weapons-grade nuclear material. Thus began a very long contract between the University of Georgia and the federal energy agency (now called the Department of Energy) for ecological research on SRS that continues to this day. In 1958 a permanent University of Georgia laboratory facility, now known as the Savannah River Ecology Laboratory (SREL), was established on the site. An account of the first proposals and the first decade of work by the University of Georgia team has been published (Odum 1987).

Research emphasis during the first decade was on (1) ecological succession on the abandoned farmland (about 40% of the area), (2) inventories of selected species or species groups as a basis for assessing the effects of plant operations and future changes that would come with the expected extensive land-use changes, and (3) radioecology, especially use of radionuclide tracers for elucidating ecological processes such as energy flow and food chain dynamics.

Bird censuses and the preparation of a detailed annotated checklist became a major part of the inventory phase of the program because Odum, three graduate students, and the first University of Georgia resident ecologist, Dr. Robert Norris, were competent field ornithologists. John Hatcher, Director of the SRS U.S. Forest Service program (the "Savannah River Project"), then engaged in large-scale pine tree planting on the abandoned agricultural fields, was an avid bird-

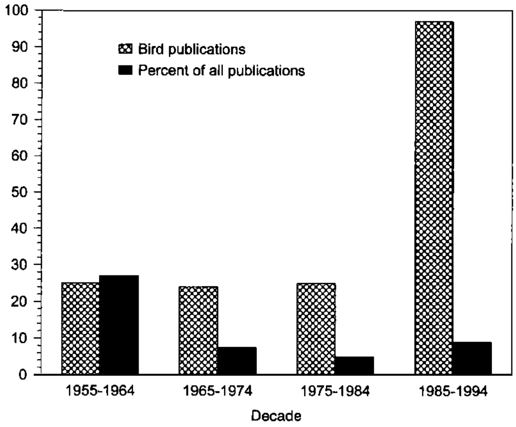

FIGURE 1. Trends in bird publications in comparison with all publications of the Savannah River Ecology Laboratory, Savannah River Site, South Carolina, 1955–1994.

watcher whose contributions are acknowledged in Norris (1963). In addition, the late Dr. Fred Denton, then a University of Georgia Medical School professor and leading authority on birds of the Augusta region, Dr. David Johnston (another Odum graduate student), and Gordon Hight, an amateur bird-bander from Rome, Georgia, contributed a great deal to the early bird studies.

An inventory of breeding birds conducted by Robert Pearson from 1952–1953 covered successive stages of ecological succession from old fields to mature forests (E. P. Odum, unpubl. report to AEC, 1953–1954). Robert Norris's censuses of floodplain and hammock broad-leaved forests followed in 1956–1957 (Norris 1963). Pearson was a student of S. Charles Kendeigh of the University of Illinois and was a research associate at SRS from 1952–1953. Norris obtained his M.S. with Odum at the University of Georgia and his Ph.D. with Dr. Joseph Grinnell at the University of California, Berkeley. He was the University of Georgia's first resident ecologist and worked full time on SRS from 1956–1958.

About 27% of the University of Georgia papers published during the first decade dealt with birds (Fig. 1), compared with <10% during the next three decades, as interests of the SREL staff shifted to other taxonomic groups such a cold-blooded vertebrates, and other research interests such as wetland ecology, biogeochemistry, ecotoxicology, and population genetics. Of the current SREL senior staff, only Dr. I. Lehr Brisbin has published extensively in ornithology, with waterfowl being a special interest because of the concern that migratory species might transport radioactive substances off the site (Brisbin 1991a). Among campus staff, Dr. H. Ronald Pulliam and his students and post-doctoral associates have recently completed an important study of the relationships between Bachman's Sparrow (considered to be a species of concern; see Appendix for scientific names of all species mentioned in text or tables) and alternative timber harvest programs (Pulliam et al. 1992, Dunning et al. 1995). Their models show how sparrow populations can be sustained with an economically feasible management program that includes both short- and long-rotation timber harvesting (Liu et al. 1995). Dr. David Krementz of the USGS Patuxent Wildlife Research Center and his students have recently completed research on survival and habitat relations of shrub-scrub birds of the SRS. In the last decade, Dr. Malcolm Coulter and Larry Bryan (see *this volume*) have published extensively on Wood Stork biology and management, which provided information for the recovery of this endangered bird. Recently, a new group of avian researchers from the Savannah River Institute and Warnell School of Forest Resources, The University of Georgia, and the Department of Biological Sciences, Clemson University, have published their work on breeding birds at the SRS (Kilgo et al. 1997,1998; Savannah River Site, SC, breeding bird censuses in Supplement to *Journal of Field Ornithology* from 1993–1997). As with bird studies everywhere, amateurs have contributed observations on the SRS, including Christmas Bird Counts.

To put all this in perspective of the 45-year history of SRS, we have prepared Table 1, which shows the distribution of the 171 SREL bird papers (out of 2,100 total, or 8%) published between 1955 and 1994 by the SREL. Most papers deal with single species or groups of related species of waterbirds, passerines, and game birds. Breeding birds censuses of the SRS have been published recently (not included above) and are valuable information for determining changes in SRS avian populations and communities since the 1950s.

EARLY AVIAN STUDIES AT THE SAVANNAH RIVER SITE

Detailed descriptions of the environment of the SRS may be found in White and Gaines (*this volume*). Much of the avian research at the SRS centered on avian populations and census methods, especially in the first years (see below). Ecological studies require good baseline data on the animal populations involved, which was the first objective of the research team under the direction of Odum. After completion of these studies, avian research branched into studies on

TABLE 1. DISTRIBUTION OF SAVANNAH RIVER ECOLOGY LABORATORY (SREL) PUBLICATIONS ON BIRDS (171 OR 8%) OUT OF 2,100 TOTAL PUBLICATIONS FROM 1953–1996

Publication groups	Number of publications (%)
By hierarchical levels	
Single species	112 (66)
Multiple species (usually families or related groups)	43 (25)
Population level (censuses)	5 (3)
Avian radioecology (see Brisbin 1991a)	10 (6)
Savannah River Site and region (Norris 1963)	1 (<1)
By taxonomic or ecological group	
Waterfowl	50
Passerines	30
Storks	16
Herons	10
Game birds	11
Birds of prey	9
Experimental birds	9
Woodpeckers	3
Avian Radioecology	10

physiology, energy flow, predation, radiation biology, and territoriality. Researchers concentrated on the old fields that developed after the abandonment of thousands of agricultural fields. These areas were simple systems that could be studied easily and that would provide an ecological understanding of the SRS. Two major research projects, energy flow through old-field consumers and selective predation of Savannah Sparrows, provided in-depth information on the old field habitat in relation to bird populations (Norris 1960, Odum et al. 1962).

OLD FIELD EMBERIZID STUDIES

The Savannah Sparrow population dominated the winter bird community of old fields at the SRS during in the 1950's (Norris 1963). Avian research concentrated on this species and provided important information for one of the major consumers in old fields (Johnston 1956, Norris and Hight 1957, Odum and Hight 1957; Norris 1960, 1961a,b; Odum 1960, Odum et al. 1962). Some of the methods developed and improved upon during this study are still in use today. For example, Norris (1961b) significantly improved the aging of birds using skull development (modified from Miller 1946) by eliminating cutting of the skin to view the skull. Most bird banders use this important method today. Investigators also demonstrated that effective use of mist nets could provide valuable data on bird populations, especially during winter (Odum and Hight 1957). However, it was Norris's intensive research of Savannah Sparrows that provided some fascinating results of the effects of predation on races of this species, as well as a novel method of studying birds confined in the wild under semi-natural conditions (Norris 1960).

Five geographical races of Savannah Sparrows co-existed in old field 3–412 of the SRS and intermingled in the same areas and habitat (Norris and Hight 1957, Odum and Hight 1957, Norris 1960). Norris (1960) enclosed a circular area (0.4 ha) of the old field and studied an experimental population of wing-clipped Savannah Sparrows from January to May, 1957. He called this beta-confinement in comparison to alpha-confinement, which he described as birds confined in small cages. Heavy predation began in early March and continued for weeks. Norris attributed the mortality mainly to owl predation, because of field signs and because an index of predation intensity was high on moonlit nights. It seemed also that a density-dependant relationship was apparent in the beta-confined population; however, this relationship was not a simple one when affected by the intensity of moonlight and on the particular method used to analyze the intensity of predation. Other observations by Norris indicated that the confined sparrow population was more vulnerable during nights of migratory unrest. During this time, flying sparrows gathered in the fields in preparation for their presumable northerly, nocturnal departure. Large fluttering flocks of sparrows may have attracted predators. Norris supported this with further evidence that remains of wing-clipped birds were found more than expected at the northern edge of the enclosure.

Norris's Savannah Sparrow study also demonstrated evidence of selective predation. A darker race of the Savannah Sparrow (*P. s. labradorius*), declined at a much slower rate than the other four races for the wing-clipped birds. One possible explanation of this was that dark races remained longer in the spring of 1956 (Norris and Hight 1957); however, in the spring of 1957, this was not true for *labradorius*, which migrated northward at the same period as other races (Norris 1960). Therefore delays in migratory unrest were not responsible for lower mortality. Although *labradorius* is darker than other races, it's doubtful that color had much effect on predation since it occurred at night. Comparison of dorsal coloration also provided no difference in protective coloration between the races. The *labradorius* race was the heaviest and most socially dominant of the five sparrow races. Its status, size, and moderate conspicuousness probably provided *labradorius* with increased ability to survive the winter.

Odum et al. (1962) contributed a functional approach, through energy flow, to an ecological study by using the population level to elucidate the systems ecology of old fields. The three most important consumer groups of the fields were studied: old field mice (*Peromyscus polionotus*), Savannah Sparrows, and grasshoppers and crickets (*Melanoplus femur-rubrum, M. biliterous,* and *Oecanthus nigricornis*). The granivores, Savannah Sparrows and old field mice, required 10–50% of the annual seed crop in the fields to survive. In contrast, the herbivorous orthopterans required only 2–7% of the energy of the annual above ground standing crop. Energy flow in kilocalories m^{-2} yr^{-1}, however, was only 3.6 for the sparrows, almost double at 6.7 for the mice, and eight times at 25.6 for the orthoptera. Very little energy was channeled into production (2% for mice, 15% for grasshoppers, and very small amounts for sparrows in the form of fat deposits); most of the energy flow was required in the form of respiration to maintain the standing crop. Therefore, food was more likely to be limiting to granivores than to foliage-consuming herbivores in the old-field ecosystem. Odum et al. (1962) concluded that granivores in terrestrial ecosystems were intermediate between herbivores and carnivores in terms of density and energy flow.

Premigratory Fat and Departure of Hummingbirds

Norris et al. (1957) research on migration physiology was another important contribution of the 1950s avian studies. The opportunistic investigators studied a notable concentration of migrating Ruby-throated Hummingbirds on the SRS by marking, observing, and measuring fat gained during September and prior to their southerly departure. Mass, and particularly fat content, increased significantly after mid-September (Fig. 2). At the time of this study many doubted that birds, and especially hummingbirds, traveled nonstop across the Gulf of Mexico, but believed instead that they followed the coast. The heaviest hummingbirds in this study carried about 2 g of fat, which was calculated to be enough to migrate nonstop for 1,333 km, more than the distance across the Gulf of Mexico to Central America.

Territorial and Home Range Studies

Odum and Kuenzler (1955) developed methods of measuring home range and territory characteristics in birds, which was important to development of the concepts in home range and territory today. They followed singing males and plotted territories, the quantitative aspect of which had been relatively unexamined at that time. A result of the study was the concept of maximum territory versus utilized territory in birds. Its development used the observational-area curve, which was refined from the species-area curve used by ecologists. In all three species of birds studied they found that territory size was much smaller while adults were engaged in feeding nestlings than when the pair was engaged in nest building and incubation. This finding refuted the idea that territories are defended only for food resources.

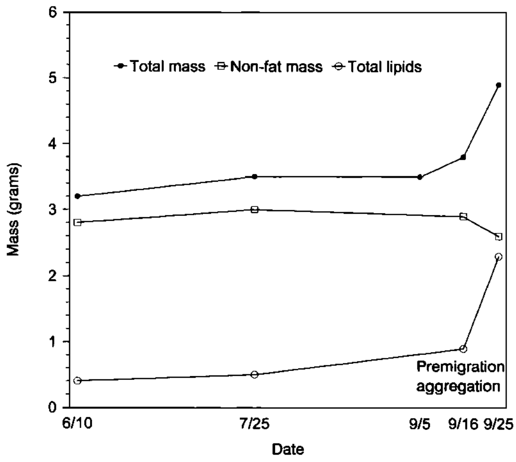

FIGURE 2. Changes in weight and fat deposition in Ruby-throated Hummingbirds in late summer and fall (redrawn from Norris et al. 1957).

Early Avian Radiation Study

Radiation effects on wildlife at the SRS provided some idea of the potential effects on humans. Norris (1958) conducted one of many of these studies on nesting Eastern Bluebirds. Birds were exposed to X-irradiation at a high dosage rate of 23.5 r/min while incubating in nest boxes. Most received 200 to 600 r. Although the sample size was small, adults and nestlings were suspected of having a much greater resistance to radiation. Embryos, however, were deemed more vulnerable to radiation.

BASELINE AVIAN STUDIES

An important component of the avian research conducted on SRS consisted of a series of censuses designed to develop baseline information on bird species abundances and distribution. Researchers selected avian study areas to represent all available successional habitat types in 1950 (Table 2), which are described in detail with photographs in Norris (1963). They surveyed 15 habitat types (N = 76 areas, total of 729 ha) with compass, tape, or pacing, and made maps for locating the positions of birds. Avian surveys were conducted from just before dawn for 2–5

TABLE 2. BREEDING BIRD DENSITIES BY HABITATS, SAVANNAH RIVER SITE, SOUTH CAROLINA, 1951–1953[a]

Habitats	N	Total area (ha)	Number of species	Mean density of breeding birds (pairs/km^2)
Cultivated fields				
Corn	8	38	1	3
Cotton	6	31	0	0
Other	4	30	0	0
Uncultivated fields				
Horseweed	1	12	1	7
Aster	11	174	4	10
Broomsedge	11	136	1	22
Carolina bays	3	80	8	44
Forests				
Pine (young)	6	30	6	74
Pine-scrub oak	4	47	11	103
Scrub oak	2	16	9	136
Oak	4	24	16	170
Deciduous (no oak)	2	23	26	452
Creek flood plain	2	74	11	227
River swamp	1	10	23	682
Fence rows/house sites	11	4	11	741

[a] R. Pearson's unpublished data, as recorded in E. P. Odum's annual report to the Atomic Energy Commission, 1953–1954.

hr, depending on the habitat. In most habitats, observers spot-mapped singing males in the established area according to Williams's method (1936); however, in the swamp forest, surveyors established a line transect and mapped singing males within 100 m of the line (200-m strip). All areas were visited for five or more times, depending on habitat type, to establish the number of surveys necessary to account for 90% of the total observed bird populations. Thereafter for open fields, with sparse bird populations, only two surveys were necessary to meet the 90% rule, but four to five surveys were necessary in forested areas with relatively high avian densities.

Initially, observers conducted avian surveys from 1951–1953 (E. P. Odum, unpubl. report to AEC, 1952, 1953). Later, some additional surveys were conducted in swamp forests and Carolina bays by spot-mapping singing males (Norris 1957a,b) and in oak hammocks and swamp forests by recording singing birds along a transect (Norris 1963). Norris also compiled avian information into an annotated list (Norris 1963).

For game birds (e.g., Mourning Doves and Northern Bobwhite), road-side surveys were conducted along 32-km routes with stops every 1.6 km (Golley 1962). At each stop, up to four observers counted the number of calls independently for each species. Surveys began 30 min before sunrise and lasted 2 hr. Three routes were surveyed for 8 yr from 1952–1959.

These baseline studies revealed that breeding bird species richness (total number of species) and densities increased with succession of the plant community (Table 2). Below, we present breeding bird census results for plant successional stages arrayed from young to old.

FIELDS

Cultivated areas lacked any bird community. Of the 18 areas investigated during two years, only one, a corn field, was occupied by a Mourning Dove, which probably nested along the field edge (Table 3). Considerably more species (range 1–8) occupied uncultivated fields (N = 23) at low densities ($\bar{x}$ range from 7–22 pairs/km^2; Table 2). Eastern Meadowlarks, Field Sparrows, and Prairie Warblers dominated uncultivated fields at relatively low densities (3–9 pairs/km^2). Other birds, such as the Eastern Kingbird, Eastern Bluebird, and Orchard Oriole were found nesting in uncultivated fields; however, their home ranges extended well beyond the field boundary (Table 3).

BAYS

Species richness and breeding pair density of bay communities were relatively low (8 species and $\bar{x}$ = 44 pairs/km^2) but higher than fields (Table 4). As would be expected, both terrestrial and aquatic species occupied Carolina bays. Eastern Meadowlarks (as in uncultivated fields), Red-winged Blackbirds, and Killdeer dominated bay habitat in 1952–1953 (Table 4). Least Bitterns, Purple Gallinules, King Rails, and Virginia Rails occurred at lower densities (1–4 pairs/km^2) and frequencies (1 of 2 yr), and their presence probably depended on the amount of standing water during the breeding season. Later in 1957, Norris (1957b) found no change in breeding densities of bitterns, no breeding rails, and gallinules present but not breeding (Table 4). Norris also found much higher densities of Red-winged Blackbirds and much lower densities of Eastern Meadowlarks 5 yr later.

PINE AND PINE-OAK SCRUB FORESTS

Species richness and breeding bird density increase with the height and layering of the vegetation, which is true for most bird community changes associated with plant succession. Consequently, pine and pine-oak forests contained more breeding species and higher densities than early successional fields (Table 2). Pine-oak habitats (N = 4) with an additional vegetative layer contained higher species richness (11) and densities of breeding birds ($\bar{x}$ = 103 pairs/km^2) than pine habitat that lacked the scrub oak layer (N

TABLE 3. Breeding Bird Population Densities (pairs/km^2) by Species for Cultivated Fields, Uncultivated Fields, and Pine and Pine-oak Scrub Habitats, Savanna River Site, South Carolina, 1951–1953[a]

Species common name	Cultivated fields[b] 1951–1952	Uncultivated fields[c] 1952	Uncultivated fields[c] 1953	Pine and pine-oak scrub[d] 1952	Pine and pine-oak scrub[d] 1953
Mourning Dove	*[e]	*		*	*
Red-headed Woodpecker			*	*	
Eastern Wood-Pewee					3.5
Great Crested Flycatcher				*	*
Eastern Kingbird		*	*		
Blue Jay				*	*
Caroline Chickadee					+[f]
Tufted Titmouse					5.2
Brown-headed Nuthatch				4.0	3.5
Blue-gray Gnatcatcher				+	
Eastern Bluebird		*		*	
White-eyed Vireo				+	
Pine Warbler				23.7	30.4
Prairie Warbler		3.0	+	21.0	16.1
Summer Tanager				2.1	+
Northern Cardinal				5.2	12.3
Eastern Towhee				4.0	3.5
Bachman's Sparrow				11.9	10.6
Chipping Sparrow				2.7	+
Field Sparow		5.2	3.7		
Eastern Meadowlark		9.1	7.4		
Orchard Oriole			*		

[a] R. Pearson's unpublished data, as recorded in E. P. Odum's annual report to the Atomic Energy Commission, 1953–1954.
[b] Three sites totaling 99 ha.
[c] 23 sites totaling 302 ha in 1952 and 304 ha in 1953.
[d] 10 sites totaling 76 ha in 1952 and 8 sites totaling 56 ha in 1953 (pine trees harvested on two sites).
[e] Species nesting on the site but territory or home range extends beyond the site for an undetermined distance.
[f] Species with territories but <1.2 pairs/km^2.

= 6, species richness = 6, $\bar{x}$ = 74 pairs/km^2). Species common to southern pine forest dominated pine and pine-oak scrub (Table 3). Pine Warblers, a species dependent on southern pine forests, dominated the bird community in these habitats (23–30 pairs/km^2). Another parulid and neotropical migrant, the Prairie Warbler, was also common (16–21 pairs/km^2). The Bachman's Sparrow, which is also limited to southern pine forest, occurred at lower densities (11–12 pairs/km^2). Most of the species breeding in pine habitat were residents (e.g., Pine Warbler, Bachman's Sparrow, Carolina Chickadee, Tufted Titmouse, Brown-headed Nuthatch, Northern Cardinal, Eastern Towhee, and Chipping Sparrow). Only a few other neotropical migratory birds, such as the White-eyed Vireo and Summer Tanager, occurred in pine forests, and then at much lower densities (<3 pairs/km^2) than in other forests (Tables 3 and 5).

TABLE 4. Breeding Bird Population Densities (pairs/km^2) by Species for Carolina Bays, Savannah River Site, South Carolina, 1952, 1953, and 1957

Species	Carolina bays[b] 1952	Carolina bays[b] 1953	Carolina bays[b] 1957
Pied-billed Grebe		*[c]	
Least Bittern	3.7	4.9	5.2
King Rail	2.5		
Virginia Rail	1.2		
Purple Gallinule	2.5	3.7	+[d]
Killdeer	4.9	8.6	
Eastern Kingbird			6.9
Red-winged Blackbird	9.9	13.8	63.8
Eastern Meadowlark	22.5	18.8	3.5
Others (upland passerines)	1.2		6.9

[a] R. Pearson's unpublished data, as recorded in E. P. Odum's annual report to the Atomic Energy Commission and published surveys (Norris 1957b).
[b] Three bays totaling 80 ha in 1952–1953 and same 3 totaling 58 ha in 1957.
[c] Species nesting on the site but territory or home range extends beyond the site for an undetermined distance.
[d] Species with territories but <1.2 pairs/km^2.

Old Home Sites and Fence Rows

Using 10 as the most abundant indicator for a species' density, the following breeding birds were ranked for residential areas and along fence row vegetation: Northern Mockingbird 10, Orchard Oriole 7, Northern Cardinal 6.5, Eastern Kingbird 5.5, Brown Thrasher 4.5, Blue Jay 3, Eastern Bluebird 2.5, Yellow-breasted Chat 2.5, House Sparrow 2, Indigo Bunting 1.5, Northern Bobwhite 1, Purple Martin 1, Painted Bunting 1, and European Starling 1. Breeding

TABLE 5. BREEDING BIRD POPULATION DENSITIES (PAIRS/KM^2) OF DECIDUOUS FOREST HABITATS, SAVANNAH RIVER SITE, SOUTH CAROLINA, 1952–1953

Group[b]	1952	1953
Group A (occurred in all wetland and upland forests)		
Mourning Dove	*[c]	*
Yellow-billed Cuckoo	8.4	6.7
Red-bellied Woodpecker	*	*
Downy Woodpecker	*	*
Hairy Woodpecker	*	*
American Crow	*	
Carolina Chickadee	3.5	15.3
Tufted Titmouse	10.1	8.4
Carolina Wren	20.5	24.2
Blue-gray Gnatcatcher	27.2	22.0
Red-eyed Vireo	54.4	30.6
Northern Cardinal	34.1	22.0
Eastern Towhee	8.4	3.5
Group B (occurred in upland oak and deciduous forests)		
Northern Flicker	*	
Eastern Wood-Pewee	6.9	4.4
Great Crested Flycatcher	*	*
Eastern Kingbird	*	
Blue Jay	*	*
Brown Thrasher		*
Pine Warbler	+[d]	4.4
Summer Tanager	11.6	9.4
Blue Grosbeak	*	*
Indigo Bunting	*	*
Orchard Oriole	*	
Group C (occurred in all forests except oak)		
Turkey Vulture	*	
Broad-winged Hawk	*	*
Ruby-throated Hummingbird	2.7	5.7
Acadian Flycatcher	31.1	50.9
Wood Thrush	22.7	14.1
White-eyed Vireo	45.5	39.5
Yellow-throated Vireo	8.4	8.4
Northern Parula	62.5	57.1
Yellow-throated Warbler	8.4	19.8
Kentucky Warbler	14.1	8.4
Hooded Warbler	24.7	19.8
Group D (confined to flood plain and swamp forests)		
Yellow-crowned Night Heron	*	
Wood Duck	*	
Barred Owl	*	
Chimney Swift		*
Pileated Woodpecker		*
American Redstart		*
Prothonotary Warbler	49.4	61.8
Swainson's Warbler		6.2
Louisiana Waterthrush	12.3	6.2

[a] R. Pearson's unpublished data, as recorded in E. P. Odum's annual report to the Atomic Energy Commission, 1953–1954.

[b] Group A was 9 sites totaling 57 ha; Group B was 6 sites totaling 42 ha; Group C was 5 sites totaling 35 ha; Group D was 3 sites totaling 16 ha.

[c] Species nesting on the site but territory or home range extends beyond the site for an undetermined distance.

[d] Species with territories but <1.2 pairs/km^2.

species occurring at the lowest relative density (0.5) in this habitat were Loggerhead Shrike, Red-bellied Woodpecker, Blue Grosbeak, Summer Tanager, Chipping Sparrow, Mourning Dove, and Common Yellowthroat. Painted Buntings and Yellow-breasted Chats were found only in lowland fence rows. House Sparrows, Purple Martins, and European Starlings were confined to old home sites.

DECIDUOUS FORESTS

Both wetland and upland deciduous forests contained relatively high avian species richness and densities (Table 2). Available SRS data were categorized initially by birds that were found in Group A = all deciduous forests (wetland and upland), Group B = upland oak and other upland deciduous forests, Group C = all deciduous forests except oak, and Group D = only in flood plain and swamp forests (Table 5). Neotropical migratory species were commonly found at higher species richness and densities in deciduous than pine forests (Tables 3 and 5).

Group A (all deciduous forests—wetland and upland)

The Red-eyed Vireo dominated in all deciduous forests and occurred most frequently of all the neotropical migratory birds (Table 5). The most frequent resident, the Northern Cardinal, co-dominated deciduous forests with the Carolina Wren and other residents (Carolina Chickadee, Tufted Titmouse, and Eastern Towhees), and the Blue-gray Gnatcatcher, another neotropical migrant. Yellow-billed Cuckoos were also found frequently at lower densities.

Group B (upland oak and other upland forests)

Species in this group are commonly referred to as "woodland edge species" and most are neotropical migrants (Table 5). Summer Tanagers and Eastern Wood-Pewees dominated this habitat type. All other species' densities were low or the species were using other habitat for most of their home range (e. g., Brown Thrasher and Orchard Oriole).

Group C (all deciduous forests except oak)

Almost all species of this group were neotropical migrants (Table 5). Northern Parula, Acadian Flycatcher, and White-eyed Vireo dominated all deciduous forest habitat except oak. Other common breeding species in this habitat were Hooded Warbler, Wood Thrush, Yellow-throated Warbler, Kentucky Warbler, and Ruby-throated Hummingbird.

Group D (floodplain and swamp forests only)

Important breeding birds of wetland forests were all neotropical migratory birds (Table 5).

TABLE 6. BREEDING BIRD POPULATION DENSITIES (PAIRS/KM^2) OF OLD GROWTH FOREST HABITATS, SAVANNAH RIVER SITE, SOUTH CAROLINA, 1956–1957

Species	Upper Three Runs Creek-flood plain forest 1956[a]	Upper Three Runs Creek-flood plain forest 1957[b]	Steel Creek-oak hammock forest 1956[a]
Yellow-billed Cuckoo	25	30	25
Barred Owl		10	
Ruby-throated Hummingbird		12	10
Red-bellied Woodpecker	10	+[c]	17
Pileated Woodpecker	5		10
Acadian Flycatcher	62	82	62
Great Crested Flycatcher		+	7
Fish Crow		+	
Carolina Chickadee	20	10	
Tufted Titmouse	37	+	40
Carolina Wren	20	40	22
Wood Thrush	5	10	12
Blue-gray Gnatcatcher	15	40	12
White-eyed Vireo	47	49	47
Yellow-throated Vireo	10	10	10
Red-eyed Vireo	136	111	74
Pine Warbler		+	
Northern Parula	49	30	96
Prothonotary Warbler	12	20	32
Swainson's Warbler	17	10	10
Kentucky Warbler	12	30	32
Louisiana Waterthrush		10	
Hooded Warbler	32	69	54
Summer Tanager		20	7
Northern Cardinal	22	49	40

[a] Strip census of singing males (total area unknown), Norris 1963.
[b] Area spot-mapping of singing males (5-ha survey), Norris 1957a.
[c] Species with territories but <10 pairs/km^2.

Prothonotary Warblers dominated forested wetlands with standing water during the breeding season. Less frequent and at much lower densities were Louisiana Waterthrush and Swainson's Warbler.

Four to five years later

Norris (1957a,b, 1963) recensused breeding birds in deciduous forests for the floodplain and oak hammock sites during 1956 and 1957 at Upper Three Runs Creek and Steel Creek (Table 6). Areas censused were smaller than prior censuses. He found similar species richness (19–23) and breeding bird densities (573–662 pairs/km^2) in these forests when compared to earlier censuses by Pearson. Red-eyed Vireos still dominated both forests. Six other neotropical migratory birds (Yellow-billed Cuckoo, Acadian Flycatcher, White-eyed Vireo, Northern Parula, Kentucky Warbler, and Hooded Warbler) co-dominated these forests. Blue-gray Gnatcatchers, another migrant, occurred at slightly lower densities. Norris found fewer Prothonotary Warblers and a new breeding bird, Yellow-throated Vireo, 5 yr later. Other neotropical migratory birds occurred at similar densities censused 5 yr earlier (Tables 5 and 6).

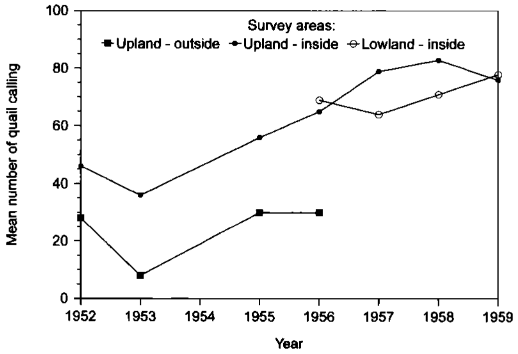

FIGURE 3. The mean number of Northern Bobwhite calling on three survey routes located inside and outside of the Savannah River Site, 1952–1959 (redrawn from Golley 1962).

Northern Cardinals remained the most abundant resident breeding bird 5 years later, while others, e.g., the Carolina Wren and Tufted Titmouse, occurred at similar low densities after 5 yr. Norris found considerably more Downy Woodpeckers in 1956–1957 than 5 yr earlier.

GAME BIRDS

Eight years of Northern Bobwhite roadside surveys revealed a significant positive trend in relative population within the SRS and no change outside the SRS (Fig. 3; Golley 1962). Relative densities of Mourning Doves remained fairly constant inside and outside the SRS from 1952–1959 (Fig. 4; Golley 1962). Establishment of the SRS created thousands of fallow fields, which are considered excellent habitat for bob-

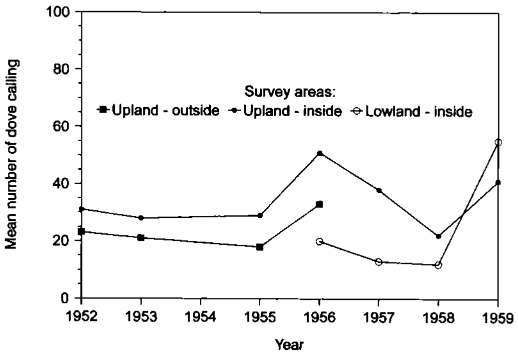

FIGURE 4. The mean number of Mourning Dove calling on three survey routes located inside and outside of the Savannah River Site, 1952–1959 (redrawn from Golley 1962).

whites, especially during the first 3–4 yr (Stoddard 1931:362). Bird hunting was not allowed on the SRS after 1951.

DISCUSSION

BREEDING BIRD COMMUNITIES OF THE SAVANNAH RIVER SITE

Species richness within the successional seres of the SRS during the 1950s were similar to other areas in the southeastern United States (Johnston and Odum 1956, Meyers and Johnson 1978, Meyers and Odum 1991). Compared to other southeastern areas, SRS breeding bird densities were considerably lower in Carolina bays and young pine forests. Breeding bird densities in fields, oak forests, and forested wetlands varied within the ranges for those found in the southeast (up to 750 pairs/km^2).

The SRS's ephemeral grasslands provided little structural diversity for a rich breeding bird community. The fields changed rapidly during the first years, from 1 to 4 and sometimes up to 7 yr, when shrubs and trees began to dominate the grassland. Densities of <100 pairs/km^2 and ≤ 8 breeding species are expected in this habitat (Johnston and Odum 1956). Although breeding bird populations are low in uncultivated fields, they do provide substantially more habitat for breeding birds than cultivated fields, which provide little to no habitat.

Carolina bays provided habitat for few breeding birds species with low densities. Species richness (7–8) in the bays equaled that found in three similar habitats of the Okefenokee Swamp, Georgia (Meyers and Odum 1991). Breeding bird density, however, was considerably lower in the SRS bays than in similar Okefenokee wetland habitats, which were two- to eight-times higher in densities. Compared to other wetland habitats in the eastern United States, Carolina bay breeding bird densities were from 25% of the densities found in the southeast to only 5% of densities found in similar wetlands of the northeast (Meyers and Odum 1991). One explanation for large differences in breeding bird density between Carolina bays and other similar wetland habitat may be an energetic relationship. Unlike other swamps with inputs from rivers, Carolina bays on the SRS receive very little nutrient input from outside the system. They are also deficient in available nutrients, with precipitation as the main external source of nutrients (Sharitz and Gibbons 1982).

Shrub or young forest habitat provides more habitat layers than grasslands, and therefore more niches, for species of breeding birds (MacArthur et al. 1962). Young pine forest habitat, however, with a closed canopy and little spatial heterogeneity, provides less (Johnston and Odum 1956, Odum and Kroodsma 1977). Both statements were true for these habitats on the SRS during the 1950s. However, breeding bird densities were 30–50% lower than those found in similar pine forests of the Piedmont and Coastal Plain of Georgia (Johnston and Odum 1956, Meyers and Johnson 1978, Meyers and Odum 1991). We offer no clear explanation for this, but suspect that low nutrient availability or lack of moisture (especially in the sandhills) on these habitats may reduce the breeding bird densities. Similar habitats in southeastern Georgia with much higher breeding bird densities were prescription burned every 4–5 yr, which releases nutrients to the soil, and were much wetter than the sandhill habitat on the SRS.

Older upland and wetland forests on the SRS supported a species richness (19–23) and breeding bird density (300–750 pairs/km^2) similar to other forests in the southeast with few exceptions (Johnston and Odum 1956, Meyers and Johnson 1978, Meyers and Odum 1991). Older upland pine-hardwood and hardwood forest habitat investigated in Arkansas, Louisiana, and North Carolina provided habitat for 900–1940 pairs/km^2 of breeding birds, which is 36–190% higher than those on the SRS (maximum of 662 pairs/km^2) in the 1950s (Meyers and Johnston 1978). However, a 10-year breeding bird census in the same old growth pine forest in Savannah, Georgia, revealed that densities can vary widely, from 300–900 pairs/km^2 in any given year (Meyers and Johnston 1978). Therefore, it is likely that breeding bird densities in older upland forests of the SRS may be higher or lower than 700 pairs/km^2 in certain years. Breeding bird densities (900 pairs/km^2) of black gum swamp forests in the Okefenokee Swamp were only slightly higher than those found in river swamp forest on the SRS, while species richness was slightly lower in the Okefenokee Swamp habitats, which could be related to the phenomenon that fewer bird species breed at southern than at more northern latitudes in the eastern United States (Figs. 5 and 6; Meyers and Odum 1991).

GAME BIRDS

Migratory game bird populations are monitored by the state of South Carolina in cooperation with the federal government, but not on the SRS. Mourning Dove roadside survey routes should be repeated on the SRS to determine changes since the 1950s (Golley 1962). South Carolina's dove population is the only one that has declined under hunting regulations in the southeastern United States (J. Berdin, pers. comm.). Some comparisons have been made of

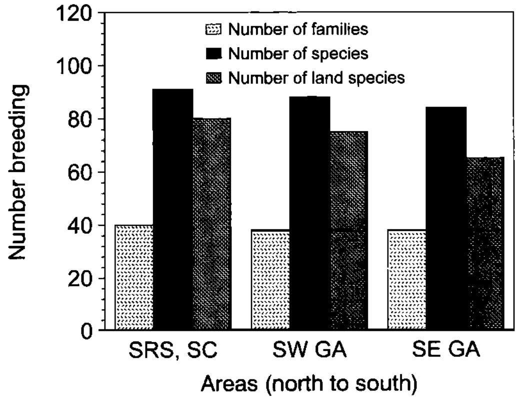

FIGURE 5. The regional diversity of breeding bird families and species for the southeastern U. S. (from Norris 1951, 1963; Laerm et al. 1980). Demonstrates the "reverse latitudinal gradient" from north to south (left to right on graph).

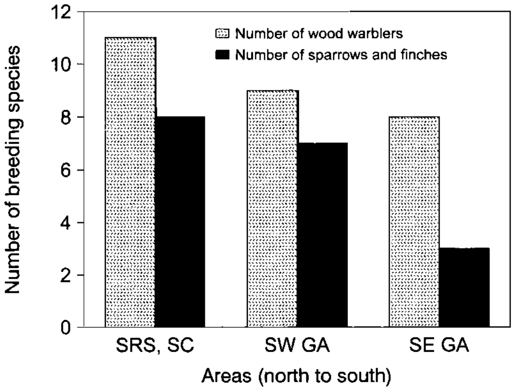

FIGURE 6. The regional diversity of breeding wood warblers, sparrows, and finches for the southeastern U. S. (from Norris 1951, 1963; Laerm et al. 1980). Demonstrates the "reverse latitudinal gradient" from north to south (left to right on graph).

Mourning Dove and Northern Bobwhite surveys on and off the site with counts higher off the SRS (Kilgo et al. 1997; J. Kilgo, pers. comm.). It is possible that recent and repeated investigations may provide valuable information in managing doves, because dove hunting is not allowed on most the SRS.

Declines of Northern Bobwhites have also been of concern in the South recently (Brennan 1991). Although bobwhites increased in the first decade after establishment of the SRS, expected declines occurred after 1950s as forests gradually replaced abandoned farmland (Golley 1962). By investigating if these declines have continued, we should be able to hypothesize causes for decline throughout the range of the bobwhite by looking at land use changes, use of pesticides, and other factors inside and outside the boundary of the SRS. Statistically designed quail call counts (same method as Golley 1962) should be repeated at least every 3 years for at least 2 consecutive years (if possible, annually), so that these hypotheses can be investigated.

FUTURE RESEARCH, QUESTIONS OF BREEDING STATUS, AND WHAT TO MONITOR?

Breeding bird reinvasions and range expansions in the southeastern U.S.

Of great importance in the study of breeding bird communities in the eastern United States, though it is usually overlooked, is the relationship that fewer species of birds breed at southern latitudes (Cook 1969). Unlike in the western United States, where the number of breeding bird species increases with decreasing latitude, a "reverse latitudinal gradient" is present in the east, even over relatively short distances from South Carolina to Georgia (Figs. 5 and 6). From the SRS to southeastern Georgia the number of breeding wood warblers and finches declines by eight species (Figs. 5 and 6). This relationship must be taken into account when comparing regional avifauna in the South. More specifically, it is important to monitor species at the SRS that have ranges in the entire eastern range as well as the southeastern region. Breeding bird species of the southeastern region may have a wider range of habitats, which could translate into more available habitat for the species (MacArthur 1972, Tramer 1974, Odum et al. 1993).

Invasions of new breeding birds into the SRS are possible and more than likely are occurring now. Fewer breeding birds in the South may mean more habitat available for breeding birds, which could invade from northern or western U.S. Since the 1940s in Georgia, many new breeding species have established southern extensions or recolonizations of their ranges, which may have been accelerated by habitat changes (Odum et al. 1993). For example, breeding Song Sparrows can be found in abundance in central Georgia now, whereas during the 1940s they were not known to breed south of Georgia's mountain valleys (Odum et al. 1993). Residential areas with water nearby seem to be the first breeding habitat occupied by invading Song Sparrows in Georgia. However, most of the residential habitat at SRS has declined since 1951, so we would not predict range extensions by this species into the SRS. Many other species, however, may be expanding their ranges into the SRS and South Carolina (see Savannah River Site, SC, sites in 1993–1997 *Journal of Field Ornithology* Supplements; Kilgo et al. 1997, 1998). These recent surveys revealed that Black-and-White Warblers, Ovenbirds, and American Redstarts are uncommon breeding birds in the 1990s, whereas they were absent in the 1950s. Invasions are more likely to come from the north or west than from the south (Odum et al. 1993).

Neotropical migratory birds in decline

"Neotropical migratory birds" has become popular term in the last decade because of bird population declines. Unfortunately, many people have different ideas on what species or groups actually are declining, and surveys can be biased (Geissler and Link 1988). Thus the question has become: are neotropical migratory birds really declining?

Peterjohn et al. (1995) highlighted patterns of population trends for neotropical migratory birds based on the Breeding Bird Survey (BBS, 1966–1991), a road-side 50-stop survey of 3 min/stop at 0.8 km intervals. Peterjohn et al. used a binomial test: does the percentage of the species that have positive trends differ from 50%? Early during the survey period (1966–1979), 78% ($P < 0.01$) of all neotropical migratory birds in the eastern region had increasing trends, but more recently (1980–1991) only 36% ($P < 0.01$) of the species were increasing. Over the entire period (1966–1991), no trend was evident, with 58% of the neotropical migratory species increasing ($P > 0.10$) in the eastern region. It is possible that the current downward trend (from 78% increasing to 36% increasing) will reverse itself in the next decade. However, continued declines both for those species already in a 30-year decline and for additional species will mean more populations at risk of extirpation or extinction.

It is evident that monitoring all breeding birds at the SRS may not answer questions about declining populations and how to reverse these trends. Also, intensive monitoring only can be cost effective by using trained volunteers, e.g., the BBS, which may or may not be possible at the SRS. It may be more reasonable or cost effective to emphasize groups of breeding birds, specific habitats, and absence or presence of rarer birds (e.g., breeding invaders or local extinctions) that usually can not be surveyed in a way that provides reliable population trends (Geissler and Link 1988).

What populations of breeding bird species may be declining at SRS?

In the eastern United States from 1966–1991 the following breeding birds, which also occur on the SRS, have had significant annual declines (%/yr): Yellow-billed Cuckoo (−1.7%, $P < 0.01$), Eastern Wood-Pewee (−1.3%, $P < 0.01$), Wood Thrush (−2.9%, $P < 0.01$), Prairie Warbler (−2.2%, $P < 0.01$), and Painted Bunting (−2.8%, $P < 0.01$) (Peterjohn et al. 1995). Most of these species occurred on the SRS at numbers >5–10 pairs/km^2. We recommend a selected habitat/species approach to monitor declining populations that have densities >5 pairs/km^2. Habitats to include in the surveys are older growth pine forests with an open canopy, clear cut pine forests, bottomland forests, and swamp forests.

Prairie Warblers and Eastern Wood-Pewees should be surveyed over a long term (20 yr) to determine possible causes for their decline. This might be accomplished in cooperation with current and future research of Bachman's Sparrow at the SRS. The survey should be designed to sample an adequate number of pewee's since this species is the least common of the three (Droge et al. 1993a,b). Other species, especially the common residents (e.g., Pine Warblers), also could be included in the survey to provide additional information on potential causes for declines. Declining populations of Wood Thrushes and Yellow-billed Cuckoos should be monitored by surveying breeding populations in mature bottomland hardwood forests, oak hammocks, and swamp forests. Other species that would be important to monitor in these forests, because they are common and because populations are stable or increasing (Peterjohn et al. 1995), might include Red-eyed Vireo, White-eyed Vireo, Prothonotary Warbler, Northern Parula, and Hooded Warbler. Long-term information on breeding bird populations of bottomland and swamp forests is also an excellent way to monitor many neotropical migratory birds, which are found at higher densities and species richness in these forests than in most pine forests (Meyers and Odum 1991). Pre-1950s losses of southern pine forests, particularly the longleaf pine community, as well as recent losses of forested wetlands in the South may affect bird populations (Sharitz and Mitsch 1993, Ware et al. 1993). These losses as well as the changes in landscape structure complicate the scientists' and managers' tasks of developing management plans for the conservation of birds (Freemark et al. 1995). Long-term monitoring of the avian community may provide managers with results that benefit biodiversity management (multi-species approaches) on the SRS (Block et al. 1995). The SRS's large land area provides excellent opportunities to monitor bird populations. Experimentation or modeling also may be required to further explain the causes of declines in neotropical migratory birds on SRS or in the region.

TABLE 7. Bird Species That Are Likely Indicators of Change and Where Current Status Should Be Compared to That Reported in the 1950s (Norris 1963)

Species	1950s status
Pied-billed Grebe	breeding bird in Carolina bays and ponds
Herons and egrets	none found breeding with possible exception of Green-backed Heron
Least Bittern	breeding bird in Carolina bays
Canada Goose	not breeding
Hooded Merganser	not found breeding
Broad-winged Hawk	rare breeding bird
American Kestrel	uncommon breeding bird
Northern Bobwhite	common resident, need to repeat 1950s call counts
King Rail	breeding bird in Carolina bays
Purple Gallinule	breeding bird in Carolina bays
American Woodcock	rare breeding bird in 1950s
Mourning Dove	common breeding bird, need to repeat 1950s call counts
Common Ground-Dove	rare, occasional visitor near fields and Carolina bays
Yellow-billed Cuckoo	common breeding bird in floodplain and hammock forests
Great Horned Owl	uncommon resident
Short-eared Owl	common winter visitor in old fields
Common Nighthawk	common breeding bird in open-canopy pine forests
Red-headed Woodpecker	common breeding bird near wooden power poles
Red-cockaded Woodpecker	infrequent permanent resident
Great Crested Flycatcher	fairly common breeding bird in pine-hardwood forests
Barn Swallow	not breeding
House Wren	winter resident only, not breeding
Bewick's Wren	fairly common winter resident
Marsh Wren	breeding bird in Carolina bays
Wood Thrush	fairly common breeding bird in floodplain hardwoods
Eastern Bluebird	common resident in fields or open woodlands
Blue-gray Gnatcatcher	common breeding bird of hammocks and floodplain forests
Loggerhead Shrike	common resident in fields and shrub-scrub habitat
White-eyed Vireo	common breeding bird in broadleaf forests and scrub
Red-eyed Vireo	most common breeding bird in broadleaf forests
Northern Parula	abundant breeding bird in broadleaf forests
Yellow-throated Warbler	uncommon, probable breeding bird in swamp forests
Prairie Warbler	common breeding bird in fields, scrub, and young forests
American Redstart	suspected rare breeding bird in broadleaf forests
Prothonotary Warbler	common breeding bird in swamp forests and along streams
Swainson's Warbler	fairly common breeding bird in swamp and broadleaf forests
Kentucky Warbler	fairly common breeding bird in moist broadleaf and floodplain forests
Hooded Warbler	common breeding bird in broadleaf forests and bottomland near swamp forests
Yellow-breasted Chat	common breeding bird in fields, scrub, and young forests
Orchard Oriole	common breeding bird at old home sites and hedgerows
Brown-headed Cowbird	not detected as breeding bird
Summer Tanager	fairly common breeding bird in open pine-hardwood forests
Painted Bunting	fairly common breeding bird along lower terraces of river
Eastern Towhee	common permanent resident of shrubby pine-hardwood forests
Savannah Sparrow	abundant winter resident of old fields
Grasshopper Sparrow	uncommon winter visitor, regular occurrence
Bachman's Sparrow	fairly common permanent resident of open pine forests, rarer in winter
Field Sparrow	common permanent resident of old fields, breeding on lower terraces
Song Sparrow	very common winter visitor of open, scrubby areas

Rare birds and species' extinction and immigration

Rare bird populations are difficult to monitor. We propose that rare to uncommon species previously known on the SRS, or suspected to be there in the near future because of changes in land use, be monitored using presence/absence surveys for the species by habitats from stratified random transects (or areas, e.g., timber compartments) on the SRS. Species richness estimates for rare to uncommon species (or the "species at risk" bird community) as well as rate of change in species richness over time can be determined and tested with probability (Boulinier et al. 1998, Nichols et al. 1998a,b). These new methods will allow us to better understand changes associated with the environment. Changes in species richness would be quantitative and testable (significantly increasing or decreasing) rather than a number index (Burnham 1981).

For which species should we expect changes (local extinctions and invasions)? Species that are likely indicators of change (e.g., regional population declines/increases for reasons other than habitat loss) should be compared with information from the 1950s and with future surveys (Table 7; Norris 1963). Obviously one type of survey will not be sufficient to locate all the species. Waterbirds have increased because of large increases in open water habitat and habitat changes caused by operations on the SRS during the last 40 years. Roosting, nesting, and aerial counts may be required to adequately survey waterbirds. Many common landbirds that are likely indicators of landscape change, such as the Red-eyed Vireo, should be monitored (Table 7). These species can be surveyed most effectively by line transects; however, point counts and spot-mapping of territorial males should be done for comparisons. Others, e.g., the Loggerhead Shrike and Common Ground Dove, may be monitored efficiently by roadside surveys, such as the call counts developed for game birds (with and without call playbacks). For the more secretive birds, tape playbacks of calls or songs may be required for adequate surveys. Both winter and spring-summer surveys must also be considered to determine avifaunal changes on the SRS. With standardization of methods and continual surveys, e.g., every 3–4 yr or more often, much could be learned about birds of the SRS. This knowledge may elucidate causes for declines and increases, as well as potential methods through management and preservation to maintain the bird community on the SRS and in the eastern United States. With such a large area available for research it would be prudent to use the landscape of the SRS to test hypotheses involving the bird community. Much could be learned about bird communities and populations in relation to habitat change by studying an adjacent similar area of the same size as SRS, but with completely different land use trends in the last 45 yr. With increases in human populations, especially in the southeastern United States, more research of large species groups or bird communities on the SRS may be important to the survival of many bird populations as well as to our knowledge on how to manage our resources for the future.

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APPENDIX 1 SCIENTIFIC NAMES OF BIRDS MENTIONED IN TEXT OR TABLES

Pied-billed Grebe	*Podilymbus podiceps*
Least Bittern	*Ixobrychus exilis*
Yellow-crowned Night Heron	*Nyctanassa violacea*
Wood Stork	*Mycteria americana*
Turkey Vulture	*Cathartes aura*
Canada Goose	*Branta canadensis*
Wood Duck	*Aix sponsa*
Hooded Merganser	*Lophodytes cucullatus*
Broad-winged Hawk	*Buteo platypterus*
American Kestrel	*Falco sparverius*
Northern Bobwhite	*Colinus virginianus*
King Rail	*Rallus elegans*
Virginia Rail	*Rallus limicola*
Purple Gallinule	*Porphyrula martinica*
Killdeer	*Charadrius vociferus*
American Woodcock	*Scolopax minor*
Mourning Dove	*Zenaida macroura*
Common Ground Dove	*Columbina passerina*
Yellow-billed Cuckoo	*Coccyzus americanus*
Great Horned Owl	*Bubo virginianus*
Barred Owl	*Strix varia*
Short-eared Owl	*Asio flammeus*
Common Nighthawk	*Chordeiles minor*
Chimney Swift	*Chaetura pelagica*
Ruby-throated Hummingbird	*Archilochus colubris*
Red-headed Woodpecker	*Melanerpes erythrocephalus*
Red-bellied Woodpecker	*Melanerpes carolinus*
Downy Woodpecker	*Picoides pubescens*
Hairy Woodpecker	*Picoides villosus*
Red-cockaded Woodpecker	*Picoides borealis*
Northern Flicker	*Colaptes auratus*
Pileated Woodpecker	*Dryocopus pileatus*
Eastern Wood-Pewee	*Contopus virens*
Acadian Flycatcher	*Empidonax virescens*
Great Crested Flycatcher	*Myiarchus crinitus*
Eastern Kingbird	*Tyrannus tyrannus*
Loggerhead Shrike	*Lanius ludovicianus*
White-eyed Vireo	*Vireo griseus*
Yellow-throated Vireo	*Vireo flavifrons*
Red-eyed Vireo	*Vireo olivaceus*
Blue Jay	*Cyanocitta cristata*
American Crow	*Corvus brachyrhynchos*
Fish Crow	*Corvus ossifragus*
Purple Martin	*Progne subis*
Barn Swallow	*Hirundo rustica*
Carolina Chickadee	*Poecile carolinensis*
Tufted Titmouse	*Baeolophus bicolor*
Brown-headed Nuthatch	*Sitta pusilla*
Carolina Wren	*Thryothorus ludovicianus*
Bewick's Wren	*Thryomanes bewickii*
House Wren	*Troglodytes aedon*
Marsh Wren	*Cistothorus palustris*
Blue-gray Gnatcatcher	*Polioptila caerulea*
Eastern Bluebird	*Sialia sialis*
Wood Thrush	*Hylocichla mustelina*
Northern Mockingbird	*Mimus polyglottos*
Brown Thrasher	*Toxostoma rufum*
European Starling	*Sturnus vulgaris*
Northern Parula	*Parula americana*
Yellow-throated Warbler	*Dendroica dominica*
Pine Warbler	*Dendroica pinus*
Prairie Warbler	*Dendroica discolor*
Black-and-White Warbler	*Mniotilta varia*
American Redstart	*Setophaga ruticilla*
Prothonotary Warbler	*Protonotaria citrea*
Swainson's Warbler	*Limnothlypis swainsonii*
Ovenbird	*Seiurus aurocapillus*
Louisiana Waterthrush	*Seiurus motacilla*
Kentucky Warbler	*Oporornis formosus*
Common Yellowthroat	*Geothlypis trichas*
Hooded Warbler	*Wilsonia citrina*
Yellow-breasted Chat	*Icteria virens*
Summer Tanager	*Piranga rubra*
Eastern Towhee	*Pipilo erythrophthalmus*
Bachman's Sparrow	*Aimophila aestivalis*
Chipping Sparrow	*Spizella passerina*
Field Sparrow	*Spizella pusilla*
Savannah Sparrow	*Passerculus sandwichensis*
Grasshopper Sparrow	*Ammodramus savannarum*
Song Sparrow	*Melospiza melodia*
Northern Cardinal	*Cardinalis cardinalis*
Blue Grosbeak	*Guiraca caerulea*
Indigo Bunting	*Passerina cyanea*
Painted Bunting	*Passerina ciris*
Red-winged Blackbird	*Agelaius phoeniceus*
Eastern Meadowlark	*Sturnella magna*
Brown-headed Cowbird	*Molothrus ater*
Orchard Oriole	*Icterus spurius*
House Sparrow	*Passer domesticus*

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HISTORICAL WINTER STATUS OF THREE UPLAND *AMMODRAMUS* SPARROWS IN SOUTH CAROLINA

DOUGLAS B. MCNAIR AND WILLIAM POST

Abstract. Museum specimens can be a resource to ornithologists who wish to examine the status of birds because they may provide reliable field data that document the historical status of birds of management interest. We compared the historical winter status of Le Conte's (*Ammodramus leconteii*), Henslow's (*A. henslowii*), and Grasshopper (*A. savannarum*) sparrows in South Carolina based on specimens collected by Arthur T. Wayne and Leverett M. Loomis in the late 19th and early 20th centuries. In comparison to Henslow's and Grasshopper sparrows, Le Conte's Sparrow was abundant during "incursion" years (4–5 fold increase above the maximum annual count for any other year), inland (Piedmont), and on the coast, and had a significantly higher proportion of females. Le Conte's Sparrow was less common on the coast than Henslow's Sparrow during non-incursion years. Henslow's and Grasshopper sparrows were not regular winter residents in the Piedmont. Compared to their present known winter status in South Carolina, Le Conte's and Henslow's sparrows were much more abundant 70–115 years ago. This change in past and current winter abundance could be attributed to breeding range contractions and reductions of eastern populations because of habitat loss, to similar events on the winter range, or a combination of factors on both the breeding and winter range. These problems and possible biases associated with specimen data are discussed. This study demonstrates the usefulness of historical museum data toward detecting changes in the population status of selected species.

Key words: abundance, *Ammodramus henslowii, Ammodramus leconteii, Ammodramus savannarum,* distribution, Grasshopper Sparrow, Henslow's Sparrow, Le Conte's Sparrow, South Carolina, winter.

Museum specimens can be a resource to ornithologists and other individuals who wish to examine the status of birds because they may provide reliable field data that document the historical status of birds of management interest. We use a museum approach in historical ornithology to understand long-term bird populations of three secretive sparrows pertinent to the Savannah River Site (SRS) and the southeastern United States. The data are not from the SRS directly, but they are from the general region (South Carolina). Therefore, the results of our analyses are relevant to managers assessing status of these sparrows in the SRS.

Ammodramus sparrows that occupy upland habitats in winter are secretive, and prefer open areas with dense groundcover. Consequently, these sparrows are difficult to detect on their winter range. Odum and Hight (1957), Norris (1963), Johnston (1969), and Maxwell et al. (1988) used mist-nets at isolated locations in South Carolina (Savannah River Site, Aiken and Barnwell counties), Florida (Gilchrist County), and western Texas to determine the winter status of Le Conte's (*A. leconteii*) and Grasshopper (*A. savannarum*) sparrows in specific habitats. Snead et al. (1957, 1958), Imhof (1960), and Viers (1974, 1978, 1980, 1981, 1982, 1983) counted both of these sparrows on winter bird population study plots in Alabama (Jefferson County) and Louisiana (Natchitoches Parish) to determine their status at two air fields. Recent research has expanded our knowledge of the winter status of Le Conte's, Henslow's (*A. henslowii),* and Grasshopper sparrows in the north Gulf coastal plain of the southeastern United States (McNair 1998, unpubl. data; Plentovich et al. 1998; R. Carrie et al., unpubl. data; M. Woodrey et al., unpubl. data). However, knowledge of the historical winter status of these sparrows is limited. Observers on Christmas Bird Counts, for example, seldom detect these species (Lowther 1996, Vickery 1996; Butcher and Lowe 1990 in Pruitt 1996 and references therein; contra Herkert 1997). Most other historical sources of information have also been inadequate (e.g., for Henslow's Sparrow, see Pruitt 1996; for Le Conte's Sparrow, see Walkinshaw 1968, Lowther 1996).

The only detailed information on the historical winter status of these three species in the Southeast is from South Carolina. Arthur T. Wayne (1888, 1894, 1910, 1918; Brewster 1886) collected many specimens of all three species during winter on the coast (Beaufort and Charleston counties) in the late 19th and early 20th centuries (1884–1927). Leverett M. Loomis (1879, 1882, 1885, 1886, 1891) collected many specimens of Le Conte's Sparrow inland (Chester County), during the late 19th century (1879–1892), and fewer Grasshopper and Henslow's sparrows (Loomis 1891, Post and Gauthreaux 1989). The collecting activities of Loomis and Wayne overlapped during eight winters (1884–1892). The publications of both men focused on Le Conte's Sparrow, which was not discovered in South Carolina until the 1880s (Loomis 1882, Brewster 1886), later than Grasshopper and Henslow's sparrows (cf. Baird et al. 1874).

We evaluate the historical winter status of these three upland *Ammodramus* sparrows in South Carolina by assessing specimen evidence collected by Wayne and Loomis, and the associated information available from their publications. We focus on Wayne's data from Charleston County.

METHODS

We recorded the specific localities, years, and numbers for each species of upland *Ammodramus* sparrow collected by Wayne and by Loomis. For Wayne, we treated the data from Charleston and Beaufort counties separately; data from Beaufort County are too limited to permit detailed analyses. These data and additional information on sex and age were extracted from specimen labels or from Wayne's journals, which are deposited in the Charleston Museum. We verified or checked this information when possible with the published accounts by Wayne and Loomis. We found no discrepancies.

Our analyses assume that each species is approximately equally conspicuous and difficult to detect on the winter range, where birds are usually flushed individually (see Grzybowski 1983a,b for data on Grasshopper and Le Conte's sparrows; McNair 1998, pers. obs.) (although see Odum and Hight 1957 and Norris 1963, who stated that local Le Conte's Sparrows flushed less readily). Hence, we assume that each species is approximately equally collectible. We used Chi-square tests in our analyses.

RESULTS

DISTRIBUTION AND ABUNDANCE

Wayne collected Grasshopper, Henslow's, and Le Conte's sparrows on the coast of South Carolina in Charleston County at a minimum of 14, 20, and 17 sites, respectively, from a total of 42 sites. The distribution of sites where Le Conte's and Grasshopper sparrows were collected was significantly different ($\chi^2 = 10.81$, $P < 0.01$). Pairwise combinations between the other two species were not different (Le Conte's vs. Henslow's: $\chi^2 = 3.36$, $P > 0.05$; Grasshopper vs. Henslow's: $\chi^2 = 1.03$, $P > 0.05$).

Over 42 winters, Wayne collected Grasshopper, Henslow's, and Le Conte's sparrows on the coast of South Carolina in Charleston County in 20, 24, and 18 years, respectively (Table 1). The frequency of occurrence among species over these years was not significantly different ($\chi^2_2 = 0.90$, $P > 0.05$), nor were any pairwise comparisons between species.

Le Conte's Sparrow had three incursion years (4–5 fold increase above the maximum annual count for any other year: 1893–1894, 1909–1910, 1917–1918), when Wayne (1894, 1910, 1918; journals) collected a total of 116 birds in Charleston County (yearly maxima of 34–42, daily maxima of 6; Table 1). Neither Henslow's or Grasshopper sparrows had incursion years.

Henslow's Sparrow (77 birds) was significantly more numerous than Le Conte's (44 birds) or Grasshopper (33 birds) sparrows in Charleston County during Le Conte's non-incursion years ($\chi^2_2 = 25.67$, $P < 0.01$). The maximum number of Henslow's, Le Conte's, and Grasshopper sparrows collected during non-incursion years was 7, 9, and 5 birds (daily maxima of 4, 5, and 2), respectively.

During non-incursion years in Charleston County, Wayne collected Henslow's Sparrows on about twice as many days (66) as Le Conte's (34 days) and Grasshopper (30 days) sparrows. The greater abundance of Henslow's Sparrow during Le Conte's non-incursion years compared to the other two species is based on this difference, and not on the daily average of collected birds: 1.17 birds/day each for Grasshopper and Henslow's sparrows and 1.29 birds/day for Le Conte's Sparrow. During incursion years, Wayne's daily average of Le Conte's Sparrow was 1.63 birds/day. Although Wayne did not collect any birds in 10 winters, all three *Ammodramus* sparrows were collected over approximately the same number of years.

In Beaufort County, Wayne (1888, 1910; journals) collected 36 Henslow's Sparrows (daily maximum of 5) in January and February 1888 in an old rice field near Yemassee. During this expedition, he also collected three Grasshopper and one Le Conte's sparrows at the same site. Wayne's daily average in Beaufort County of Henslow's Sparrow was 2.25 birds/day.

In the Piedmont at Chester County, Loomis (1882, 1885, 1891) collected at least 66 Le Conte's Sparrows and saw many others during four consecutive incursion winters (1881–1885). In one incursion winter (1884–1885; Brewster 1886, Loomis 1886), Le Conte's Sparrow was present inland, but absent on the coast, indicating that Le Conte's Sparrows incursions do not always reach the coast. In the following five winters (1885–1890), Loomis (1886, 1891) collected or saw five birds in three seasons, compared to the two birds that Wayne collected in two seasons on the coast. Over all years, Le Conte's Sparrow occurred in 7 of 13 (54%) winters in the interior, not significantly different from its frequency of occurrence on the coast (43%; $\chi^2 = 0.43$, $P > 0.05$). Extreme dates of occurrence of Le Conte's Sparrow in the interior were 11 November (1881) to 30 March (1885) (non-incursion years only: 19 December 1889 to 3 March 1888), where the maximum count was 12 on 10 December 1881 (Loomis 1882).

Loomis (1885) collected at least 15 specimens of Henslow's Sparrow during autumn and spring migration. Unlike Le Conte's Sparrow, Hen-

TABLE 1. NUMBER OF BIRDS BY SEX RATIO AND NUMBER OF DAYS BIRDS WERE COLLECTED PER YEAR BY A.T. WAYNE OVER 42 WINTERS (1883–1925) FOR EACH OF THREE SPECIES OF UPLAND *AMMODRAMUS* SPARROWS ON THE COAST OF SOUTH CAROLINA IN CHARLESTON COUNTY

	Number of birds (number of days birds were collected)			
Winter year	Grasshopper	Henslow's	Le Conte's	Total
1883–1884	1[a]/0[b]			1
1884–1885		1/0		1
1885–1886	5/0 (4)	7/0 (4)	0/1	13 (8)[c]
1886–1887	1/0	1/0		2 (2)
1887–1888	1/0	2/3 (3)		6 (3)
1888–1889				
1889–1890				
1890–1891				
1891–1892		1/0		1
1892–1893		0/1		1
1893–1894		0/1	7/25/8U[d] (18)	41 (19)
1894–1895		2/4 (4)		6 (4)
1895–1896	1U			1
1896–1897	0/1/1U (2)	1/0	0/7 (5)	10 (8)
1897–1898		1/1 (2)	1U	3 (3)
1898–1899	0/1	2/0 (2)	1U	4 (3)
1899–1900	1/0	2/0 (2)		3 (3)
1900–1901	1U			1
1901–1902				
1902–1903	1/1 (2)	2/0/2U (3)	0/3/1U (3)	10 (7)
1903–1904	2U (2)		0/2 (2)	4 (4)
1904–1905		2/4 (5)	1/1 (2)	8 (5)
1905–1906	1U	1/1 (2)		3 (3)
1906–1907	0/1	2/2 (3)	0/1/1U (1)	7 (5)
1907–1908	0/1	2/3 (5)	2/1 (3)	9 (7)
1908–1909				
1909–1910		0/1	5/32/5U (35)	43 (35)
1910–1911		2/2 (4)		4 (4)
1911–1912	0/1		0/1	2 (2)
1912–1913	1/2 (3)		2/7 (8)	12 (11)
1913–1914				
1914–1915	2/0 (2)	1U		3 (3)
1915–1916				
1916–1917				
1917–1918			5/26/3U (18)	34 (18)
1918–1919				
1919–1920				
1920–1921	1/0			1
1921–1922	2/1 (3)	2/5 (7)	0/1/2U (3)	13 (12)
1922–1923		3/2 (4)	1/2/4U (2)	12 (6)
1923–1924	2/0 (2)	3/3/1U (7)	0/1	10 (10)
1924–1925		1/0		1
Subtotal	18/9/6U	40/33/4U	23/111/26U	na[e]
TOTAL	33 (32)	77 (66)	160 (105)	270 (193)

[a] male.

[b] female.

[c] total number of days birds were collected each year may be less than sum for all three species because individual birds of different species may be collected on the same day.

[d] U = Unknown.

[e] na = not applicable.

slow's was not found in winter. Loomis (1891) stated the Grasshopper Sparrow was a rare straggler during winter (December through March), with occasional arrivals in February during favorable weather; he listed only five occurrences in December and January.

TIMING OF OCCURRENCE

All three species of *Ammodramus* sparrows were collected on the coast of South Carolina in Charleston County during the same winter in 8 of 32 years (Table 1). There were no differences in species' abundance. No species pairwise comparisons were significantly different (Grasshopper vs. Henslow's: $\chi^2 = 0.52$, $P > 0.05$; Grasshopper vs. Le Conte's: $\chi^2 = 0.04$, $P > 0.05$; Henslow's vs. Le Conte's: $\chi^2 = 0.00$, $P > 0.05$). Grasshopper Sparrows were collected on the coast over a period of seven and one-half months (20 September 1895 to 8 May 1906), longer than the other two species (5–6 months). Extreme dates of occurrence for Henslow's Sparrow were 19 October to 30 March, for Le Conte's, 9 November to 27 April (during non-incursion years only, 9 November to 27 February). Most records for Grasshopper (76%) and Henslow's (88%) sparrow were from October through January, and for Le Conte's Sparrow, from November to January (89%).

SEX AND AGE RATIOS

Most Le Conte's Sparrows collected by Wayne on the coast in Charleston County were females (111 of 134, 83%; also see Wayne 1894, 1918), with no difference in the proportion between incursion and non-incursion years. The sex ratio of Le Conte's Sparrows was significantly different ($\chi^2 = 56.48$, $P < 0.01$) from that of both Grasshopper (males = 18, females = 9, $\chi^2 = 2.37$, $P > 0.05$) and Henslow's (males = 40, females = 33, $\chi^2 = 0.49$, $P > 0.05$) sparrows, based on an expected value of 1:1. Most Le Conte's Sparrows collected inland were not sexed; the available sample (N = 10; only four birds sexed) is too small to be useful.

The age ratios from a pooled sample of Henslow's (6 ad., 16 imm.; 27% adult) and Le Conte's sparrows (9 ad., 21 imm.; 30% adult) were not significantly different from an expected value (based on proportion of 2 adults, 4 immatures) of 1:2. The sample for the Grasshopper Sparrow was insufficient to test for differences in age ratios.

DISCUSSION

BIASES ASSOCIATED WITH SPECIMEN DATA

Interpretation of our results depends upon evaluation of the possible biases associated with the collection methods of Wayne, and to a lesser extent, with those of Loomis in the interior. We know the sites where Wayne sampled, but not their characteristics. From accounts in his journals, we know he located most sparrows with a bird dog (pointer), and then shot them as they flushed. We assume that Loomis used approximately the same methods. Wayne (1910) suggested that Grasshopper Sparrows occurred in sandier fields (drier, sparser sites), but possible habitat differences among collecting sites cannot be evaluated. Wayne sampled a large number of old field habitats, most of which were dominated by broomsedge (*Andropogon* spp.; e.g., Wayne 1894), but he provided few additional details. Inland at Chester, Loomis (1882, 1885, 1891) obtained most of his birds at one site, although he noted that Le Conte's Sparrow had the most restricted habitat. The results of Loomis and Wayne are generally consistent with other studies that document co-occurrence of the three sparrows at the same sites (Lowther 1996; D. B. McNair, unpubl. data; C. R. Chandler, pers. comm.). All three species probably have subtle microhabitat preferences within old field habitats (cf. Odum and Hight 1957).

The greater abundance of Le Conte's Sparrow compared to either Henslow's or Grasshopper sparrows in the Piedmont during winter is not an issue. We believe that the greater abundance of Le Conte's Sparrow compared to either Henslow's or Grasshopper sparrows on the coast during incursion years, which Wayne (1894, 1918) recognized, is a true biological event and not a result of selective collecting. During non-incursion years, Wayne collected all three species over approximately the same number of years (Table 1), and we doubt that he would deviate from this pattern in the three incursion years, as he collected Le Conte's Sparrows during both incursion and non-incursion years at the same sites (e.g., Porcher's Bluff). The greater abundance of Le Conte's Sparrow in the interior of South Carolina during both incursion and non-incursion years, which the data of Loomis and Wayne demonstrate, also supports our view that Wayne probably did not selectively collect Le Conte's Sparrow on the coast compared to the other two sparrows. While Le Conte's Sparrow was not discovered in South Carolina until the 1880s and specimens may have had more value than the other two species, any differences in motivation and collecting activities among Wayne and Loomis were probably minor, based on the similar number and length of their publications on Le Conte's Sparrow.

It is just as likely that Wayne oversampled Henslow's Sparrows and undersampled Le Conte's and Grasshopper sparrows on the coast in Charleston County during non-incursion years. We doubt that Wayne would have collected fewer Le Conte's Sparrows unless Henslow's Sparrow was more abundant.

For Grasshopper Sparrow, Wayne (1910) stated that many individuals overwintered (although the daily maximum he collected was two). His general qualitative statements were not always accurate, however (cf. Blackpoll Warbler, *Dendroica striata*; McNair and Post 1993b).

The duration of the winter period and timing of arrival of autumn migrants and wintering birds (December and January) for each of the three upland *Ammodramus* sparrows in South

Carolina in this study is consistent with other data from the Southeast (Post and Gauthreaux 1989, McNair and Post 1993a, Lowther 1996, Vickery 1996, Pruitt 1996). However, the timing of departure for these three species in late winter and early spring is not well defined because of undersampling. Wayne redirected his collecting efforts to other species after mid-winter; e.g., the sharp-tailed sparrow complex (*A. caudacutus* and *A. nelsoni*), of which he collected over 600 specimens (W. Post, unpubl. data). Habitat disturbance (e.g., prescribed winter burns; Wayne 1910, 1918) at Wayne's collection sites may also have been a factor. We are unaware of collecting biases associated with sex and age ratios for any of the three species during winter.

WINTER STATUS OF LE CONTE'S AND HENSLOW'S SPARROWS

With the possible exception of information obtained by Audubon and Bachman on Henslow's Sparrow (Baird et al. 1874), Wayne and Loomis obtained more data on the winter status of Henslow's and Le Conte's sparrows than the combined efforts of all other individuals in South Carolina (Post and Gauthreaux 1989, McNair and Post 1993a). The absence of Henslow's Sparrow from the Piedmont during winter is consistent with data from other states, which document that their primary winter range in the Southeast is largely congruent with the lower coastal plain where the longleaf pine (*Pinus palustris*) ecosystem was dominant (e.g., Mississippi; M. Woodrey in Pruitt 1996). The local abundance of Henslow's Sparrow in favorable habitat (abandoned rice fields; cf. Brown 1879) during mid-winter and scarcity of the other two sparrows at this site in Beaufort County (Wayne 1888) was probably a normal event, not an incursion. Large numbers of wintering populations of Henslow's Sparrow also occurred in other states at the turn of the century (Pruitt 1996), which coincided with well-documented increases of breeding populations on abandoned farmland in the northeast and north-central states (Herkert 1994, Pruitt 1996).

Specimen data from several states other than South Carolina document the concentration of Le Conte's Sparrow at the eastern edge of their winter range (Florida: Brewster 1882, Wayne 1895, Howell 1932; Alabama: Brown 1879; Mississippi: Allison 1899) and migratory routes (Illinois: Ridgway 1883, Poling 1890; Wisconsin: Kumlien and Hollister 1903 in Lowther 1996) in the late 19th and early 20th centuries. Le Conte's Sparrow formerly bred as far southeast as northeast Illinois (Lowther 1996), but data supporting a parallel, widespread increase in historical eastern breeding populations of Le Conte's Sparrow are lacking.

Since Wayne's work, Le Conte's Sparrow was not reported in South Carolina until the mid-1950s. Odum and Hight (1957) captured 10 birds in an old field in the upper coastal plain at the Savannah River Site during the winter of 1954–1955. One to four birds also occurred in this area in three other winters in the mid-1950s (Norris 1963). Since then through the 1980s, Le Conte's Sparrow was reported but five times (McNair and Post 1993a). In the 1990s, with an increase in observer effort for wintering grassland birds, Le Conte's Sparrow was found ca. 12 times over seven winters (McNair and Post 1993a; reports in Briefs for the Files of *The Chat*). All reports have been of single birds except for a local concentration during two years in the upper coastal plain at Santee National Wildlife Refuge; the high count was 11 birds on 9 March 1996 (Davis 1997). Since the mid-1950s, only ca. 25 credible records or reports of Henslow's Sparrow exist from South Carolina; ca. 13 during the 1990s over six winters (McNair and Post 1993a; W. Post, unpubl. data; reports in Briefs for the Files of *The Chat*). Most counts were single birds; the daily maximum was three. In Charleston County, we captured one Le Conte's and one Henslow's sparrow (and ca. 15 Grasshopper Sparrows) in a 40 ha old field dominated by broomsedge, *Paspalum,* and *Panicum* grasses. This field is located on James Island, near the Mt. Pleasant sites where Wayne collected many of his *Ammodramus* sparrows. Post also captured one Henslow's Sparrow during migration in late October at Mt. Pleasant. In the lower coastal plain of Georgia north of the Altamaha River, few Henslow's Sparrows have been located in old fields over the past five years (C. R. Chandler, pers. comm.). More birds, although still low numbers (maxima of 2–3 day) have been located in longleaf pine flatwoods (C. R. Chandler, pers. comm.). A few Le Conte's Sparrows have been observed with these Henslow's Sparrows.

All quantitative data on Le Conte's and Henslow's sparrows in South Carolina are from old field habitats, although Henslow's Sparrows are most abundant in pine savannas (Plentovich et al. 1998; D. B. McNair, unpubl. data; M. Woodrey and C. R. Chandler, unpubl. data). Broomsedge fields also were once an important habitat for these two species in South Carolina. Little is known about how loss of this habitat affected their populations (Lowther 1996, Plentovich et al. 1998). Wayne and Loomis sampled only old fields (primarily broomsedge). Old fields were burned frequently, often annually in late winter, then left undisturbed for one growing season, as in Charleston County (Wayne 1894). This practice would favor regrowth of broomsedge, which probably would make the sites more favorable to the three upland *Ammodramus* sparrows. In Alabama and Louisiana, broomsedge and bermuda grass (*Cynodon dactylon*) were the dominant species in grasslands that were mowed annually or more often at two air fields, where mean counts of Le Conte's Sparrow on winter bird population study plots ranged from 3–15 birds/40 ha during winters when the species was present (Snead et al. 1957, Snead et al. 1958, Imhof 1960; Viers 1974, 1978, 1980, 1981, 1982, 1983). In the coastal plain of Alabama, man-made sites burned the previous year on lands intensively managed for timber production had the highest densities of Henslow's Sparrows (Plentovich et al. 1998). Sampling of old fields (including Charleston County), especially in the 1990s, has failed to detect substantial numbers of these sparrows in South Carolina. Wayne and Loomis evidently had little difficulty locating Henslow's and Le Conte's sparrows, and the few records and reports of these species since the mid-1950s, underscores our perception that both sparrows were much more numerous in South Carolina 70–115 years ago than they have been since (Post and Gauthreaux 1989, McNair and Post 1993a; contra Lowther 1996). This decline is consistent with elimination of large areas of grassland habitat in the Southeast since the 1950s and of their conversion to row crops (USDA 1950, 1975, 1986; Lymn and Temple 1991) and pine plantations (Fairey 1973, Pruitt 1996). The present relative scarcity of old fields as winter habitat in South Carolina has probably contributed to the decline of Henslow's and Le Conte's sparrow winter numbers. The urbanization of Charleston County has also contributed toward the local decline of both species.

The decrease of wintering populations of Le Conte's and Henslow's sparrows in South Carolina has been substantial, although systematic surveys will probably detect more birds, as demonstrated by recent studies on the coastal plain of Georgia (C. R. Chandler, unpubl. data). The decrease of Henslow's Sparrow also coincides with a widespread decline of breeding populations from throughout its range since the 1960s (Askins 1993; Herkert 1994, 1997; Pruitt 1996). The decrease has been accompanied by a range contraction in the northeast United States (Pruitt 1996). Northeastern breeding birds probably wintered in the southeast Atlantic coastal plain, including South Carolina.

In contrast to Henslow's Sparrow, Le Conte's Sparrows have increased on Breeding Bird Survey routes (Price et al. 1995 in Lowther 1996). This increase has not been paralleled by increases in numbers on the winter range in South Carolina (McNair and Post 1993a). In South Carolina, Le Conte's Sparrow now occurs at the periphery of its winter range, but it is unclear if this was the case during the period of Wayne and Loomis. Le Conte's Sparrow was more numerous inland than on the coast in South Carolina (Post and Gauthreaux 1989; McNair and Post 1993a, this study) and had a female-biased sex-ratio, which is probably consistent with its occurrence on the periphery of its range. However, Gauthreaux (1982) stated that immatures are most likely to move the greatest distances, which we did not confirm. The basis for this apparent inconsistency needs further study.

WINTER STATUS OF GRASSHOPPER SPARROW

The Grasshopper Sparrow has remained a locally uncommon winter visitor on the coast of South Carolina since the time of Wayne (1910; see Post and Gauthreaux 1989, McNair and Post 1993a), although total numbers have undoubtedly declined because of the loss of grassland habitat. The winter status of Grasshopper Sparrow in the Piedmont is less certain (Post and Gauthreaux 1989). Historically, the Grasshopper Sparrow was less abundant than Henslow's or Le Conte's sparrows. At present, the Grasshopper Sparrow is a much more abundant autumnal migrant and winter resident on the coast than the other two species (Post and Gauthreaux 1989, McNair and Post 1993a; W. Post and D. B. McNair, unpubl. data).

MANAGEMENT RECOMMENDATIONS

All three upland *Ammodramus* sparrows inhabit large, open fields with dense groundcover (Henslow's Sparrows also occur in open longleaf pine forest with suitable groundcover). Habitat management for Henslow's Sparrow should focus on restoration of dense groundcover (wiregrass *Aristida* spp., beakrush *Rynchospora* spp.) in the longleaf pine ecosystem in the lower coastal plain of the Southeast (Pruitt 1996). Additional efforts should focus on man-altered habitats such as old fields, e.g., the coastal plain of South Carolina.

Habitat management for Le Conte's and Grasshopper sparrows should focus on 1–5 yr-old moist and dry broomsedge, crabgrass (*Digitaria ischaemum*), and *Panicum* fields in the coastal plain and mid-to-lower Piedmont (cf. Dunning and Pulliam 1989, Lane 1989). Only Odum and Hight (1957) have published some details on habitats used during winter in South Carolina, that of a 4-yr old field inhabited by Le Conte's and Grasshopper sparrows in the Savannah River Site. Perhaps because it occurs at the periphery of its range, Le Conte's Sparrow probably has the most specialized habitat requirements of the three species in the Southeast. It appears, however, to tolerate more forbs among grassy vegetation than the other two species, at least in old fields (Loomis 1882, Odum and Hight 1957). Large fields should be maintained to promote habitat diversity for all three species, including trickles or runs. Most sites for the three grassland sparrows in the Southeast have been 40–80 ha (Loomis 1882, Odum and Hight 1957, Imhof 1960, Johnston 1969, Viers 1974), although Wayne (1918) collected Le Conte's Sparrows concentrated in a broomgrass field as small as 4 ha. In the absence of better information, the minimum recommended size is 40 ha, identical to breeding season requirements (Pruitt 1996).

We rarely have detailed, reliable field data in the southeastern United States that document the historical status of birds of management interest. Museum data can fill this gap, if carefully analyzed (cf. McNair 1986a,b). The present study provides an example by demonstrating the usefulness of historical museum data toward detecting changes in the population status of three secretive sparrows in South Carolina. Biases may be associated with museum data (specimens and egg sets), however, and the investigator should be aware of these pitfalls (McNair 1985, 1987, 1995; Post 1995; McNair and Post 1999, this study).

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INTEGRATION OF RESEARCH WITH LONG-TERM MONITORING: BREEDING WOOD DUCKS ON THE SAVANNAH RIVER SITE

ROBERT A. KENNAMER AND GARY R. HEPP

Abstract. In 1981, long-term monitoring of the breeding of Wood Ducks (*Aix sponsa*) was initiated on the Savannah River Site by the Savannah River Ecology Laboratory in partial response to environmental legislative requirements surrounding the restart of a U.S. Department of Energy nuclear production reactor (L-Reactor). Although the reactor itself was operated only for two years, the study of Wood Ducks continues today, 15 years following its initiation, and has made significant contributions to our basic understanding of the population ecology of this unique species, and waterfowl in general.

Marking and recapturing individual females in nesting boxes were key aspects of the long-term study because it enabled us to produce annual population parameter estimates (e.g., population size, survival rate, recruitment), which are valued indicators of population stability. We were able to generate precise parameter estimates, though marking relatively small numbers of breeding females, because capture probabilities were high. Identifying field methods (e.g., long-term consistency in capture effort) that allowed precise parameter estimation was among the most important consequences of our work. The longevity of the monitoring effort was also important because it allowed us to examine the natural range of variation in reproductive characteristics of this species. We used retrospective analyses of the long-term data and initiated companion short-term studies to explore factors related to and responsible for the identified variation within the population.

Our work illustrates some of the beneficial aspects of ecological research derived from long-term monitoring efforts: they generate essential baseline data and provide a means of continually refining management practices, provide answers to important ecological questions that cannot be addressed easily by using experimental methods, and establish a foundation for formulating and testing new hypotheses. In this paper, we review the conditions that motivated the initiation of this study, the initial goals of the work, and the ecological knowledge that has been gained thus far from the commitment of SRS managers and researchers to long-term population monitoring.

Key Words: *Aix sponsa*; Anatidae; breeding ecology; long-term study; population ecology; Savannah River Site; South Carolina; Wood Duck.

In 1980, the U.S. Department of Energy (DOE) made a decision to restart a nuclear production reactor, L-Reactor, on the Savannah River Site (SRS) in west-central South Carolina because of increased demand for weapons-grade plutonium. The L-Reactor previously had been operated from 1953 until 1968 when it was placed on stand-by status. Since reactor operations required the discharge of circulated cooling water, the DOE intended to release L-Reactor thermal effluents directly into Steel Creek upon restart as it had done during earlier operations of that same reactor. Heightened public awareness of environmental issues during the 1970s, however, had resulted in the passage of extensive legislation related to environmental protection. The National Environmental Policy Act (NEPA) and the Federal Water Pollution Control Act (including the Clean Water Act of 1977) specified numerous areas such as water quality, wetlands protection, and habitat alteration that the DOE was required to evaluate before restarting the reactor (Smith et al. 1981). Furthermore, Executive Orders 11988 and 11990 specifically addressed alterations of wetland ecosystems for federal projects, while regulations such as 10 CFR 1022 and the Sikes Act (PL 93–425) placed controls over habitat and wildlife management issues on federal lands (Smith et al. 1981). Under the provisions of these legislative mandates, the DOE developed plans to prepare an Environmental Impact Statement for the project. The University of Georgia's Savannah River Ecology Laboratory received DOE funding to assist in the collection of environmental information for addressing the legislatively mandated questions.

Wood Ducks (*Aix sponsa*) occur naturally on no other continent and are uniquely adapted to living in forested wetlands where they nest in cavities of trees. Sportsmen, bird watchers, and researchers have long been attracted by this colorful waterfowl species. Wood Ducks, for example, comprise more than 10% of the annual waterfowl harvest in the United States, and in the Atlantic and Mississippi Flyways it is second only to the Mallard (*Anas platyrhynchos*) in numbers of birds shot annually (Hepp and Bellrose 1995).

Much of the popularity of Wood Ducks can be associated with their highly publicized population collapse and subsequent recovery during the early part of the 20th century. In the late 1800s, populations of Wood Ducks began to decline largely due to the market hunting profession, and by the early 1900s concern was expressed for the observed dramatic decrease (Bellrose 1990). In 1918, legal hunting of Wood Ducks was banned by the Migratory Bird Treaty Act, leading to a population upswing over the next 20 years (Bellrose 1990). Since the 1930s, thousands of nest boxes have been erected by the public and government agencies; these have further contributed to the success and expansion of locally breeding populations of this species.

As early as the mid-1930s, Wood Ducks commonly were found in swamps and lagoons along the Savannah River forming the border between South Carolina and Georgia (Murphy 1937). Wood Ducks were considered locally abundant in the vicinity of the SRS as a breeding species prior to the closure of the site to the public in 1952 (Murphy 1937). Fendley (1978) studied the ecology of Wood Ducks using nest boxes in the Steel Creek area on the SRS in the mid-1970s, following the 1968 shutdown of the L-Reactor, and provided baseline information from which new studies could be developed.

INITIATION OF THE LONG-TERM WOOD DUCK STUDY

Impacts resulting from earlier operations of the L-Reactor had altered habitats within the lower reaches of Steel Creek and the surrounding Savannah River Swamp System into which Steel Creek emptied, creating a large flooded herbaceous marsh (Steel Creek delta, >100 ha) with extensive standing dead timber (Sharitz et al. 1974, Smith et al. 1981). In addition to the thermally induced effects on the ecosystem, from 1960 to 1970 approximately 260 curies of the fission products collectively termed radiocesium (primarily ^{137}Cs, 30-yr half-life) were released inadvertently into Steel Creek (Marter 1970).

Earlier research of Fendley (1978) suggested that the impacted/recovering Steel Creek area had a higher carrying capacity for breeding Wood Ducks than either before or during the period of reactor effluent discharges. The proposed reactor restart therefore had the potential to substantially reduce local habitat for breeding Wood Ducks and other species of wintering migratory waterfowl.

The primary emphasis of the newly organized study was to assess Wood Duck reproduction within the Steel Creek ecosystem with a nest box monitoring program. Nest boxes also were established in several other SRS wetlands to serve as "control" habitats for comparative studies. Nest boxes (Fig. 1) were checked approximately weekly during the breeding season. We estimated dates of nest initiation, and counted and individually labeled eggs; females were captured, weighed, and banded, and nest fates were determined. In some years, we weighed newly hatched ducklings and then web-tagged the young with #1 monel fish-fingerling tags for future identification. Other methodological details are given in Hepp et al. (1989, 1990) and Hepp and Kennamer (1992, 1993).

IMPACT STUDIES OF THE NUCLEAR REACTOR RESTART

Results of nest box monitoring from the early 1980s confirmed that habitat alterations in lower Steel Creek associated with former thermal effluent discharges from L-Reactor were favorable to breeding Wood Ducks (Smith et al. 1981, 1982). The opening of the otherwise closed-canopy swamp allowed establishment of an extensive herbaceous/shrub marsh with species such as parrot-feather (*Myriophyllum brasiliense*), cut grass (*Leersia* spp.), knot grass (*Scirpus cyperinus*), smartweed (*Polygonum* spp.), buttonbush (*Cephalanthus occidentalis*), and black willow (*Salix nigra*; Sharitz et al. 1974, Smith et al. 1981). Wood Ducks probably were attracted to such an area because it provided the essential requirements for both nesting and brood-rearing; natural cavities produced by primary excavators were abundant in the dead standing timber, and the herbaceous/shrub marsh provided an abundance of food and cover for young Wood Ducks. Nest-box use by Wood Ducks in this habitat averaged 30–70% annually (Smith et al. 1982).

At Upper Three Runs Creek, a natural southeastern blackwater stream that also empties into the Savannah River, no habitat alterations from site activities ever had occurred. This river swamp forest was characterized generally by a closed canopy of bald cypress (*Taxodium distichum*) and tupelo gum (*Nyssa aquatica*) along the stream channel, with mixed bottomland hardwood species such as white ash (*Fraxinus americana*), red maple (*Acer rubrum*), water hickory (*Carya aquatica*), and water elm (*Planera aquatica*) found throughout the seasonally inundated floodplain (Smith et al. 1981, Workman and McLeod 1990). Such floodplain areas are considered the traditional habitat of Wood Ducks in the southeastern United States (Bellrose and Holm 1994). Nest box use by Wood Ducks in this undisturbed riparian habitat (10–20% annually), however, was consistently lower than that in disturbed sites (Smith et al. 1982).

Since ongoing environmental studies in 1981 and 1982 identified habitats in the Steel Creek corridor and delta as being favorable to breeding and wintering waterfowl, as well as to endangered Wood Storks (*Mycteria americana*) and threatened American Alligators (*Alligator mis-*

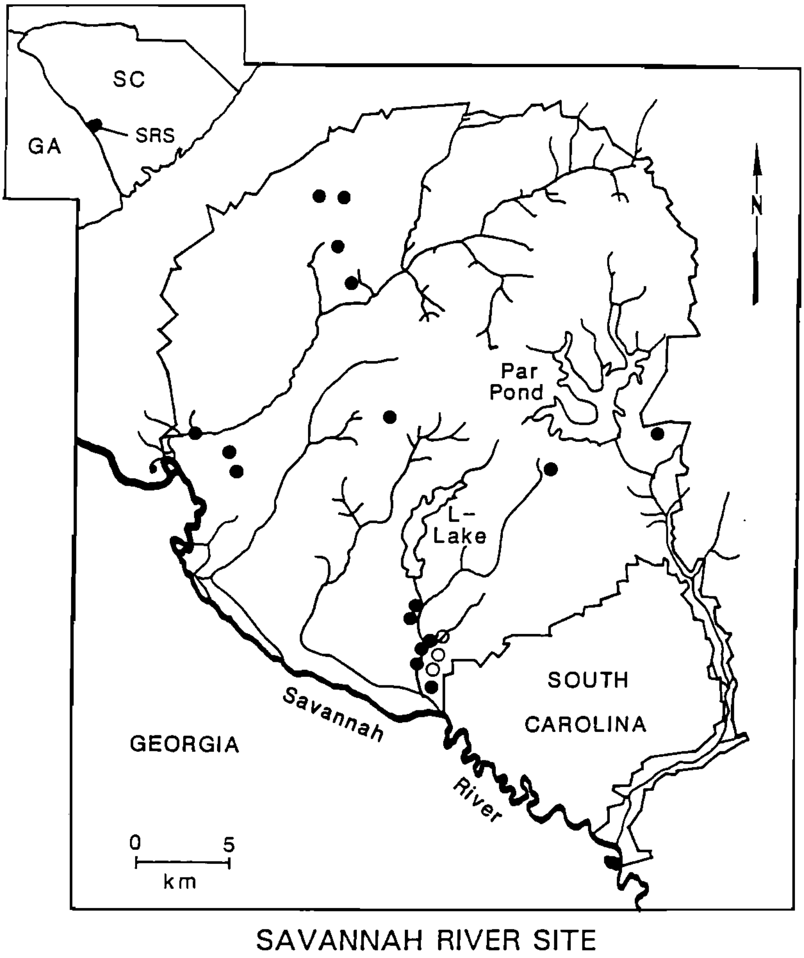

FIGURE 1. Distribution of Wood Duck nest box locations on the Savannah River Site, South Carolina. Locations (N = 16) designated by closed circles were available prior to 1984; additional locations (N = 3) designated by open circles were available beginning in 1984.

sissippiensis), further concerns focused on ecosystem impacts likely to result from restarting the reactor and their effects on these species. The consensus was that if reactor effluents were to be discharged directly into Steel Creek in a manner similar to earlier operations, the Steel Creek corridor and delta would revert to highly simplified communities typical of other SRS streams already receiving thermal effluents at that time (Smith et al. 1982). For any chosen course of action, the unavoidable increased water flows would alter the natural hydrology of the system and a process of mitigating the possible negative impacts would have to be implemented. Thus, in 1984, additional Wood Duck nest boxes were erected in wetlands adjacent to the Steel Creek floodplain (Fig. 1, open circles) that would not be affected by the proposed reactor restart (Smith et al. 1983). These "mitigation" boxes along with existing nest structures continued to be monitored for Wood Duck use in the long-term study.

Among the options considered for handling thermal reactor effluents was the DOE-preferred direct discharge of effluents into streams and the less-desirable construction of a cooling-water impoundment or cooling tower. However, the National Pollution Discharge Elimination System (NPDES) provisions of the Clean Water Act no longer allowed direct discharge of thermal waters, thus excluding the DOE's preferred option as a viable alternative (McCort et al. 1988). Therefore, in the fall of 1984, construction began on a 405-ha cooling impoundment (L-Lake; Fig. 1) within the Steel Creek drainage, upstream from the delta. L-Reactor was finally restarted on 31 October 1985, but was only in operation for about two years.

STUDIES USING THE LONG-TERM MONITORING DATA

Estimation of Population Parameters

The study of life-history characteristics is an important facet of ecology, particularly in studies of population regulation. Along with information on fecundity of individuals or groups of individuals, estimates of population parameters such as survival and recruitment are essential to examine fitness and to infer the stability of populations. In the case of game species such as the Wood Duck, population parameter estimates can be used by resource managers to assess effects of hunter harvest on populations.

Most female Wood Ducks that nested in boxes on the SRS each year were captured and marked with U.S. Fish and Wildlife Service leg bands. We used capture histories of individual females to estimate several population parameters for breeding females on the SRS (Hepp et al. 1987a). Annual survival rates of waterfowl, including Wood Ducks, had been determined previously through the development and use of models to analyze band-recovery data (e.g., Anderson 1975, Nichols et al. 1982, Conroy and Eberhardt 1983), but few studies had used capture-recapture models to estimate population parameters of breeding birds (Hepp et al. 1987a). We estimated annual survival, population size, and recruitment of breeding females using the Jolly-Seber (J-S) capture-recapture model for open populations (Table 1). Capture probabilities over the course of the study were generally high (Table 1), averaging 0.85 ± 0.02 (SE), and resulted in relatively precise parameter estimates. High capture probabilities were a consequence of consistent researcher commitment to capture nesting females among years, aided by weekly nest box checks.

Female Recruitment

To examine sources of variation in recruitment of female Wood Ducks, we marked over 2,900 day-old ducklings in six breeding seasons and tested whether hatch date and body mass at hatching influenced subsequent recruitment of females into the breeding population (Hepp et al. 1989). Most studies have reported an inverse relationship between survival probability and hatch date (Perrins 1965, Pierotti 1982, Cooke et al. 1984, Dow and Fredga 1984, Martin and Hannon 1987), and tests of the relationship between body mass and post-fledging survival in birds have produced varying results (Perrins 1980, Nur 1984, Newton and Moss 1986, Martin and Hannon 1987).

Most (73%) returning females were first found nesting as yearlings (Table 2). We found that females hatching late in the nesting season returned to breed at the same rate as early-hatched females. We attributed this result to the long breeding season of Wood Ducks in South Carolina (15-yr mean of 129 days for nest establishment) and suggested that hatching date may be relatively more important at more north-

TABLE 1. JOLLY-SEBER ESTIMATES OF POPULATION PARAMETERS FOR BREEDING WOOD DUCKS USING NEST BOXES ON THE SAVANNAH RIVER SITE, SOUTH CAROLINA[a]

	Population size		Survival rate		Recruitment		Capture probability	
Yr (t)	N_t	SE (N_t)	ϕ_t	SE (ϕ_t)	B_t	SE (B_t)	P_t	SE (P_t)
1979	–	–	0.41	0.11	–	–	–	–
1980	29.5	5.9	0.71	0.17	23.4	10.4	0.69	0.17
1981	44.4	11.8	0.62	0.12	10.0	6.7	0.44	0.14
1982	37.5	3.8	0.59	0.09	25.7	1.9	0.83	0.11
1983	48.0	0.0	0.52	0.09	36.6	5.1	1.00	0.00
1984	62.6	8.1	0.50	0.07	11.4	3.4	0.83	0.10
1985	42.1	2.9	0.68	0.08	34.3	2.3	0.84	0.08
1986	62.8	2.0	0.77	0.06	46.8	4.0	0.95	0.05
1987	95.3	5.0	0.64	0.07	48.2	6.4	0.89	0.06
1988	109.1	8.7	0.52	0.06	24.1	4.7	0.79	0.07
1989	80.6	4.9	0.62	0.07	47.3	4.9	0.84	0.07
1990	97.7	5.9	0.52	0.05	41.4	2.5	0.88	0.06
1991	92.0	0.0	0.61	0.05	55.7	3.2	1.00	0.00
1992	111.4	4.3	0.56	0.05	61.2	4.5	0.93	0.05
1993	123.2	5.5	0.58	0.05	38.7	4.3	0.91	0.05
1994	109.5	5.7	–	–	–	–	0.88	0.06
1995	–	–	–	–	–	–	–	–
Means	76.3	1.5	0.59	0.02	36.1	0.7	0.85	0.02

[a] Bias-adjusted estimates of Seber (1982) are presented. Goodness-of-fit (Pollock et al. 1985) $\chi^2 = 11.7$, 15 df, $P = 0.70$.

TABLE 2. AGES OF FEMALE WOOD DUCKS WHEN CAPTURED DURING FIRST NESTING ATTEMPTS[a]

Year of hatch	Female age (yr) 1	2	3	4	5	6	Total returns
1982	9	1	0	0	0	0	10
1983	6	0	0	0	0	0	6
1984	4	5	1	0	0	0	10
1985	7	0	0	0	0	0	7
1986	16	2	1	0	0	0	19
1987	16	7	4	0	1	0	28
Total	58 (73%)	15 (19%)	6 (8%)	0	1 (1%)	0	80

[a] Data from 2,945 web-tagged ducklings (males and females) hatched from 1982–1987, and with at least 8 years of potential recovery.

ern latitudes where shorter breeding seasons (e.g., 7-yr mean of 66 days for nest establishment in Massachusetts; Grice and Rogers 1965) may limit the ability of late-hatched young to mature sufficiently before fall migration. We also found that body mass at hatching had no effect on recruitment of Wood Duck neonates in 5 of 6 years, and suggested that duckling body mass may be linked to recruitment only in years when habitat conditions are poor and food for growing Wood Ducks is not readily available.

PHILOPATRY AND NEST-SITE FIDELITY

Many species of migratory birds exhibit a high degree of fidelity to natal areas and previous breeding sites (Greenwood and Harvey 1982). We used long-term data involving the capture and recapture of breeding females and day-old ducklings to study philopatry and nest-site fidelity of female Wood Ducks (Hepp et al. 1987a, 1989; Hepp and Kennamer 1992). Waterfowl exhibit female-biased philopatry (Rohwer and Anderson 1988), so analyses were limited to females. There were two objectives to these studies. First, we assessed the degree of philopatry and nest-site fidelity exhibited by Wood Ducks. Second, we evaluated sources of variation in nest-site fidelity and determined the benefits of returning to the same nest site in consecutive years.

Philopatry of adult female Wood Ducks initially was assessed indirectly by comparing the average annual survival rate estimated with the J-S capture-recapture model for open populations (see discussion above and Table 1) with survival estimated using band-recovery models (Hepp et al. 1987a). The J-S model estimates the proportion of females surviving and returning to the general study area, while band recovery models estimate only survival. We found no difference in these two survival estimates and concluded that surviving adult females on the SRS showed a high probability of returning to the study area (Hepp et al. 1987a).

Natal philopatry was examined by marking day-old ducklings with web-tags and recapturing the females as adults when they returned to nest in boxes (Hepp et al. 1989). Forty percent (27 of 67) of returning females nested on the wetland study site where they had hatched; returning females that did not nest on their natal wetland nested nearby ($N = 40$, $\bar{x} = 1.6 \pm 0.2$ [SE] km). Local density of breeding females (females/box) did not influence whether females nested on their natal wetland (Hepp et al. 1989).

Female ducks often return to use the same breeding site from one year to the next (Anderson et al. 1992). We tested several predictions concerning sources of variation in nest-site fidelity of Wood Ducks and the consequences of returning to the same nest site (Hepp and Kennamer 1992). Females that nested successfully used the same box to a greater extent (47.2%) in the next breeding season than those that were unsuccessful (10.8%). A positive association between nest success and nest-site fidelity also occurred within breeding seasons, between first and second nests. However, female age (yearling or adult) and population size did not influence nest-site fidelity.

Females returning to the same box nested earlier than females using different boxes, but did not have larger clutches (Table 3) or greater nest success. Females that nested unsuccessfully improved their nest success the following year by using a different nest box (Hepp and Kennamer 1992).

EFFECTS OF AGE AND EXPERIENCE ON REPRODUCTIVE PERFORMANCE

Parental age often has been shown to have an important effect on reproductive success in birds (Sæther 1990). Older individuals of many species nest earlier in the season, produce larger clutches, and have greater fledging success than younger conspecifics (Raveling 1981, Rockwell et al. 1983, Afton 1984, Reese and Kadlec 1985, Nol and Smith 1987, Harvey et al. 1988). However, most studies do not separate the effects of age from the potentially confounding effects of

TABLE 3. LEAST-SQUARES MEANS ± SE OF THE RELATIVE DATE OF NEST INITIATION AND CLUTCH SIZE OF FIRST NESTS (BY TYPE OF NEST SITE FIDELITY) FOR FEMALE WOOD DUCKS ON THE SAVANNAH RIVER SITE (SAMPLE SIZES IN PARENTHESES; HEPP AND KENNAMER 1992)

Nest fidelity type	Relative date of nest initiation[a]	Clutch size[b]
Same nest box	23.3 ± 2.3 (106) A[c]	12.3 ± 0.4 (33) A
Different nest box, same wetland	35.9 ± 2.3 (95) B	11.2 ± 0.4 (31) A
Different nest box and wetland	42.4 ± 3.2 (52) B	12.0 ± 0.5 (20) A

[a] Initiation date of nests was expressed as the number of days elapsed since initiation of the first nest each year.

[b] Nonparasitized nests.

[c] Least-squares means in columns followed by different upper case letters are significantly different ($P < 0.05$).

breeding experience. We used data from the long-term study to test whether reproductive success of Wood Ducks was age specific and to evaluate several explanations for age-specific variation (Hepp and Kennamer 1993).

Yearling females initiated nests 11–19 days later than older females. Heavy females, independent of age, nested earlier than light females. However, clutch size, mean egg mass, and number of ducklings were not affected by female age when body mass and nesting date were considered (Table 4). We also found no evidence that differential survival of yearling females explained age-related patterns of reproduction (Hepp and Kennamer 1993).

We separately tested the effects of breeding experience and age on nesting date and female body mass. Two year-old females that had nested as yearlings were heavier and initiated nests almost 4 weeks earlier than two-year-old females not known to have previous breeding experience (Table 5). Nesting date of inexperienced two-year-old females did not differ from that of yearlings, but body mass of the former group was greater (Table 5). These results suggest that prior breeding experience has a greater effect on nesting date than female age per se.

Overall, age had little effect on reproductive success of Wood Ducks. Breeding experience influenced timing of nesting, and females that nested early in the breeding season had several advantages over those that initiated nests later; early-nesting females produced larger clutches, hatched more young from successful nests, were at less risk from predators (primarily black ratsnakes, *Elaphe obsoleta*), and were more likely to initiate second nests (Hepp and Kennamer 1993).

SECOND BROODS

Most North American waterfowl do not nest successfully more than once each breeding season. Wood Ducks, however, are capable of having two broods in a single nesting season (e.g., Odom 1970, Fredrickson and Hansen 1983). On the SRS, females commonly produced two broods in a season, but frequency of double broods varied annually (0–19% of successful nests).

We found that frequency of double broods was related positively to length of the breeding season (Fig. 2). In general, mild winters with abundant rainfall contribute to an early nesting season onset, while drought conditions reduce late-season nesting. Typically, less than 5% of all successful nests were second nests when the period of nest initiations was less than about 110 days. Conversely, when periods of nest initiation were 145 days or longer, as much as 19% of all successful nests were second nests. This relationship is similar to that reported from a broad geographic area, where both breeding season

TABLE 4. ONE-WAY ANALYSIS OF COVARIANCE TESTING THE EFFECTS OF WOOD DUCK AGE (1-5 YRS) ON CLUTCH SIZE, MEAN EGG MASS, AND NUMBER OF DUCKLINGS PER NEST WITH NESTING DATE AND FEMALE BODY MASS AS COVARIATES (HEPP AND KENNAMER 1993)

	Clutch size			Mean egg mass			Ducklings per nest		
Independent variable	F	df	P	F	df	P	F	df	P
Age	1.05	4,91	NS	0.38	4,88	NS	0.56	4,65	NS
Nesting date[a]	43.17	1,91	***	7.08	1,88	**	12.25	1,65	***
Female body mass	4.09	1,91	*	45.14	1,88	***	4.09	1,65	*
R^2		0.36			0.50			0.34	

[a] Nesting date of first nests standardized ($x - \bar{x}$) to control for annual variation. NS > 0.05; * < 0.05; ** < 0.01; *** < 0.001.

TABLE 5. RESULTS OF T-TESTS EVALUATING EFFECTS OF FEMALE WOOD DUCK AGE AND EXPERIENCE ON REPRODUCTIVE PERFORMANCE CHARACTERISTICS, TIME OF NESTING (DEVIATION FROM POPULATION MEAN, IN DAYS) AND FEMALE BODY MASS (G) (FROM HEPP AND KENNAMER 1993)

	Nesting date[a]				Female body mass			
Comparison	$\bar{x}$	t	df	P	$\bar{x}$	t	df	P
Experienced adults	−12.8				591			
vs.		8.07	180	0.0001		2.12	316	0.03
Inexperienced adults	13.0				581			
Inexperienced adults	13.0				581			
vs.		0.09	204	0.93		4.82	200	0.0001
Yearlings	13.5				551			

[a] Time of nesting standardized ($x - \bar{x}$) to control for annual variation in nest initiation date.

length and incidence of second broods declined with increasing latitude (see Moorman and Baldassarre 1988).

We found no relationship between female age or early incubation body mass and the probability of producing a second brood (Kennamer and Hepp 1987). However, double-brooded females lost a smaller percentage of body mass (4.3%) during incubation of first nests than single-brooded females (9.4%). We suggested that greater weight loss by females during incubation reduced the chance of producing a second brood by increasing the time necessary to replenish nutrient reserves. Alternatively, weight loss exhibited by single-brooded females may have been sufficiently stressful to terminate reproductive activity (Bluhm et al. 1983).

CONCURRENT SHORT-TERM STUDIES

Long-term population monitoring provided the foundation for developing useful new field techniques, exploring natural sources of variation in the population, and developing and testing new hypotheses. Numerous short-term studies were initiated that served not only to complement our long-term study, but also to advance our understanding of Wood Duck population ecology and enhance the species' management potential.

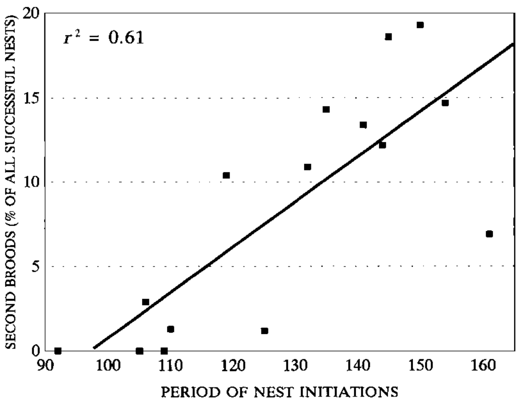

FIGURE 2. Relation between Wood Duck breeding season length (i.e., period of nest initiations) on the Savannah River Site in South Carolina and the occurrence of second broods, 1982–1996.

AGE DETERMINATION OF BREEDING FEMALES

Techniques for determining age are important for studying many aspects of population ecology. Knowledge of population age structure is useful for estimating annual production rates, and for determining age-specific differences in survival and reproduction. We developed a quantitative method using wing feather characteristics to distinguish yearling from adult female Wood Ducks during the breeding season (Harvey et al. 1989a). We used a sample of females that included adults (N = 39), yearlings (N = 31), and females of unknown age (N = 48) from which we pulled the tenth secondary (S10), first primary (P1), and the most proximal greater covert (MPGC). A total of 16 measurements was taken of these three feathers, and discriminant analysis procedures selected three variables that provided the greatest separation of the age groups. These variables included the length (mm) of S10 from the first dark barbs to the tip of the vane, mass (mg) of P1, and width (mm) of the MPGC. The discriminant model correctly classified >90% of known-age female Wood Ducks (Harvey et al. 1989a). This technique has allowed us to age unmarked females captured at nests, thereby increasing our sample of known-age females.

VARIATION IN EGG AND DUCKLING COMPONENTS

There has been great interest in how waterfowl acquire and use nutrients for reproduction (Alisauskas and Ankney 1992). Allocation of nutrients by breeding females can influence subsequent growth (e.g., O'Connor 1975) and survival (e.g., Ankney 1980) of offspring. We therefore examined within- and among-female

TABLE 6. Variation in Mass and Composition of Eggs among Wood Duck Hens (N = 87 eggs from 29 females; Hepp et al. 1987b)

Variable	Among-female variance component (%)[a]	R^2 [b]
Fresh-egg mass	71.0	0.35**
Yolk		
Wet	53.0	0.18*
Dry	52.3	0.21*
Water	56.4	NS
Lipid (%)	68.9	NS
Lipid (g)	52.0	0.19*
Lean dry mass	55.9	0.20*
Albumen		
Wet	78.2	0.36**
Dry	74.5	0.31**
Water	78.1	0.34**
Shell		
Wet	73.1	0.25*
Dry	79.7	0.18*
kJ/egg	55.0	0.29**

[a] $P < 0.0001$ for all variables.

[b] Summarizes results of regression analyses to test effects of the body mass of female Wood Ducks on the mass and composition of eggs. Values used in the analyses were within-clutch means (N = 24).

NS = $P > 0.05$; * = $P < 0.05$; ** = $P < 0.01$.

variation in the size and composition of eggs and investigated the relationship between egg mass and the structural size, body mass, and lipid reserves of ducklings (Hepp et al. 1987b).

Most variation (52–80%) in the size and composition of eggs was due to variation among females (Table 6). Composition of eggs did not vary with female age; however, mass and composition of eggs were related positively to body mass of females, and the relationship was strongest for albumen components. Heavy females produced heavier eggs with larger yolk, albumen and shell components than light females. In addition, female body mass was independent of female structural size (i.e., tarsus and wing length).

We suggested that early incubation body mass provides a good index to the "quality" of prebreeding females. Estimates of female lipid reserves before egg-laying, for example, were correlated positively ($r_s = 0.66$, $P = 0.001$) with body mass in early incubation. Heavy females with large lipid reserves may be more effective in gathering exogenous protein than light females, which could explain the stronger relationship between female mass and the protein-rich albumen component. These results are consistent with the idea that female Wood Ducks may delay egg production until they reach a threshold level of lipid reserves (Alisauskas and Ankney 1992).

For females producing two clutches in a single breeding season, egg mass and clutch size were greater in first nests than in second nests (Kennamer and Hepp 1987), indicating a lower commitment of nutrients to second clutches. We examined egg composition for two complete sets of first and second clutches (41 eggs). Total clutch lipids averaged 14.9 g less in second clutches than in first clutches; reduced lipid allocation to individual eggs of second clutches accounted for 14% of the total reduction in clutch lipids, while 86% of the total reduction in lipids was due to reduced clutch size in second clutches.

Relationships between egg size and the size and composition of the neonate indicated that components of day-old Wood Ducks increased in direct proportion to fresh-egg mass. While egg mass was a relatively good predictor of duckling mass, there was not a strong relationship between egg mass and lipid content of the neonate, suggesting that rate of lipid metabolism varied among developing embryos (Hepp et al. 1987b).

Body Mass Dynamics and Reproductive Costs to Incubating Females

Incubating birds must provide the proper thermal environment for embryonic development while maintaining their own physical condition. The ability of individuals to successfully balance these conflicting demands potentially could influence current and future reproductive success. Body mass of female waterfowl varies in an annual cycle and typically is lowest at the end of incubation. Interspecific differences in the proportion of body mass lost during incubation reflect different levels of metabolic reserves and varying incubation strategies (Afton and Paulus 1992). We documented changes in female body mass during incubation and examined sources of variation in these changes (Harvey et al. 1989b). We also tested whether body mass of incubating females was related to their reproductive success and survival (Hepp et al. 1990).

Incubating female Wood Ducks lost an average of 1.3 ± 0.1 (SE) g/day (31-day average incubation period; Bellrose and Holm 1994), which is among the lowest reported for waterfowl (Afton and Paulus 1992). Change in body mass was highly variable (range = +1.5 to −4.3 g/day) and was not related to clutch mass, nesting date, or female age; females that were heavier at the beginning of incubation lost body mass at a greater rate than light females. We suggested that heavy females possess greater post-laying lipid reserves to use during incubation than light females. These remaining lipids may provide incubating females with an important buffer, beyond which they must use endogenous protein or spend less time incubating and more time foraging to meet energy requirements.

Early incubation body mass of individual females was similar in consecutive years, but there was little consistency in rate of incubation body-mass change between years. Varying and unpredictable environmental conditions (e.g., food availability, wetland conditions) may affect the rate at which female mass changes during incubation (Harvey et al. 1989b).

Body mass at the start of incubation was not related to either hatching success or length of the incubation period (Hepp et al. 1990). In one of three years, females that were heavy at the end of incubation survived better to the next breeding season than those that were light. Reduced survival of light females in the one year coincided with greater loss of body mass in that year, indicating that incubation can be an important reproductive cost to females in some years. We found no evidence that incubation costs affected reproduction in the next breeding season (Hepp et al 1990).

INTRABROOD DEVELOPMENTAL ASYNCHRONY

Waterfowl commonly begin incubation before they finish laying eggs (Afton and Paulus 1992), thus creating developmental asynchrony within clutches. However, precocial broodmates must be prepared to leave the nest together shortly after hatching, generally $\leq$24 hr. Embryos apparently are able to synchronize time of hatch by adjusting developmental rates (Vince 1964, 1968).

We examined levels of developmental asynchrony in Wood Duck clutches and found that at the end of laying, embryo development ranged from 0–5 days ($\bar{x}$ = 2.2 days; Kennamer et al. 1990). Large clutches showed greater levels of developmental asynchrony than small clutches, and in one of two years, clutches with more than 3 days of developmental asynchrony had reduced hatching success.

Arnold et al. (1987) showed that viability of duck eggs declines with time, and they proposed that females begin incubation before clutches are complete to maintain high hatching success. Flint et al. (1994) suggested that variation in egg composition within clutches may permit synchronized hatch. We therefore investigated the relationship of laying sequence to the size and composition of Wood Duck eggs (Kennamer et al. 1997).

We found that patterns of Wood Duck egg size and composition were related to laying sequence; egg size increased during the first half of laying and decreased thereafter (Fig. 3, top). Furthermore, egg-laying sequence effects were

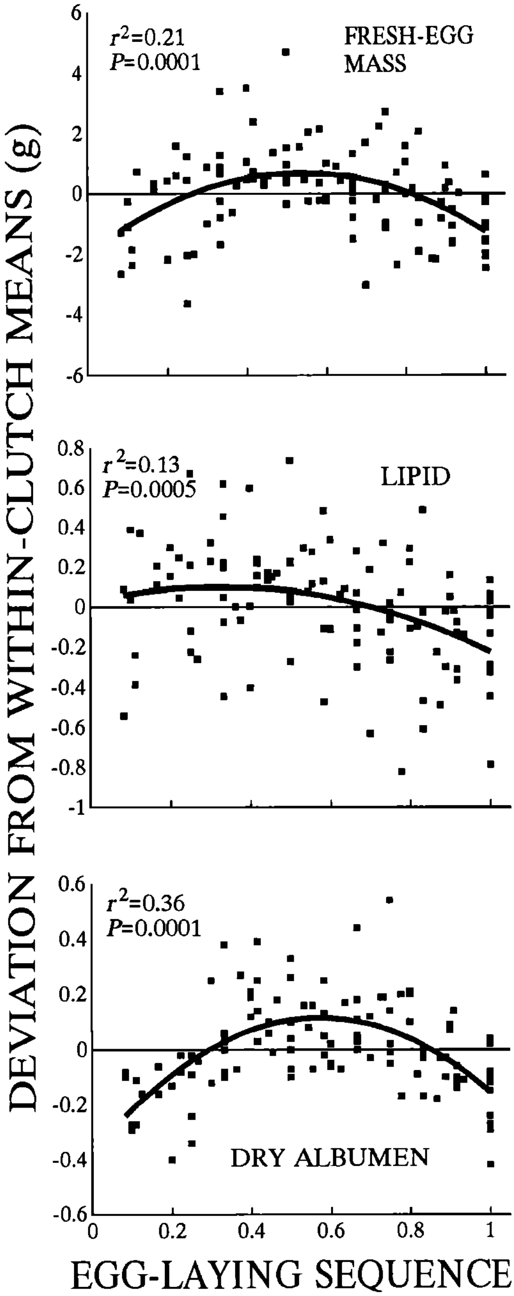

FIGURE 3. Relations between fresh-egg, yolk lipid, and dry albumen masses (deviations from within-clutch means) and laying sequence (standardized for different clutch sizes) for 11 first clutches of Wood Ducks from the Savannah River Site in South Carolina, 1991–1992. Figures are taken from Kennamer et al. (1997).

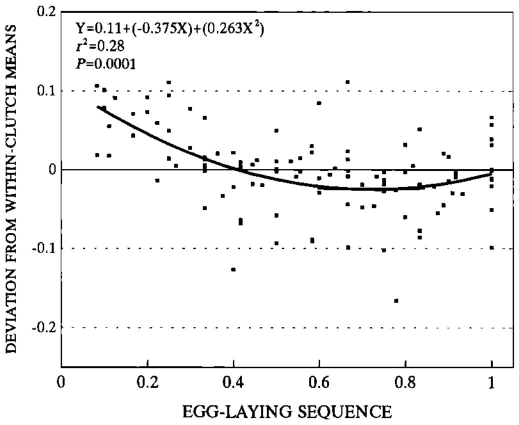

FIGURE 4. Relation between lipid indices (lipid mass/lean-dry egg-content mass; deviations from within-clutch means) and laying sequence (standardized for different clutch sizes) for 11 first clutches of Wood Ducks from the Savannah River Site in South Carolina, 1991–1992. Figure is taken from Kennamer et al. (1997).

component specific; for neutral lipids (comprising 65.5% of dry yolk), near-average absolute levels were evident until about 75% of the clutch was completed and then declined (Fig. 3, middle). Mass of dry albumen tended to increase sharply initially and then decrease as with fresh-egg mass (Fig. 3, bottom). We further found that fat indices (g egg lipid/g lean-dry egg contents) indicated that first-laid eggs of Wood Ducks were proportionately better provisioned with lipids than all other eggs in the clutch (Fig. 4), containing about 2.5 kJ more energy per gram of lean-dry egg contents than even the largest eggs in the clutch. These extra lipids could provide the energy necessary for the young of first-laid eggs to delay hatching while later-laid eggs complete incubation. Our results thus support the idea that intraclutch variation in egg size and composition may enable female Wood Ducks to initiate incubation before clutch completion and still allow for a synchronous hatch without compromising the hatching success of first-laid eggs (Kennamer et al. 1997).

CONCLUSIONS

Potential impacts on wetland habitats from reactivating a nuclear production reactor provided the initial motivation and funding for the study of Wood Duck breeding on the Savannah River Site. The work originally was designed simply to monitor breeding by this species and compare reproduction in areas affected versus not affected by thermal effluent from the reactor. Although the proposed habitat changes were never fully realized, Wood Duck reproductive data have been collected for 15 years. We have used these data to produce descriptive studies and to test specific hypotheses using retrospective analyses (Nichols 1991) where questions were formulated a priori.

Using nest boxes to monitor reproduction of Wood Ducks had two clear advantages. First, females used nest boxes extensively, so the time-consuming activity of searching for nests was eliminated; nest boxes made it easy to examine nests and to collect reproductive data. Second, females and their ducklings could be captured more easily in nest boxes and marked through vigilant efforts. Marking and recapturing individuals were key aspects of both the long-term monitoring and research, because it enabled us to estimate important population parameters and to study within population movements of females. Because recapture probabilities were high, we showed that precise parameter estimates could be obtained by marking relatively small numbers of breeding females. Identifying methods that allowed precise estimation of important population parameters with which to establish baseline information on the population was one of the most important outcomes of our research.

Long-term studies are essential for answering questions about slow processes and rare events (Likens 1989). However, duration of many population-level studies is relatively short (1–3 yrs) because of funding constraints. Results from short-term studies may be misleading, especially if the biological phenomena of interest are linked to processes with high annual variation. The intent of many of our analyses was to explore sources of variation in female survival and reproduction. Thus, the long-term aspect of our research was important because it allowed us to measure the natural range of variation likely to be found in the system. Survival of adult females, for example, was not constant but varied annually, ranging from 41 to 77%. Reproductive variables (e.g., length of the nesting season, clutch size, and frequency of producing a second brood) also showed significant annual variation. Using data encompassing numerous years and different environmental conditions provided for more powerful tests of specific hypotheses. Our long-term work provided more meaningful and effective monitoring because of the insight gained through examination of the factors related to and/or responsible for the wide range of natural variation in population characteristics. In the future, continued monitoring will allow SRS natural resource managers to better project population responses to different habitat management scenarios by taking into consideration the full range as well as the causes of this natural variation.

Field experiments are generally the best way to test hypotheses in ecology because the variable(s) of interest can be manipulated while controlling other factors or allowing them to vary independently of main effects (Hairston 1989). However, it frequently is impossible to adequately conduct manipulative field experiments. Long-term mensurative data (like ours) allow testing of hypotheses in situations where manipulative field experiments are impractical (Krebs 1991). For example, we were able to separately test the effects of age and breeding experience of females on their reproductive success by simply posing appropriate a priori questions that the long-term data could answer (Hepp and Kennamer 1993). Although a controlled experiment that manipulated breeding experience of similar aged females may have provided a stronger test of the age-experience hypothesis, it would have been extremely difficult to accomplish under field conditions.

We believe that our research illustrates some of the beneficial aspects of ecological research derived from long-term rigorous monitoring efforts: they generate baseline data and the comparative data essential for resource managers to continually assess effects of management practices, provide answers to important ecological questions that cannot be easily addressed using experimental methods, and establish a foundation for formulating and testing new hypotheses.

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MITIGATION FOR THE ENDANGERED WOOD STORK ON SAVANNAH RIVER SITE

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Abstract. A proposed change in facility operations at the U.S. Department of Energy's Savannah River Site in the early 1980s potentially threatened Wood Storks, a recently classified federally endangered species that foraged on that facility. The resulting interagency consultation was highly successful in that the impacted habitat was "replaced" by an approximately equal amount of foraging impoundments, managed specifically for this species, that were used extensively by the birds. Ecological studies conducted in support of this mitigation strategy provided invaluable information addressing many of the "tasks" listed in the Wood Stork recovery plan as important to the recovery of the species.

Key Words: Department of Energy, endangered species, foraging habitat, mitigation, *Mycteria americana,* Wood Stork, Savannah River Site.

The Wood Stork (*Mycteria americana*) is a large wading bird that nests and forages in wetland habitats. In 1984, the species was listed as federally endangered as a result of population declines believed to be related to the loss of foraging habitat (USFWS 1986). Unlike many wading birds that feed visually, Wood Storks forage by tactilocation, requiring shallow wetlands with high densities of their aquatic prey to forage efficiently (Kahl 1964). High densities of prey in shallow freshwater wetlands are typically present as a result of decreasing water levels due to seasonal variation in rainfall and evapotranspiration patterns (Coulter 1988). As wetland acreages have declined in the 1900s, particularly in southern Florida, so have populations of Wood Storks.

Concerns increased for this species as population estimates declined by approximately 60–80% through the mid-1900s (Ogden and Patty 1981, Kushlan and Frohring 1986). Concurrent with the population decline, the "center" of the population's breeding range shifted northward (Ogden et al. 1987), with breeding first documented in both Georgia and South Carolina in the 1970s and 1980s, respectively (Harris 1995, Murphy 1995).

The U.S. Department of Energy's (DOE) Savannah River Site (SRS) occupies approximately 78,000 ha of upper coastal plain/sandhill habitat in west-central South Carolina, and is bounded on its south-western border by the Savannah River. The primary function of the SRS was to operate nuclear reactors to produce plutonium and tritium to meet national defense needs for nuclear weapons. Since the mid-1950s water used to cool these reactors has been discharged into several streams feeding into the Savannah River. The discharged cooling waters altered many downstream aquatic habitats due to high water temperatures and fluctuating flow rates, including the creation of deltas where these streams entered the swamp system associated with the river (Savannah River Swamp System, SRSS). The L-reactor, which had discharged cooling water effluent into Steel Creek since 1953, was placed on standby status in 1968. Due to an increased need for nuclear materials, in 1980 the DOE decided to initiate the process of restarting the L-reactor. This process included the evaluation of potential environmental impacts on the Steel Creek delta, downstream of the L-reactor.

Wood Storks have been observed in the central Savannah River drainage, which includes the SRS, since the early 1900s. Murphey (1937) reported that although storks did not breed in this area, sightings of large, late summer flocks of young-of-the-year birds were frequent. Norris (1963) also documented seeing storks on the Savannah River "Plant" (now the SRS) in the mid-1950s and early 1960s. Research concerning the potential impacts of restarting the L-reactor, which would increase water flow into the Steel Creek delta, included an assessment of restart on Wood Storks, then a candidate species of concern being assessed for federal protection as an endangered species. This research suggested that effluents from the L-reactor would preclude the use of this habitat by feeding Wood Storks and that storks inhabiting the Birdsville Colony (approximately 45 km to the south) likely would be negatively impacted by this habitat loss (Smith et al. 1982). All impacts suggested in this study were based purely on increased water levels, and did not consider possible contaminants in the effluent as a potential threat.

After the Wood Stork was classified as an endangered species in 1984 (Bentzein 1984), the DOE entered into a Section 7 consultation (Endangered Species Act) with U.S. Fish and Wildlife Service (USFWS) concerning potential im-

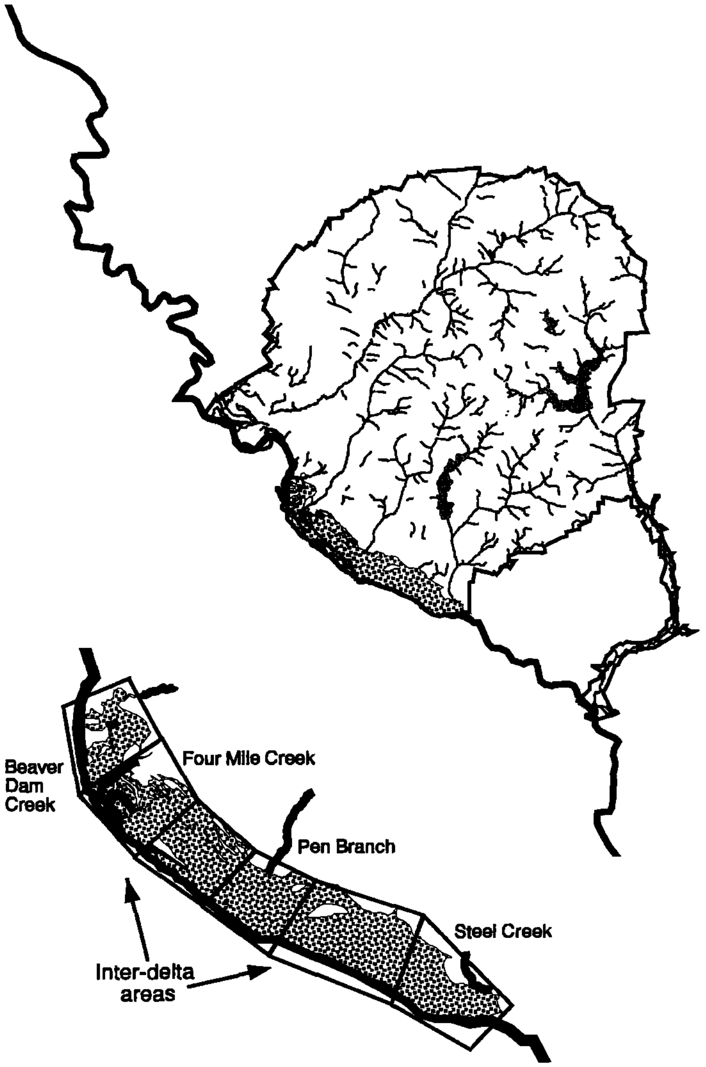

FIGURE 1. The Savannah River Site, including the surveyed areas of the Savannah River Swamp System (SRSS).

pacts on storks resulting from the L-reactor restart. The USFWS agreed with the determination that the restart could impact negatively the endangered Wood Storks breeding at the nearby Birdsville colony. Due to this determination, the DOE entered an Interagency Agreement with USFWS to mitigate the lost foraging habitat by creating impoundments (the Kathwood foraging ponds; see description below) managed as Wood Stork foraging habitat (McCort and Coulter 1991). Also, the DOE initiated a program to monitor the following: the SRSS to determine patterns of stork use; the breeding biology and foraging ecology of the Birdsville Colony; and Wood Stork use of the Kathwood foraging ponds. Since this initial consultation, the research program also has addressed additional potential impacts to this species resulting from SRS operations, including the drawdown of the Par Pond reservoir.

INITIATION OF WOOD STORK RESEARCH ON SRS

Monitoring to document Wood Stork use of the SRS initially focused on the SRSS, since the proposed restart would presumably impact the Steel Creek delta within that system (Fig. 1). The entire SRSS was monitored by aerial surveys of the open wetlands and drainages within the forested-palustrine system from 1983

TABLE 1. WOOD STORK USE OF THE SAVANNAH RIVER SWAMP SYSTEM BY YEAR AND AREA, 1983-1996[a]

Year	N[b]	Steel creek delta	Inter-delta area	Pen branch delta	Inter-delta area	Four mile creek delta	Beaver dam creek	Average number storks observed
1983	35	87	0	6	0	0	170	7.51
1984	89	95	0	21	102	46	106	4.16
1985	120	9	0	9	236	346	0	5.00
1986	115	81	0	0	0	94	15	1.65
1987	123	139	0	0	0	11	0	1.22
1988	143	6	1	0	0	0	0	0.05
1989	99	9	1	5	6	6	2	0.29
1990	12	1	0	0	0	12	0	1.08
1991	34	1	16	1	17	36	7	2.29
1992	41	9	79	70	10	0	4	4.20
1993	40	22	1	16	68	55	6	4.20
1994	29	21	2	1	0	5	1	1.03
1995	26	5	7	0	1	0	0	0.50
1996	16	4	0	0	0	1	0	0.31
Totals	880	480	100	129	439	611	311	33.50
Ave. Storks/ Area/Yr		34.29	7.14	9.21	31.36	43.64	22.21	
Ave. Storks/ Area/Survey		0.55	0.11	0.15	0.50	0.69	0.35	

[a] Numbers represent the total storks counted during that year.

[b] N = number of aerial surveys.

through 1996. Six areas within the SRS were delineated: Beaver Dam Creek, Fourmile Creek delta, Pen Branch delta, Steel Creek delta, and the two inter-delta sections of the SRSS (Fig. 1). Approximately 900 aerial surveys for storks have been flown since 1983, with 89–143 flown per year in 1984–1989 and 12–41 surveys flown per year in 1983 and 1990–1996 (Table 1).

Wood Stork use of the SRSS appeared to vary in relation to year, season, and area (of the SRSS). Annual averages suggest a general decline in stork use since the surveys were initiated (Table 1). These averages probably were influenced by the reduction in surveying effort in the last 5 years (1990–1996) of the project. Peaks of stork occurrence were observed in the SRSS from 1983–1985 and 1992–1993, and these peaks likely were associated with reactor operations. In 1983–84, testing of the L-reactor resulted in fluctuating water levels in the Steel Creek delta, presumably trapping fish in the delta areas and attracting storks in high numbers (Table 1; Fig. 2a). In 1985, C-reactor ceased operations, which resulted in lower water levels in the Four Mile delta and the inter-delta area to the east, also presumably trapping fish and attracting high numbers of storks (Fig. 2b). Finally, in 1992, K-reactor was tested for several weeks, which led to water level fluctuations in the Pen Branch delta. This area had received little stork use previously, but attracted storks during the reactor testing (Fig. 2c). Variation in stork use probably was also affected by (1) varying annual reproductive success rates of the stork colonies (in a "good" year there are more juveniles dispersing), and (2) the influence of rainfall patterns on the availability of "natural" foraging habitats. Also, as reactor operations (and water flows) were reduced, vegetative succession within the open areas of the SRSS probably resulted in a reduced amount of foraging area within this system.

Seasonal patterns were noted in regard to stork occurrence. The majority of stork observations occurred in the late summer months, as breeding activity at the nearby Birdsville colony was coming to a close (Fig. 3). These observations suggested that parent storks foraging for their nestlings rarely made trips to the SRSS to obtain prey, and that this wetland system was more important as a post-breeding/dispersal foraging area.

PAR POND DRAWDOWN

Par Pond is an 1,100 ha reservoir on the SRS that served as a cooling reservoir for thermal effluent from two nuclear reactors from 1960 to 1988. It was maintained at a constant water level from 1960 until July of 1991, when structural anomalies discovered in the reservoir dam resulted in the lowering of its water level by 6 m, reducing its volume and surface area by 50%

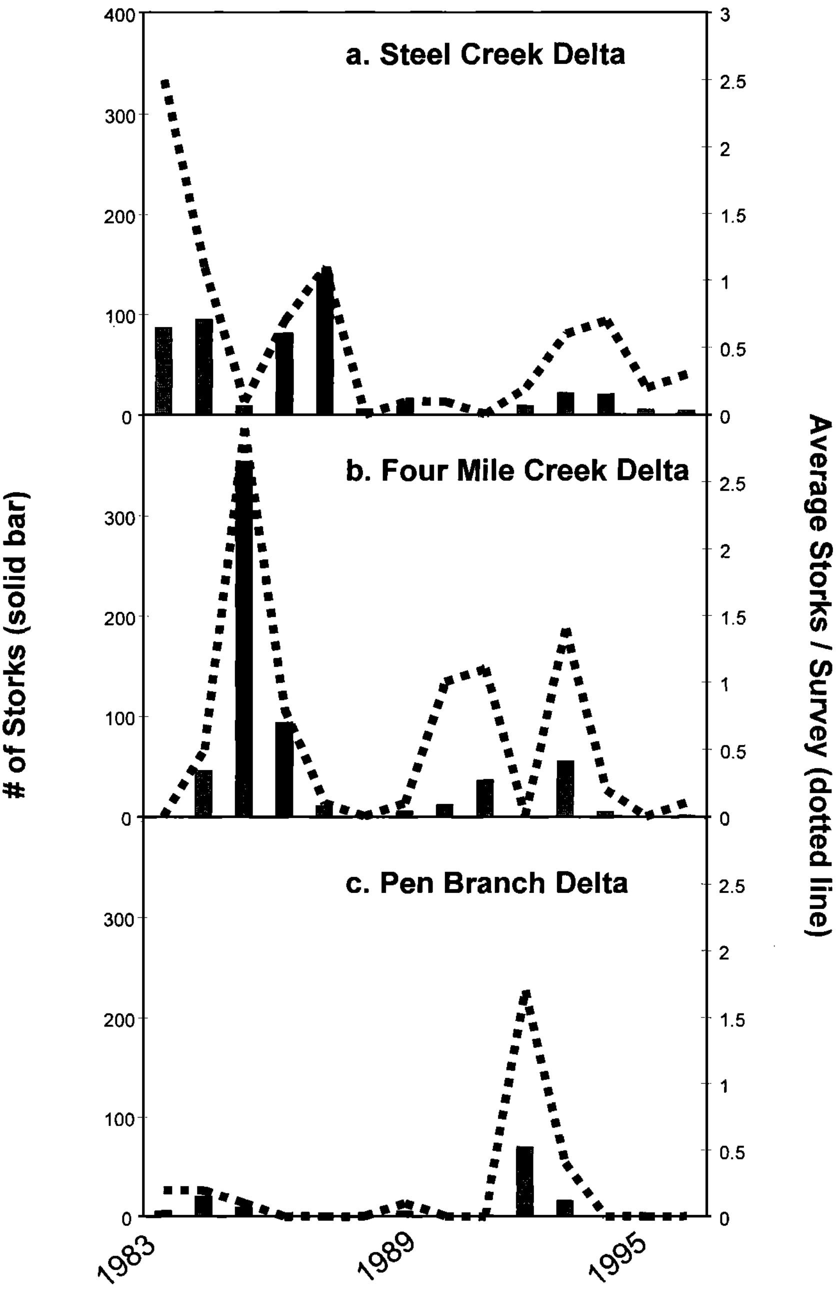

FIGURE 2. Total Wood Storks observed and average storks per aerial survey in the SRSS from 1983–1996. A. Steel Creek delta; B. Four Mile Creek delta; C. Pen Branch Delta.

and 65%, respectively. Wood Storks do not typically forage in lacustrine habitats; however, surveys were initiated to see if this large-scale drawdown would make shallow parts of the reservoir available for foraging storks and thus attract the birds to the site. The concern over stork use of this site was due to the presence and concentration of mercury and several radionuclides, particularly the gamma-emitting cesium 137, within this reservoir. Mercury concentrations in smaller stork prey-sized fish (Bryan et al. 1997) have been documented at levels higher than rec-

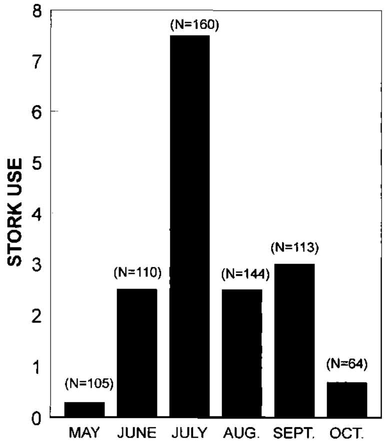

FIGURE 3. Seasonal use of the SRSS by Wood Storks, 1983–1996. Use equals the total number of storks observed during that month divided by the number of surveys (shown in parentheses).

ommended in the diet of sensitive avian species (0.1 μg Hg/g fresh weight; Eisler 1987). Aerial surveys (weekly) of this reservoir for Wood Storks were initiated in July of 1991 and have been maintained from March–October through 1996.

Seventeen aerial surveys were flown over the Par Pond reservoir in 1991. Wood Storks were observed consistently on the reservoir from late July through mid-October. An average of 26.1 ± 29.5 (SD) storks were observed on Par Pond per survey, with a maximum count of 85 storks on a single survey. Ground counts of the birds indicated the storks used the reservoir continuously during this period. Small, stork prey-sized fish, which typically inhabit the protective cover of the reservoir's well-established macrophyte bed, were exposed to stork predation when water levels dropped below the level of the protective macrophytes. Surveys in subsequent years (approximately 30 surveys per year, from March through October) have documented only one additional stork using this reservoir since that time, despite the continued low water level through 1994. Presumably, the lack of use in subsequent years was the result of either (1) the density of prey-sized fish not recovering from predation pressures of storks and other aquatic predators in 1991, or (2) that the reservoir in its second year of drawdown (and beyond) no longer looked conducive visually as a foraging habitat (exposed mudflats perhaps suggesting a recent drawdown and concentrated prey) to attract storks.

Another proposed action on the SRS that could potentially impact Wood Storks is a recent proposal to cease using the DOE's "river water system" to maintain water depths in both the Par Pond and L-Lake reservoirs (DOE 1996a). This cessation could result in the fluctuation of Par Pond water levels and would result in the complete draining of L-Lake, a 405 ha reservoir perched on the Steel Creek drainage, which would then return to its original streambed. Both reservoirs contain fish with high mercury levels and, if their water levels drop substantially, they both potentially could attract Wood Storks seeking foraging areas. We have monitored both sites for stork use since 1991, as well as the mercury concentrations in prey-sized fish, to provide information necessary to assess the potential risk, if any, of this proposed operation to the Wood Stork. Also, we monitor stork use and contaminant levels of prey in natural wetlands on the SRS, typically Carolina bays and other ephemeral wetlands with fish populations (Snodgrass et al. 1996), to provide information to DOE as custodian of the SRS and to allow comparisons to the impacted reservoir sites. Stork use of Carolina bays is linked to rainfall patterns and their effects on wetland hydroperiod, particularly when and if a drawdown in water level occurs.

CONTAMINANT STUDIES

In response to contaminant concerns for the Wood Stork on the SRS, we initiated studies addressing mercury intake by storks in colonies throughout the state of Georgia. First, prey fed to nestlings (and collected as regurgitant) were analyzed for mercury to determine the concentrations present in typical (and non-SRS) food. This study indicated that mercury was present in all prey fed to nestlings, often at levels (0.1 *ug* Hg/g fresh weight; Eisler 1987) which can affect sensitive avian species (Gariboldi et al. 1998). Freshwater prey species fed to stork nestlings throughout Georgia contained levels of mercury equal to or greater than levels in SRS prey-sized fish (Bryan et al. 1997). A study determining mercury concentrations present in nestling tissues (blood and feathers) in the same Georgia colonies is on-going.

BIRDSVILLE COLONY STUDIES

Studies were initiated in 1984 to address many baseline ecological and behavioral unknowns concerning Wood Storks nesting in the Birdsville colony (Jenkins County, GA), the nearest source of storks foraging on the SRS. These baselines were needed in order to judge the impacts of SRS operations and mitigation attempts on this colony. While these studies were initiated in response to and in support of the mitigation efforts, they also provided much-needed information regarding this species in an unstudied (i.e., northern) portion of their expanding range. This information included colony size fluctuation, reproductive success and breeding biology, foraging ecology, and habitat use.

The Birdsville Colony expanded from approximately 100 nests in 1984 to over 300 nests in 1993, then declined to about 250 nests in 1994 (Coulter and Bryan 1995a; A. L. Bryan, unpubl. data). This latter decline probably has resulted from the formation in 1993 of a satellite colony within 5 km of Birdsville in Chew Mill Pond (also Jenkins County, GA) and its subsequent expansion from 45 nests to 100 nests. Therefore, this area has supported a total of approximately 350 stork nests since 1993. Reproductive success for Birdsville storks is typically high (>2 fledged young per nest), although interannual differences suggest catastrophic nest losses related to differences in weather patterns in some years (Coulter and Bryan 1995a). Documented mortality factors included conspecific aggression (Bryan and Coulter 1991), raccoon predation, cold and/or severe weather, as well as the influence of prey availability (Coulter and Bryan 1993).

Observations of parent storks within the colony documented an average foraging trip duration (parent departing nest until it returns with food for young) of 4 hours (Bryan et al. 1995), suggesting a low likelihood of parent storks traveling as far as the SRS (45 km) to forage. Also, this program has placed leg bands on nestling storks since 1984. A number of these banded individuals have been observed back in the Birdsville colony each year, and a Birdsville stork banded as a nestling was observed nesting in the neighboring Chew Mill colony in 1995. Marked Birdsville storks have also been regularly observed in low numbers at the Kathwood mitigation ponds (see below). Banding operations also have allowed for the collection of nestling food habits data, which indicated that the Birdsville storks typically prey on fish, particularly sunfish (Centrarchidae), although other fish species common to ephemeral wetlands also are found in the diet (Depkin et al. 1992).

More than 250 Wood Storks were followed from the Birdsville colony to foraging sites to determine foraging habitats used. The average direct foraging site distance was 12.0 km from the colony (Bryan et al. 1995), and 86% of the foraging sites were within 20 km of the colony (Coulter and Bryan 1993). Although single storks were followed from Birdsville to the SRSS in 1983 (Meyers 1984) and 1984, less than 5% of the total number of sites were in the foraging range associated with the distance to the SRS (≥40 km). Seasonal patterns were observed, with storks tending to travel greater distances to forage in the latter half of the breeding season (Bryan and Coulter 1987). Storks or other wading birds were already present at 55% of the foraging sites visited by storks, but they were typically present in very low numbers. The foraging sites visited were highly variable in regard to habitat type (small farm ponds and ditches to forested wetlands), but typically had little to moderate vegetative cover (Coulter and Bryan 1993). This habitat data was incorporated into a foraging habitat mapping study utilizing satellite imagery, which documented the effects of weather patterns (primarily rainfall) on available foraging cover. Satellite imagery data suggested that the amount of foraging habitat could be reduced by as much as 47% in a dry (lower than average rainfall) year (Hodgson et al. 1998). Fish were present at the majority of these sites in varying densities (0.0 to 249 per m^2). Comparisons of fish abundance at foraging sites with nestling dietary studies indicated that sunfish occurrence in nestlings' regurgitations was disproportionately higher than their occurrence at foraging sites and that other species typically abundant at these sites, such as mosquitofish (*Gambusia holbrookii*), generally were not selected as prey (Depkin et al. 1992).

KATHWOOD LAKE MITIGATION PONDS

In order to "replace" the 16 ha of SRS foraging habitat (Steel Creek delta) presumed to be impacted by the restart of L-reactor, the DOE negotiated with the National Audubon Society for the right to lease and modify the drained Kathwood Lake on their Silverbluff Sanctuary adjacent to the SRS in Aiken County, South Carolina. This was approved and foraging impoundments were constructed in 1985 and 1986. The four resulting impoundments were part of a gravity-flow water system in which each impoundment could be raised or lowered independently (Coulter et al.1987, Coulter and Bryan 1995b). The impoundments were stocked with bluegill sunfish (*Lepomis macrochirus*) and brown bullhead (*Ameiurus natalis*), both documented stork prey (Depkin et al.1992) and thought to be compatible/non-competitive within this type of system. The ponds were maintained at full pool during the majority of the season and were lowered to a suitable depth for stork foraging, typically in July, when stork nestlings were fledging and dispersing from the Birdsville colony. The impoundments were first available for storks in the summer of 1986.

Storks used the impoundments from July through September 1986, and have foraged there every year since through 1996 (Bryan and Coulter 1995; A. L. Bryan, unpubl. data). Most storks using the impoundments were immature birds (<4 yrs old), who made up >70% of the total storks present in most years (Bryan and Coulter 1995). Storks banded as nestlings in the Birdsville colony have been observed foraging at Kathwood in almost every year of its operation, indicating its importance to storks dispersing from that colony. However, in 1988, approximately 35 nestlings fledged from Birdsville and over 150 fledged juveniles (hatching year storks) were observed at Kathwood in a group at one time, thus indicating that fledged juvenile storks from other colonies were using the impoundments as well. And, in 1995 and 1996, nestlings banded in 1995 at the Harris Neck colony on the coast of Georgia also were observed foraging in the Kathwood impoundments. These impoundments also function as a field laboratory in which to study the foraging behavior and interactions of Wood Storks and other wading birds. For example, Walsh (1990) compared foraging success rates of different-aged Wood Storks on these impoundments and nocturnal foraging has been found to be a common behavior of storks in this setting (Bryan 1996).

CONCLUSIONS

In response to a perceived threat to the endangered Wood Stork, an integrated long-term program was initiated to determine the timing and extent of stork use of the SRS site and the habitat requirements of the species. The findings from these studies led to the creation of managed foraging impoundments to replace the impacted habitat on the SRS, based on scientific data from this region rather than data from other studies. This research was initiated in an unstudied part of the species' range, with the majority of the previous research occurring in the south Florida Everglades. The results of monitoring from various components of this project, in contrast to the preliminary findings of the original L-reactor restart EIS research (Smith et al. 1982), suggest that the majority of stork use of the SRS occurs post-breeding, with the SRS probably being more important to dispersing juveniles than to breeding adults. Regardless, the initial mitigation need (foraging habitat replacement) was met very successfully (McCort and Coulter 1991), and the program has adapted to provide data for current and possible future assessment needs (Par Pond, River Water System Shutdown, etc.) of the managers of the SRS.

The studies also have gathered information that was not necessarily required to aid with the mitigation, but which has filled gaps in our understanding of this species and, therefore, may be important to its recovery. Not only has this project met the required needs for DOE mitigation, it also has addressed many of the "tasks" designated in the initial recovery plan for this species: Task 111-locate foraging habitat; Task 1111-develop technique to identify potential feeding area (GIS); and Task 1121-monitor prey response to water management (USFWS 1986). Recent contaminant studies address Task 3.8 in the revised recovery plan for this species (USFWS 1996). In this way, this program has proved to be of benefit to the long-term recovery of the Wood Stork over and beyond the need to understand and mitigate the possible negative effects of nuclear industrial activities at this particular DOE site.

ACKNOWLEDGMENTS

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LONG-TERM STUDIES OF RADIONUCLIDE CONTAMINATION OF MIGRATORY WATERFOWL AT THE SAVANNAH RIVER SITE: IMPLICATIONS FOR HABITAT MANAGEMENT AND NUCLEAR WASTE SITE REMEDIATION

I. LEHR BRISBIN, JR. AND ROBERT A. KENNAMER

Abstract. Past nuclear industrial activities at the U.S. Department of Energy's Savannah River Site (SRS) have resulted in low-level radionuclide contamination of a variety of the site's wetlands, including a series of abandoned reactor cooling reservoirs. As a result of their long-term stable water levels and protection from public hunting and disturbance, these reservoirs have come to serve as a regionally important inland wintering site for diving ducks (Anatidae: Aythyinae) and other waterfowl species. These birds have been studied to determine the rates and patterns by which radionuclide levels in their whole body and muscle tissue have changed over time. Studies have focused particularly on the American Coot (*Fulica americana*) as a sentinel species. Coots have proved to consistently have the highest levels of contamination with the long-lived gamma-emitting radioisotope radiocesium (^{137}Cs), the most ubiquitous of the radioactive contaminants accumulating in biota on the SRS. From 1971 through 1986, radiocesium body burdens of 311 coots decreased in a negative-exponential pattern, with an ecological half-life of about four years. Radiocesium levels were initially higher in two of the reservoir's three arms where contaminated effluent had entered the watershed in the late 1950s to mid-1960s. Differing rates of decline of coot radiocesium burdens among arms of the reservoir reflected histories of reactor effluent flow that caused differential movement of this contaminant within the system. For the past two decades, average radiocesium levels in wintering coots have been well below those generally considered to be of concern for human consumption. However, our findings suggest the importance of continuing these contaminant monitoring programs while also maintaining a thorough understanding of the ecology and natural history of these birds on the SRS. Future options under consideration by the Department of Energy for its former reactor cooling reservoirs, intended as either cost-saving or remediation activities, include the cessation of make-up water pumping (leading to widely fluctuating reservoir water levels) and permanent partial or complete reservoir drawdown. Our long-term information together with continued monitoring programs will be necessary to predict some of the possible radiological consequences of any such reservoir management activities.

Key Words: American Coot, contamination, *Fulica americana*, long-term study, radiocesium, radionuclide, risk assessment, Savannah River Site, U.S. Department of Energy, waterfowl.

Nuclear production facilities of the U.S. Department of Energy (DOE) such as the Savannah River Site (SRS) are charged with assuring that habitats previously contaminated by site radionuclide releases will not threaten the health and well-being of wildlife populations, site workers, or the general public. Since the SRS is closed to public access, there is little or no opportunity for persons to come directly into contact with contaminated habitats, and offsite airborne and groundwater contaminant releases are monitored routinely to assure that all associated health risks are minimized (e.g., Ashley and Zeigler 1978, Zeigler et al. 1987). However, a frequently overlooked vector of onsite contaminants to the food chain of the public offsite is the hunting and consumption of mobile fish and wildlife species, particularly gamebirds including waterfowl. Birds that reside in contaminated habitats within the secured boundaries of the SRS can leave the site quickly and move to nearby public hunting lands where they could be harvested and consumed by hunters and their families. This possibility is of particular concern at the SRS where the site's abundant wetlands are protected from public disturbance and have come to represent an important inland wintering refuge for diving ducks in the state of South Carolina (Mayer et al. 1986). As a result of these concerns, a waterfowl research and monitoring program on the SRS was initiated by the Savannah River Ecology Laboratory in the early 1970s. From its inception, this program has focused on ^{137}Cs (radiocesium), a long-lived gamma-emitting radioisotope that is one of the most ubiquitous of the fission-product contaminants of biota on the SRS (Brisbin 1991a, 1993). The purpose of the present investigation was to examine long-term changes in the bioavailability and accumulation of radiocesium in waterfowl on the SRS and to discuss the results within the context of risk to human consumers and the need for site managers to be able to predict the radiological consequences of future habitat remediation and management activities in these or similar reservoirs.

Early studies of radiocesium levels in the migratory waterfowl community wintering on the SRS have shown that the American Coot (hereafter coot), one of the most abundant members of that community (Brisbin 1974, Mayer et al. 1986), was also the "worst possible case" for radiocesium contamination in that it consistently showed higher body burdens of this radionuclide than other wintering species investigated (Brisbin et al. 1973). The latter study also showed that radiocesium levels increased in SRS coots from October through February, with peak body burdens from December through February. Body burdens then declined from March through May, as the SRS's winter-resident population was "diluted" by northward-moving spring migrants that had not wintered in SRS contaminated wetlands. On the basis of this annual pattern, Brisbin and Vargo (1982) recommended the more-or-less stable period of peak body burdens between early December and late February of each year as the most appropriate time to sample coots to assess changes in radiocesium levels across years. Using this plan, these authors then showed that radiocesium levels in coots wintering on the SRS's Par Pond reservoir declined during the period of 1971–1972 through 1975–1976 as the isotope continued to undergo radioactive decay (physical half-life = 30 yr) and/or was sequestered in the reservoir's bottom sediments, thus reducing its availability to the birds (Brisbin 1991a).

The Par Pond reservoir (Fig. 1) includes three major extensions—the North Arm (NA), Hot Arm (HA), and West Arm (WA). The history of previous reactor discharges to these three arms of the reservoir has created a spatial mosaic in contamination levels, with radiocesium levels in sediments and biota from the North Arm exceeding those of the Hot and West Arms (Brisbin et al. 1973). Brisbin and Vargo (1982) stated that this spatial contamination mosaic was maintained as radiocesium levels declined from the winter of 1971–1972 through 1975–1976, with coots from the North Arm continuing to show the highest body burdens. Their analysis showed no significant effects upon radiocesium levels in the birds that could be attributed to any two-way or the three-way interaction of location (arm of the reservoir), month, and year, thus indicating that during that four-year period, the levels of greatest contamination in coots had not shown any tendency to move "downstream" out of the North Arm and into the other regions of the reservoir (Fig. 1).

In the intervening years since the study by Brisbin and Vargo (1982), a number of additional studies have been conducted of the uptake and dynamics of radiocesium in Par Pond coots (Clay et al. 1980, Harris 1981, Potter 1987, Potter et al. 1989). These and other unpublished studies provided data on coot radiocesium body burdens in one or more arms of Par Pond, through the winter of 1986–1987, using essentially the same sampling protocol as Brisbin and Vargo (1982), i.e., sampling birds during the period of maximum expected body burdens, from December through February. Although complete samples of 10 birds each were not always obtained from all three reservoir arms for all three months during these other studies, when combined with the data analyzed by Brisbin and Vargo (1982) these additional data provide a unique opportunity to determine the rates and patterns of change in the radiocesium body burdens of Par Pond coots over a 15-year period. Throughout these years, stable water levels were maintained in Par Pond. The data presented here thus represent long-term "baseline" patterns of contamination decline that can be expected in such reservoir habitats if no water-level manipulations are undertaken for management purposes. This information therefore can be used to predict and assess the results of continuing to maintain stable water levels or implementing other habitat management options (e.g., remediations necessitating partial or complete drawdowns) in radioactively contaminated reservoirs.

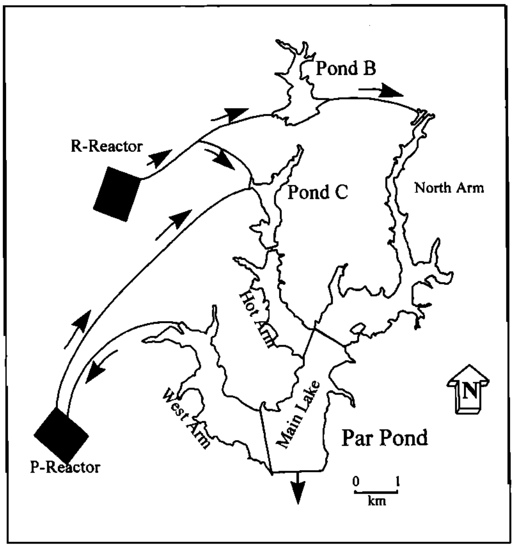

FIGURE 1. Map of the U.S. Department of Energy's Par Pond reactor cooling reservoir system, showing the P and R nuclear production reactors, effluent canals (heavy lines), Ponds B and C, and Par Pond. Regions of Par Pond, including the North Arm, Hot Arm, West Arm and Main Lake are also shown. Arrows indicate the flow of former reactor cooling effluents, some of which contained elevated levels of ^{137}Cs (see text).

The widespread occurrence of migratory waterfowl in contaminated wetlands at other former DOE nuclear weapons production sites in the

TABLE 1. Summary Statistics for Radiocesium Whole-body Burdens (Bq/g wet mass) of American Coots Collected from December to February While Wintering on the Par Pond Reservoir of the DOE Savannah River Site

	Hot arm		North arm		West arm	
Year	Mean (SD)	Range	Mean (SD)	Range	Mean (SD)	Range
1971–72	0.44 (0.11)	0.21–0.66	0.51 (0.11)	0.28–0.71	0.40 (0.12)	0.25–0.87
1975–76	0.33 (0.14)	0.03–0.55	0.41 (0.16)	0.20–0.74	0.24 (0.14)	0.01–0.54
1977–78	0.20 (0.05)	0.10–0.33	0.36 (0.50)	0.12–2.97	0.17 (0.06)	0.10–0.31
1984–85	0.04 (0.02)	0.02–0.07	0.06 (0.02)	0.04–0.08	0.05 (0.01)	0.03–0.06
1986–87			0.08 (0.01)	0.07–0.10		

Notes; Locations of the three reservoir arms are shown in Fig. 1. Arithmetic means are presented. Sample sizes for each collection are given in text.

United States (e.g., Fitzner and Rickard 1975, Halford et al. 1981) and in regions contaminated by nuclear accidents such as the Chernobyl site in the Ukraine (Brisbin 1991b) makes this information particularly important since migratory waterfowl can accumulate contaminant body burdens and then rapidly move long distances away from such sites before being harvested by hunters (see calculations in Brisbin 1991a). Information of this kind can and therefore should be considered when making decisions concerning options for long-term use, public access, and/or the need to maintain surveillance/monitoring programs at such sites until elevated levels of radioisotopes have declined due to physical decay processes.

METHODS

Using gamma-spectroscopy techniques described by Brisbin et al. (1973) and Brisbin and Vargo (1982), whole-body burdens of radiocesium (expressed as Becquerels [Bq] ^{137}Cs/g wet mass) were determined for 311 coots that were collected from the three arms of Par Pond. Including coots from the earlier studies, all birds were collected (shot) as follows: December 1971–February 1972, 10 birds per month from NA, HA, and WA (90 birds); December 1975–February 1976, 10 birds per month from NA, HA, and WA (90 birds); December 1977–February 1978, 10 birds per month from NA, HA, and WA (90 birds); February 1985, 10 birds each from NA and WA, and 11 birds from HA (31 birds); and December 1986, 10 birds from NA. These data thus represented radiocesium values for 131 additional coots collected between December 1977 and December 1986, beyond those 180 birds used in the original studies of Brisbin et al. (1973) and Brisbin and Vargo (1982). The coot whole-body radiocesium data used in this study are summarized in Table 1.

Negative-exponential regressions were fit to the data for all birds, fitting each reservoir arm separately. Since radiocesium body-burden data from Par Pond coots tend to be log-normally distributed (Pinder and Smith 1975), all data were natural-log transformed before applying a homogeneity of slopes model (PROC GLM; SAS Institute 1988). We used this analysis to test for differences of slope (i.e., rate of decline in annual peak radiocesium levels attained by the wintering coot populations) and intercept (i.e., predicted 1965 geometric mean coot radiocesium levels) between individual reservoir arms. We calculated intercepts as occurring in 1965 on the assumption that this would have been the first year that the wintering coot population on Par Pond would have been exposed to the maximum extent of contaminated reactor effluent input (Ashley and Zeigler 1980). In conducting this analysis, we treated winter season (i.e., different years) as a continuous rather than as a class variable as was done in the analysis reported by Brisbin and Vargo (1982). This change in analytical approach was necessitated in part due to the absence of samples from some arms of the reservoir during some winters (1984–1985 and 1986–1987). In addition, since we analyzed data from more than two winter seasons, the interpretation of an interaction term between year and location (reservoir arm), with both effects treated as class variables as in the analysis by Brisbin and Vargo (1982), could be misleading and might not be clearly indicative of the overall similarity or dissimilarity of the rates of radiocesium decline across time among the different reservoir arms. We considered results significant at the $P \leq 0.05$ level.

RESULTS

Negative-exponential regressions describing the long-term decrease in radiocesium whole-body burdens of coots in the three arms of Par Pond are presented in Fig. 2. Parameter estimates (intercepts and slopes) are presented in Table 2 for simple linear regressions of the relationship: $ln[y] = A + Bx$, where y is the predicted whole-body radiocesium level (Bq/g wet mass) in year x. Inspection of Type I (sequential) sums-of-squares from the homogeneity of slopes model comparing these three regressions indicated significant differences among average coot radiocesium levels in the three reservoir arms and across years (Table 3). A marginally significant interaction between reservoir location and years ($P = 0.054$, Table 3) suggested that the rates (slopes) at which coot radiocesium body burdens were declining may differ between the three reservoir arms. Contrast analysis sums-of-squares indicated that the more rapid decline of radiocesium levels in coots from the Hot Arm

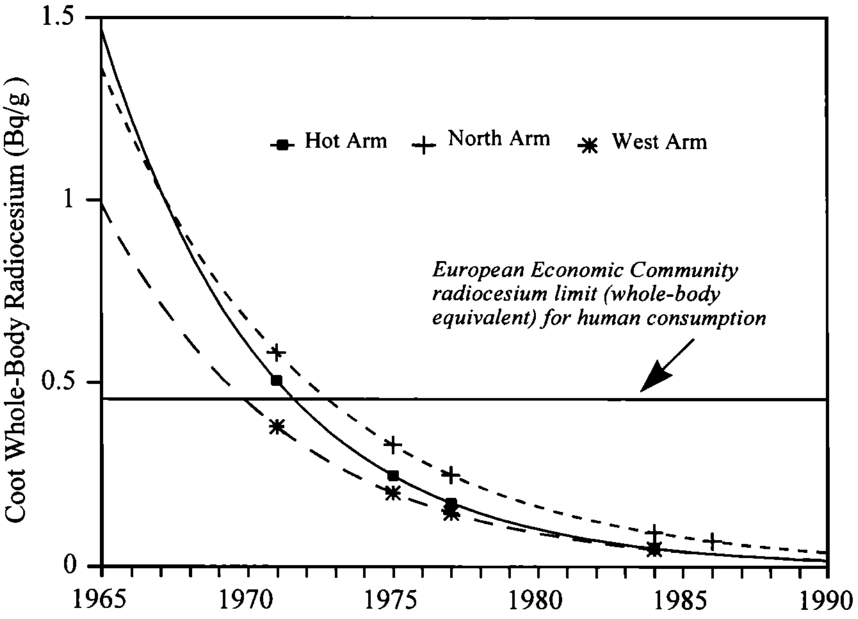

FIGURE 2. Negative-exponential regressions describing the long-term declines in American Coot whole-body ^{137}Cs from the three arms of the contaminated former reactor cooling reservoir, Par Pond. Data points represent geometric means from a total of 311 coots collected over a 15-year period. Sample sizes for given reservoir arms for given years are presented in text. The horizontal line represents the whole-body burden equivalent (0.47 Becquerels [Bq]/g wet mass) of the European Economic Community's radiocesium limit in fresh meat for human consumption (0.60 Bq/g; EEC 1986).

(Table 2) tended to differ from that of the other two arms combined (P = 0.053, Table 3), while there was no indication of a difference between slopes for the North vs. West Arms (P = 0.25, Table 3).

Type III (partial) sums-of-squares for the effect of reservoir location on intercept (coot radiocesium levels in 1965) approached significance (P = 0.09, Table 3). Contrast analysis of these intercepts indicated that the geometric mean radiocesium level in coots from the West Arm in 1965 was lower than that in coots from the combined North and Hot Arms (P = 0.029, Table 3), while those for coots from the North and Hot Arms did not differ from one-another (P = 0.65, Table 3) at that time.

Finally, we compared Par Pond coot radiocesium whole-body burdens to levels generally considered to be safe for human consumption (0.60 Bq/g fresh mass of meat; EEC 1986). Based on the relationship of whole-body to skeletal muscle levels of radiocesium in coots (Potter et al. 1989), this limit would correspond to a fresh-mass whole-body burden of 0.47 Bq ^{137}Cs/g. All geometric means of coot radiocesium body burdens on Par Pond fell below this level after 1975 (Fig. 2). However, the geometric mean body burdens for Hot and North Arm coots were both above this level in the winter of 1971–1972, and in the mid-late 1960s all such means would have been expected to exceed this level on the basis of regressions calculated in

TABLE 2. Parameter Estimates and 95% Confidence Intervals (CI) from Simple Linear Regressions ($\ln[Y] = A + Bx$) of American Coot Whole-body Radiocesium (Bq/g wet mass, Y) on Year of Collection (X)

Reservoir location	Intercept (e^A)		Slope (B)		
	Estimate	95% CI	Estimate	95% CI	R^2
Hot Arm	1.47	1.16–1.87	−0.179	−0.201–−0.157	0.72
North Arm	1.36	1.11–1.67	−0.141	−0.159–−0.123	0.71
West Arm	0.99	0.72–1.35	−0.159	−0.188–−0.130	0.54

Notes; Estimates of intercepts (e^A, where e is the base of the natural logarithm) in Bq ^{137}Cs/g and slopes (B), are presented for the Hot, North, and West Arms of the Savannah River Site's reactor-cooling reservoir, Par Pond. Intercept parameter estimates correspond to radiocesium levels that would have been expected to be found in coots in the year 1965 (see text).

TABLE 3. RESULTS OF HOMOGENEITY OF SLOPES MODEL (PROC GLM; SAS INSTITUTE 1988) TESTING SPATIAL AND TEMPORAL EFFECTS OF WHOLE-BODY RADIOCESIUM (LN BQ/G WET MASS) IN AMERICAN COOTS WINTERING ON THE PAR POND REACTOR-COOLING RESERVOIR

Source of variation	df	SS[a] (Type)	*F*	*P*
		(Model SS)		
Overall model	5, 305	138.53	125.90	0.0001
		(Type I SS)		
Reservoir location (Loc)	2	7.10	16.14	0.0001
Year	1	130.13	591.33	0.0001
Year*Loc	2	1.30	2.95	0.054
		(Type III SS)		
Reservoir location (Loc)	2	1.07	2.43	0.09
Year	1	127.58	579.74	0.0001
Year*Loc	2	1.30	2.95	0.054
		(Contrast SS)		
Slope contrasts:				
Hot vs. Other Arms	1	0.83	3.76	0.053
North vs. West	1	0.30	1.34	0.25
Intercept contrasts:				
West vs. Other Arms	1	1.05	4.79	0.029
North vs. Hot	1	0.05	0.21	0.65

Notes: Model intercepts are compared by examination of Type III sums-of-squares for the effect of reservoir location. Tested model intercepts were set to the year 1965 (see text).

[a] Sums-of-squares.

this study. After 1975, the radiocesium body burden of only one coot examined in this study exceeded the EEC limit. This bird contained a level of 2.97 Bq/g wet mass, and was collected in the North Arm of Par Pond in January of 1978.

DISCUSSION

RADIOCESIUM LEVELS IN COOTS

Coots wintering on Par Pond migrate from the contaminated area each spring and, while on their more northerly breeding grounds, they eliminate radiocesium accumulated from Par Pond. The summer elimination of radiocesium from coots is the result of physiological/ metabolic processes taking place in each individual bird's body (i.e., biological elimination). The rate at which this elimination occurs (biological half-life; Potter 1987, Brisbin 1991a) should be sufficiently rapid to ensure that those birds returning to the reservoir each fall are essentially at background levels. Resightings of marked coots on Par Pond in successive winters confirm some level of fidelity to the reservoir as a whole and even to specific arms of the reservoir (Potter 1987). Returning birds then re-acquire equilibrium levels of radiocesium each winter (Brisbin et al. 1973), but with successively acquired equilibrium levels being lower each year as described in the present study (Fig. 2; Table 3). However, there is also a separate and distinct process of elimination of radioisotopes from environments like Par Pond as contaminants are either sequestered in the reservoir's bottom sediments or are otherwise removed by being flushed downstream (i.e., ecological elimination). Rates of turnover of radionuclide contaminants in various abiotic or biotic components of ecological systems may be quantified and compared in terms of ecological half-lives, which represent the amount of time required for a given radioisotope level in a population or other ecosystem component to decrease by 50% under free-living natural conditions (Brisbin 1991a).

Calculated on the basis of an average regression slope for the three arms of Par Pond as determined in this study, the ecological half-life of radiocesium in the wintering coot population on this reservoir was 4.3 years. Usually five such half-lives (i.e., the time required to reduce an initial contamination by 97%) is considered to represent the time required to essentially reach "background" levels of contamination (Brisbin 1991a). According to the ecological half-life calculated here, levels near background should have been reached by Par Pond coots about 22 years after the winter of 1965–1966, or by the winter of 1987–1988. Our data (Fig. 2; Table 3) show in fact that by the winter of 1986–1987, radiocesium body burdens of Par Pond coots had begun to reach these levels, having been reduced by 94% from the winter of 1965–1966 estimates.

IMPLICATIONS FOR ECOSYSTEMS

Brisbin (1991a) presented data for ecological half-lives of radiocesium in Wood Ducks (*Aix sponsa*) and rat snakes (*Elaphe obsoleta*) inhabiting bottomland river swamp habitat on the SRS. Although the biological half-lives of radiocesium differed greatly in these two species (6 vs. 902 days, respectively), their ecological half-lives were relatively similar (1.9 vs. 3.8 years, respectively). Both of these values were less than Brisbin (1991a) reported for coots on Par Pond (>20 years). On inspection of the original data upon which this latter value was based, however, we found this estimation of the ecological half-life to have been incorrectly reported. The ecological half-life estimated for coots in this study (4.3 years) however, still reinforces the conclusion that radiocesium ecological turnover rates and/or declines in waterfowl inhabiting the lentic Par Pond reservoir system are slower than in waterfowl inhabiting lotic swamp forest habitats. Radiocesium tends to persist longer in biogeochemically stable lentic environments than in lotic habitats where radiocesium is lost from the system through downstream movement and bioavailability of remaining radiocesium is reduced because of redeposited stream sediments (Brisbin et al. 1989, Brisbin 1991a).

Some of our results contrast with conclusions reached by Brisbin and Vargo (1982) with regard to differences in rates of decline of coot radiocesium levels among the three arms of Par Pond. These authors found no significant difference in coot radiocesium levels due to the interaction of location (arm of the reservoir) and year, for birds collected in 1971–1972 and 1975–1976, and on that basis they concluded that there was a tendency for coots in all three reservoir arms to "decrease proportionally in radiocesium contents between years, . . ."(Brisbin and Vargo 1982:268). However, these authors' analysis was based on untransformed data, and Par Pond coot radiocesium burdens tend to be log-normally distributed (Pinder and Smith 1975). We therefore repeated the analysis of Brisbin and Vargo (1982) using only the 1971–1972 and 1975–1976 data as in their study, but using natural-log transformed data, and found a significant interaction between location and year ($P < 0.03$). This finding confirms our results reported here for the longer period 1971 through 1986, indicating the more rapid decline of coot radiocesium body burdens in the Hot Arm than in the remainder of the reservoir (Table 3). This pattern may relate to the past history of reactor effluent and/or radiocesium introduction into Par Pond and its effect on movements of this contaminant within the reservoir sediments and water column.

The North Arm of Par Pond received cooling-water effluent from the R-reactor (Fig. 1) from the time of reservoir completion in 1958 until all reactor input to this arm ceased in 1964 (Neill and Babcock 1971, Alberts et al. 1979). In contrast, the Hot Arm received cooling water effluent from the P-reactor (and to some extent the R-reactor; see Fig. 1) from 1958 until 1988 when that reactor finally was placed on indefinite standby (Whicker et al. 1993). The introduction of contaminated effluents from R-reactor occurred primarily in 1963 and 1964 (total release of about 130 curies [Ci] ^{137}Cs), and has been deemed responsible for the contamination of the entire reservoir since the time of its construction (Ashley and Zeigler 1980). In addition, in 1957, prior to the filling of Par Pond, contaminated R-reactor effluent, carrying about 47 Ci of radiocesium, deposited contaminants along the streambed of Joyce Branch which later became Pond C (Fig. 1) and the Hot Arm of Par Pond (Ashley and Zeigler 1980).

In the summer of 1976, Alberts et al. (1979) found Par Pond water concentrations of radiocesium to be higher in the vicinity of the lower dam retaining the Main Lake portion of the reservoir (Fig. 1) than near the upper reaches of the Hot Arm where much of this contamination originally had been introduced. They suggested that this may have resulted from the downstream flushing of contaminated water out of the Hot Arm. Later, Evans et al. (1983) found that radiocesium was remobilized annually from the sediments of Par Pond into the water column during periods of intense summer anoxia of the hypolimnion. Furthermore, Stephens et al. (1997), using Par Pond sediment slurries in laboratory experiments, determined that the release of radiocesium from sediments to overlying water is augmented by elevated levels of conductivity. The introduction of Savannah River water (median specific conductance: 85 microsiemens[μS]/cm at 25 C; Newman et al. 1986) into Par Pond as make-up water for circulation to reactors apparently increased the specific conductance in Par Pond (median value in the Hot Arm: 65 μS/cm at 25 C; Newman et al. 1986) from a level that probably was similar to that found in a nearby reservoir, Pond B, no longer receiving river water inputs (20–30 μS/cm at 25 C; Alberts et al. 1988). The increase in radiocesium in the water column as a result of this process together with the continuing effluent pumping activity described earlier, effectively moved radiocesium from the Hot Arm to the

Main Lake through the introduction of relatively less contaminated effluents from P-reactor into the Hot Arm via Pond C. We suggest that this flow process over the thirty years that effluents were introduced into the Hot Arm resulted in substantial movements of dissolved/suspended radiocesium out of the Hot Arm and into the Main Lake and West Arm of the reservoir, thereby accounting for a more rapid decline in availability of radiocesium to coots and other biota in the Hot Arm than in other portions of the reservoir, such as the North Arm.

Our findings that coot radiocesium levels and rates of decline differed spatially within Par Pond suggest that on the average, most coots must confine their activities to relatively small areas of the reservoir. A study of coot movements on Par Pond (Potter 1987) confirmed such a suggested level of site fidelity when only 2% of 272 sightings of 85 marked birds occurred outside of the region where they had been initially captured. In fact, 75% of the multiple resightings of 14 individuals were estimated to be less than 10 m from the previous sighting (Potter 1987).

MANAGEMENT IMPLICATIONS

Our study describes radiocesium movements and patterns of spatial/temporal distribution under conditions of full-pool water level in Par Pond from the time of its formation in 1958 through 1988. However, if future management needs should require alterations of water levels or flow patterns in this reservoir system, the rates and patterns of radiocesium decline indicated in this study might be altered significantly. It might even be possible for radiocesium levels to increase in these birds as the result of management practices that either would remobilize or increase the bioavailability of radiocesium currently sequestered in the reservoir's sediments. Since the physical half-life of ^{137}Cs is 30 yr and the ecological half-life of ^{137}Cs in the coot population is currently 4.3 yr, proportionally more radiocesium must still be present in abiotic portions of the Par Pond ecosystem than currently remains in coots. There is also the possibility that future departures from the reservoir's status quo might alter the rate at which radiocesium body burdens are now declining in coots and other waterfowl. If a decision should be made, for example, to return the Par Pond reservoir ecosystem to it's former lotic nature, we would predict that the ecological half-life would decrease from the current 4.3 yr, and approach Fendley's (1978) estimate of 1.9 yr for Wood Ducks inhabiting lotic swamp forest habitat. We would also predict that if the management options of either naturally fluctuating reservoir water levels or partial reservoir drawdown are selected, an ecological half-life in waterfowl near the current 4.3-yr estimate or perhaps even higher would result from ecosystem destabilization and the resultant remobilization and increased bioavailability of radiocesium.

In 1991, it was necessary to lower the water level in the Par Pond reservoir by 6 m for over three years to make repairs to the retention dam. This temporary partial drawdown exposed nearly half of the lake's bottom sediments, and provided an opportunity to evaluate any related changes in waterfowl radiocesium body burdens during this period. A preliminary assessment of samples collected during this period suggests that whole-body radiocesium levels in at least some coots increased to levels not seen since the study began more than 20 years earlier (I. L. Brisbin and R. A. Kennamer, unpubl. data). Further studies are therefore needed to document any changes that this drawdown may have produced in the ecological half-life of these birds. A study of radiocesium levels in Mourning Doves (*Zenaida macroura*) utilizing the exposed areas of the lakebed found that levels in these birds declined quickly (Kennamer et al. 1998), with an ecological half-life of about one year.

The information reported above improves the accuracy of risk assessments designed to predict the probability that a bird might become contaminated with radiocesium in a habitat such as the Par Pond reservoir and then migrate from the restricted area to be harvested and consumed by a member of the hunting public. While our data suggest that some birds in the past may have exceeded levels currently considered safe for human consumption (0.60 Bq/g fresh meat; EEC 1986), there is no evidence that any threat would exist from the consumption of coots using Par Pond under the long-term stable conditions described in this study. Since 1975, only one coot in this study exceeded the EEC limit of radiocesium for human consumption. This bird contained 2.97 Bq/g whole-body wet mass and was collected in January, 1978, in the North Arm of Par Pond, to where it had likely recently moved from Pond B (Fig. 2). Although radiocesium concentrations in Pond B coot tissues averaged 26 times higher than in Par Pond North Arm birds (Potter et al. 1989), Pond B coot densities (<2 birds per km shoreline) were about two orders of magnitude lower than at Par Pond, and Potter (1987) concluded that movement of coots between the two reservoirs probably occurred but was limited in extent.

Assessments of risks to hunters from the consumption of radiocesium-contaminated waterfowl from Par Pond must consider that annual maximum levels of contamination, as are reported here, are not attained until mid-late winter when most waterfowl hunting seasons have been closed. Earlier in the fall, when birds are more likely to be harvested, contamination levels generally are lower since many birds have not yet had sufficient time to accumulate asymptotic body burdens (Brisbin et al. 1973). Moreover, those waterfowl species most eagerly sought by sportsmen in North America tend to have lower radiocesium body burdens than coots (Brisbin et al. 1973). In contrast to numerous environmental contaminants (e.g., mercury) that bio-magnify in species feeding at higher trophic levels, in SRS reservoir systems, radiocesium accumulates in lower concentrations in carnivorous, omnivorous, and piscivorous waterbirds than in the largely herbivorous coot (Brisbin et al. 1973, Brisbin 1993). There are many parts of the world where coots are consumed regularly as a staple of the diet (Ripley 1976). Studies of flyways in eastern Europe (Brisbin 1991b) have confirmed, moreover, that migratory waterfowl passing through those areas most contaminated by the Chernobyl nuclear accident are likely to winter in regions where coots are frequently consumed by humans. The results of our study are therefore particularly relevant to the prediction of long-term future risks to human health from radiation exposure resulting from such global contaminating events.

Taken together, our results suggest the importance of long-term studies of not only radionuclide contaminant cycling, but also the basic ecology of migratory waterfowl and other gamebirds inhabiting contaminated habitats. Long-term studies can help to predict the future likelihood of contaminant uptake and human exposure, and can serve as a baseline against which the consequences of future changes in habitat management practices can be evaluated. Finally, they also can be used (with caution) to project backward in time to learn more about past contaminant uptake and exposure that might not have been as readily apparent at the time without the benefit of both long-term contaminant databases plus an enhanced understanding of the basic ecology of the birds themselves.

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INTEGRATION OF LONG-TERM RESEARCH INTO A GIS-BASED LANDSCAPE HABITAT MODEL FOR THE RED-COCKADED WOODPECKER

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Abstract. The Red-cockaded Woodpecker (*Picoides borealis*) population at the Savannah River Site in South Carolina has been the subject of intensive management and research activities designed to restore the population. By late 1985, the population was on the verge of being extirpated with only four individuals remaining. Older live pine trees that Red-cockaded Woodpeckers require for cavity construction were limited as the result of timber harvesting that had occurred primarily prior to the 1950s. To prevent the loss of this population and to provide for population growth, the habitat is now managed intensively, including construction of artificial cavities, control of cavity competitors, and removal of the hardwood mid-story to improve nesting habitat quality. Along with careful monitoring of the birds, translocations are being undertaken to enhance the number of breeding pairs and the overall population size as well as to minimize potential adverse genetic consequences of a small, virtually isolated population. During 1986–1996, we completed 54 translocations, installed 305 artificial cavities, and removed 2,304 southern flying squirrels (*Glaucomys volans*) (a user of Red-cockaded Woodpecker cavities). During this period, the number of breeding pairs of Red-cockaded Woodpeckers increased from 1 to 19 and the overall population size grew from 4 to 99 individuals. Additional data collected pursuant to arthropod prey base, foraging behavior, and home range studies, have provided information that is helping us better understand and manage this species. We are in the process of synthesizing these data into a GIS-implemented computer based landscape model to assess the possible impacts of various management options on the long-term viability of the Red-cockaded Woodpecker on the site.

Key Words: landscape habitat model, long-term research, *Picoides borealis,* Red-cockaded Woodpecker, Savannah River Site.

Red-cockaded Woodpeckers (*Picoides borealis*) are an endangered species that evolved in a fire-dependent pine ecosystem within the southeastern United States. They are cooperative breeders whose breeding unit, known as a group, consists of a breeding pair and sometimes one or more helpers, usually male offspring that the group has produced. Declines in population sizes and distribution of the species are the result primarily of extensive land use conversion from forest, short rotation lengths (Jackson 1986, Ortego and Lay 1988, Conner and Rudolph 1989), hardwood encroachment around cavity trees (Van Balen and Doerr 1978, Locke et al. 1983, Conner and Rudolph 1989, Costa and Escano 1989, Loeb et al. 1992), shortage of potential cavity trees (Hooper 1988, Costa and Escano 1989, Rudolph and Conner 1991), and demographic isolation (Costa and Escano 1989). Habitat quality and a limited number of cavities also may play a role (Copeyon et al. 1991, Walters et al. 1992a,b).

HISTORY OF THE RED-COCKADED WOODPECKER AT THE SAVANNAH RIVER SITE

A description of the Savannah River Site (SRS) including land use and management history is provided by White and Gaines (*this volume*). In 1951, the Department of Energy (DOE) acquired 80,269 ha of contiguous land to develop the SRS as a nuclear production facility. Contracted to manage a portion of the site for DOE, the USDA Forest Service began an intensive reforestation program to replant longleaf (*Pinus palustris*), loblolly (*P. taeda*), and slash (*P. elliottii*) pines. The management arm of the USDA Forest Service on the site is referred to as the Savannah River Natural Resources Management and Research Institute (SRI). The research arm of the USDA Forest Service on the site is the Southern Research Station.

Information on the historical population size of the Red-cockaded Woodpecker at the Savannah River Site is not available. By the end of 1985, the population consisted of a breeding pair and two other single males. The stark reality was that trees that were suitable for new cavity construction were scarce and older trees that had cavities were becoming senescent and dying, thus making the continued existence of the bird on the site doubtful. In addition, the limited number of cavities that were present were used by a variety of species.

In this paper we summarize the research at the SRS that has been designed both to enhance this perilously small population and to aid in the recovery of this species throughout its range. In addition, we describe a GIS-based simulation model we are developing that incorporates our knowledge of the Red-cockaded Woodpecker into a landscape oriented assessment of potential population growth and timber cutting options.

RED-COCKADED WOODPECKER RESEARCH AND RELATED MANAGEMENT ACTIONS AT THE SAVANNAH RIVER SITE

Management activities at the SRS designed to benefit the Red-cockaded Woodpecker have focused on improving habitat quality by controlling the encroachment of the hardwood midstory, by installing cavity inserts, and by minimizing use of Red-cockaded Woodpecker cavities by southern flying squirrels (*Glaucomys volans*) and other cavity users (Gaines et al. 1995). Research has been directed at improving our understanding of the population status, genetics of small populations, translocation protocols, foraging behavior, home range characteristics, and the arthropod prey base.

MIDSTORY CONTROL

Beginning in 1985, an active midstory control program has included prescribed burning, commercial thinning, and other mechanical means that is essential to maintain or create suitable nesting habitat by minimizing midstory development. Without such midstory control, Red-cockaded Woodpeckers will abandon cavities once the midstory reaches a certain height or basal area and the area is no longer characterized as the open, mature pine forest that the species prefers (Conner and Rudolph 1989, Costa and Escano 1989, Hooper et al. 1991, Loeb et al. 1992). Although it is not known why Red-cockaded Woodpeckers abandon these clusters, Conner and Rudolph (1991) speculate that the presence of an extensive hardwood midstory may increase the number of nest competitors, reduce the quality of foraging habitat near the nest trees so that feeding young becomes more difficult, or be counter to what the bird has become accustomed to through its evolutionary history. The cavity trees that are occupied by a given group are referred to as a "cluster," and cavities are used nightly throughout the year. From 1985–1996, a total of 2,182 ha ($\bar{x}$ = 181.8 ha/yr) of active clusters, inactive clusters, and recruitment stands (a recruitment stand is an area that does not contain a Red-cockaded Woodpecker group but that has been treated for midstory control and has been fitted with artificial cavities; see below) at the site were treated with some form of midstory control (W. Jarvis, pers. comm.). Intermediate and co-dominant pines in the overstory were treated mainly with commercial thinning to reduce the remaining pine basal area to 13.8–18.3 m^2 per ha. These treatments continue to be employed as a method to improve foraging and nesting habitat.

ARTIFICIAL CAVITY INSERTS

Red-cockaded Woodpeckers prefer older, live pine trees for constructing their cavities (Steirly 1957, Jackson et al. 1979, Conner and O'Hallaron 1987, Rudolph and Conner 1991). The limited availability of live pine trees of sufficient age to provide cavity trees was a major concern in the management of the population, as it precluded population expansion. After considerable time and effort, an artificial cavity insert was developed by David Allen at the SRS that could be installed inside the trunk of younger pine trees and was accepted by the birds (see Allen 1991 for details on the design, construction, and installation). A drilled cavity technique (Copeyon 1990) was developed, but was not suitable for use at the SRS because the majority of available pine trees were too young for this procedure. Cavity restrictors, consisting of metal plates that are fitted over the cavity entrances (Carter et al. 1989), have been effective in preventing other species, especially Red-bellied (*Melanerpes carolinus*) and Pileated (*Dryocopus pileatus*) woodpeckers, from enlarging cavity entrances and usurping the cavities. From 1986–1996, 305 artificial cavities were installed by Forest Service personnel at the SRS, of which 292 are still usable for roosting and nesting. Red-cockaded Woodpeckers readily accepted the artificial cavities and successfully reproduced in them.

CONTROL OF SOUTHERN FLYING SQUIRRELS AND SQUIRREL EXCLUDER DEVICES

Southern flying squirrels are known to use Red-cockaded Woodpecker cavities extensively at the Savannah River Site. To minimize the potential adverse effects of squirrel cavity use on the Red-cockaded Woodpecker population, a squirrel monitoring program was initiated and any flying squirrels encountered during the routine checks were destroyed. Active clusters, inactive clusters, and recruitment stands were included in the squirrel monitoring program.

Cavity inspections varied from a low of 282 in 1986 to a high of 4,594 in 1995 and resulted in 2,304 southern flying squirrels being removed and destroyed from artificial cavities, natural cavities, and nest boxes (Table 1). Most of the squirrels were taken from artificial cavities (1,511 squirrels from artificial cavities, 652 from natural cavities, and 141 from nest boxes).

To determine the necessity of continuing the labor intensive squirrel removal program, an evaluation was made to assess the possible impact of squirrel removal on Red-cockaded

TABLE 1. SOUTHERN FLYING SQUIRREL REMOVAL PROGRAM AT THE SAVANNAH RIVER SITE, SOUTH CAROLINA (1986–1996; FRANZREB 1997)

	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	Totals
No. of cavity or box inspections	282	515	640	588	900	1300	1500	1600	1449	4594	4992	17860
No. of artificial cavities available	NA[a]	17	28	28	33	48	101	151	195	245	292	292
No. of squirrels removed from artificial cavities	NA	3	43	47	49	54	70	97	135	430	583	1511
No. of squirrels removed from natural cavities	69	24	83	49	58	35	34	38	32	82	148	652
No. of squirrels removed from nest boxes	14	35	22	4	3	5	16	7	20	15	NA	141
No. of flying squirrels removed during inspections	83	62	148	100	110	94	120	142	187	527	731	2304
No. squirrels removed per inspection	0.29	0.12	0.23	0.17	0.12	0.07	0.08	0.09	0.13	0.12	0.16	0.13

[a] NA = not applicable.

Woodpecker reproductive success. Such testing could not be conducted at the SRS because of the small Red-cockaded Woodpecker population size. A controlled experiment was undertaken at the Carolina Sandhills National Wildlife Refuge, South Carolina, to assess whether southern flying squirrels adversely affected reproductive success of Red-cockaded Woodpeckers. The refuge provides habitat that is similar to the Savannah River Site (e.g., Upper Coastal Plain). Red-cockaded Woodpecker groups that nested in areas in which flying squirrels had been removed by ground trapping and during cavity checks produced significantly more fledglings than control clusters during both years of this study (1994 and 1995; Laves and Loeb 1996, Laves 1996). Reproductive rates at the Savannah River Site (2.5 fledglings/breeding pair in 1994 and 2.1 in 1995) were similar to those in the Sandhills study for clusters in which flying squirrels had been removed.

A squirrel excluder device, or SQED, was developed by Montague et al. (1995) in Arkansas as a means to control flying squirrels less laboriously. It consists of paired strips of aluminum flashing stapled tightly to the bark above and below the cavity entrance. During testing of the new device in Arkansas, Montague et al. (1995) found that squirrels abandoned 6 of 10 cavities that had been treated by installing excluder devices, and Red-cockaded Woodpeckers reoccupied 10 of the 11 cavities (one treated cavity was not occupied previously by squirrels). Recently SQEDs were tested at the Savannah River Site in unoccupied Red-cockaded Woodpecker clusters and results indicated that the devices were effective in impeding cavity use by flying squirrels (S. C. Loeb, in press). None of these SQED-treated cavity trees has been occupied by Red-cockaded Woodpeckers as of yet (S. C. Loeb, pers. comm.). At the SRS, a study is underway to evaluate whether Red-cockaded Woodpeckers will continue to use cavities after SQEDs have been installed.

MONITORING, POPULATION STATUS, AND TRENDS

As part of the intensive monitoring program for the Red-cockaded Woodpecker at the Savannah River Site, all cavities, whether natural (e.g., constructed by the Red-cockaded Woodpecker) or artificial, are monitored to determine cavity use. Cavities are checked from a ladder using a dentist's mirror and flashlight to furnish information on the number of eggs, number of nestlings, laying and hatching dates, and sex of nestlings. Fledging success rate is determined by counting the number of fledglings in the cluster soon after the anticipated fledging date.

Every adult on the site is banded with a U.S.

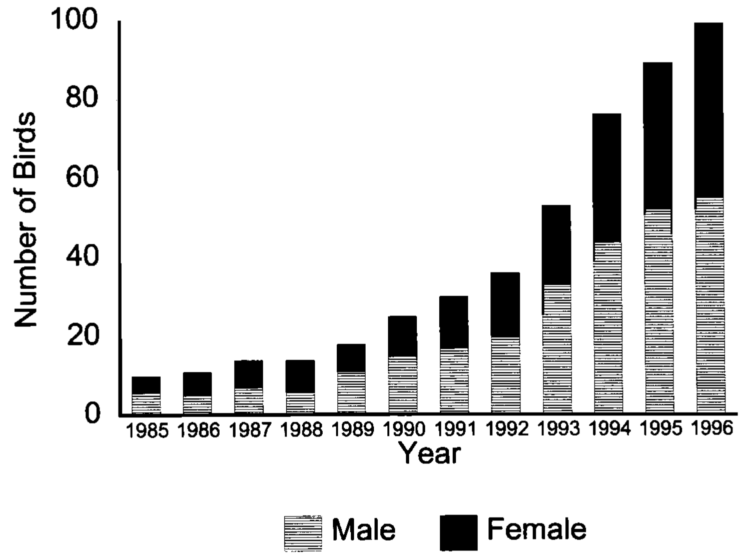

FIGURE 1. Sex ratio and population growth in response to intensive management of Red-cockaded Woodpeckers at the Savannah River Site, South Carolina (1985–1996; Franzreb 1997).

Fish and Wildlife Service aluminum leg band and with a unique color plastic leg band combination to allow individual identification in the field. Birds were banded either as nestlings, when first captured on the site, or when relocated to the site from elsewhere.

Group and cavity monitoring data indicate population status, reproductive success, spatial distribution, and group composition. Survivorship and mortality rates are determined during monthly observations of groups throughout the year. During the breeding season (April–July) monitoring efforts are intensified and each group is observed weekly. Red-cockaded Woodpeckers return each night to roost singly in cavities. By checking the last known nightly roost, the status of individual Red-cockaded Woodpeckers usually can be determined. Data are obtained routinely for each group on survival, sex ratio, number of helpers, number of active/inactive pairs, location of nests, identity of breeding adults, fledging dates, number and sex of fledglings, and reproductive success. These data have been instrumental in monitoring the status of the population and our management efforts.

From the late 1985 population level of four birds, the population at the SRS has grown to 21 active groups and a total of 99 individuals by the end of the breeding season in 1996 (Fig. 1). Of these 21 groups, there were 19 breeding pairs of which 16 were reproductively successful, producing 43 fledglings (Franzreb 1997).

For all years but 1988, the number of fledglings produced has increased every year and has varied from 3 to 43 (Fig. 2). Generally, male fledglings outnumber females; however, in 1988 all fledglings were female. From 1985–1996, the mean fledging success defined as the number of fledglings/successful nesting attempt, was 2.3. The low was 1.6 in 1991 (N = 8 nesting attempts) and the high was 3.0 in 1985 (N = 1 nesting attempt).

POPULATION VIABILITY ANALYSIS AND GENETIC CONSIDERATIONS

Haig et al. (1993) performed a series of population and pedigree analyzes on the birds on the SRS to determine the prospects for long-term population viability at the site. They used OGENES gene-drop pedigree analysis, a technique to measure genetic diversity in the current population relative to allelic diversity of its founders. Population viability, evaluated as the probability of persistence over the next 200 years, was estimated using VORTEX, a Monte Carlo simulation of demographic events. Using these procedures, Haig et al. (1993) concluded that during the next 200 years, the population has a 68–100% chance of extinction, with outcome depending on stochastic environmental events and the extent of inbreeding depression. By annually translocating at least three females and two males to the SRS from donor populations for a period of 10 years, the likelihood of survival of the population for the next 200 years is 96% (Haig et al. 1993). Based upon an assessment of genetic similarities of Red-cockaded Woodpecker populations, the Francis Marion

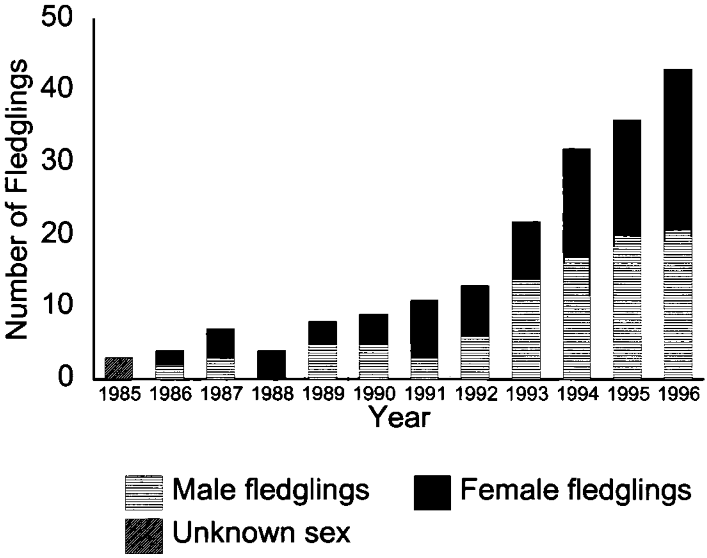

FIGURE 2. Number and sex ratio of Red-cockaded Woodpecker fledglings produced at the Savannah River Site, South Carolina (1985–1996; Franzreb 1997).

National Forest and Sandhills populations in South Carolina are genetically close to the birds at the SRS (Stangel et al. 1991). For this reason, and because both these populations are relatively large, Haig et al. (1993) recommended that these two areas serve as donor populations.

TRANSLOCATIONS AND THE EXPERIMENTAL USE OF A MOBILE AVIARY

In an effort to increase the population size and to increase the genetic diversity of the population, 54 Red-cockaded Woodpeckers were translocated from either off-site populations (N = 21) or within the Savannah River Site (N = 33) from 1986–1996 (Franzreb 1999). Birds were moved into clusters that had been provisioned with artificial cavity inserts if no vacant natural Red-cockaded Woodpecker cavities were available. The goal of these translocations was to provide a mate to an established breeding bird who had lost its partner, or to form a new pair in unoccupied territory. Allen et al. (1993) report on the results of the initial 16 translocations, and the outcome of all 54 translocations is summarized by Franzreb (1999). Success was defined subjectively as the bird remaining at the release site or close by for at least 30 days after being released. Thirty-one of 49 translocations (63.2%) involving subadult and adult Red-cockaded Woodpeckers were successful and 51.0% of the translocated birds have reproduced (Franzreb 1999). Of the 54 moves, five were of nestlings, resulting in one success.

In an effort to enhance the translocation success rate, we are testing a mobile aviary at the SRS. The aviary is approximately 5 m high and 5 m in diameter, and consists of a frame with shade cloth and hardware cloth on the outside. It is erected around a living pine tree that contains either a natural or artificial cavity. Birds are captured and transported to the release location at the SRS where they are maintained in the aviary for 10–14 days. It is hoped that during this time period, the bird will develop an affinity for the site and be more inclined to remain after it is released.

FORAGING BEHAVIOR

Providing a sufficient amount of quality foraging habitat is a requisite for the reproductive success and recovery of the Red-cockaded Woodpecker. To accomplish this requires an understanding and appreciation of the habitat characteristics that define suitable foraging habitat. Living pines were the overwhelmingly preferred foraging source for birds in Florida (Ligon 1968, 1970; Nesbitt et al. 1978, DeLotelle et al. 1983, Porter and Labisky 1986) , Louisiana (Morse 1972, Jones and Hunt 1996), South Carolina (Skorupa and McFarlane 1976, Skorupa 1979, Hooper and Lennartz 1981), Mississippi (Ramey 1980), Oklahoma (Wood 1977), Virginia (Miller 1978), and North Carolina (Repasky 1984). Red-cockaded Woodpeckers apparently prefer to forage on large trees (Skorupa 1979, Hooper and Lennartz 1981, DeLotelle et al. 1983). In an earlier foraging study of two groups of Red-cockaded Woodpeckers at the SRS, the birds foraged on trees with the largest diameters (58% utilization vs. 8% availability; Skorupa 1979).

Intersexual differences in foraging behavior have been observed for many woodpecker species, including the Red-cockaded Woodpecker. Most studies found that male Red-cockaded Woodpeckers tended to use the upper trunk area and limbs more than the females (Ligon 1968, Skorupa 1979, Repasky 1984, Hooper and Lennartz 1981; cf. Morse 1972). The mean foraging height was lower for females (8.7 m) than males (14.1 m) on the Francis Marion National Forest, South Carolina (Hooper and Lennartz 1981).

In 1992, a study was initiated at the SRS to assess foraging behavior in relation to quantified forest structural characteristics and to determine if there were any intersexual differences in foraging. The results will interface with the concurrent arthropod prey base research described below. Birds were followed throughout the day all months of the year over a 3-yr period. Observations were taken at 15-min intervals and included band identification number, sex, method (peck, probe, glean, etc.), substrate (trunk vs. limbs), location in relation to the trunk/crown, foraging height, tree height, tree species, diameter at breast height (dbh), and tree condition (alive vs. dead). Preliminary analysis of the 1992–1993 data indicates that male and female Red-cockaded Woodpeckers are segregating not by species of tree selected or by using trees of different heights, but mainly by foraging on different components of the same trees, with males using the upper strata of the tree trunks and limbs significantly more than females (K. E. Franzreb, unpubl. data). Such habitat partitioning provides a mechanism to use the available resources more efficiently, thereby, presumably enhancing survival and reproductive success. An analysis covering the entire 3-yr period is underway.

ARTHROPOD PREY BASE AND PREY USE BY THE RED-COCKADED WOODPECKER

The diet of the Red-cockaded Woodpecker is composed almost exclusively of arthropods. Red-cockaded Woodpeckers spend most of their foraging time capturing arthropods on live pine trees (Ligon 1968, Morse 1972, Wood 1977, Miller 1978, Nesbitt et al. 1978, Skorupa 1979, Ramey 1980, Hooper and Lennartz 1981, Patterson and Robertson 1981, DeLotelle et al. 1983, Repasky 1984, Porter and Labisky 1986).

To better provide for the foraging needs of this species, information is needed on the arthropod prey base and how the birds use it. Providing for the dietary requirements of the young as well as adult woodpeckers also is important. To determine the diet of nestling Red-cockaded Woodpeckers at the SRS, four nest cavities were monitored using automatic cameras and infrared tripping devices (Hanula and Franzreb 1995, Franzreb and Hanula 1995). In 65% of the 3,000 photographs of nest site visits by the adults, prey were identifiable and the majority (69.4%) were wood roaches (*Parcoblatta* spp.). Prey fed to the young were primarily a few common arthropods. Other common prey items were wood borer larvae (Cerambycidae or Buprestidae, 5.4%), Lepidoptera larvae (4.5%), spiders (Araneae, 3.6%), and ants (Formicidae, 3.1%; Hanula and Franzreb 1995).

Hooper (1996) examined the relationship of arthropod biomass on longleaf pine trees 22–127 yrs old in winter on the Francis Marion National Forest in the coastal plain of South Carolina. He found that total arthropod biomass for the entire tree increased with tree age up to 86 yrs and then declined as the tree aged further. Arthropod biomass on the bole declined with increasing tree age, but increased with tree age on the dead and live limbs for trees up to 80 yrs-old.

At the SRS, the diversity, abundance, and biomass of arthropods on 50–70 yr-old longleaf pine trunks was investigated to assess seasonal variability of prey and to determine if prey originated on the tree bole or moved there from elsewhere (Hanula and Franzreb 1998). Crawl, flight, and pitfall traps were monitored continuously for 12 months at the SRS. Results indicated that over 400 genera of arthropods were represented on the bark. In trees with barriers to arthropod movement up the tree, the arthropod biomass was reduced by 40–70%. Arthropod biomass was distributed relatively evenly along the tree bole and was highest in the fall of the year. Little of the arthropod biomass found on the trunk was comprised of organisms that resided exclusively in that area. Moreover, a large proportion of biomass on the trunk originated either in the soil/litter layer or was the result of a diverse fauna that flew onto the bark surface.

Hess and James (unpubl. ms cited in James et al. 1997) found that arboreal ants were the main component of adult Red-cockaded Woodpecker diets in the Apalachicola National Forest, Florida. James and co-workers (1997) hypothesized that fire may indirectly enhance the availability and quantity of ants because it influences how nutrients are cycled through the plant community, which is reflected in the ground cover composition. Hanula and Franzreb (1998) demonstrated that the arthropod prey base of the Red-cockaded Woodpecker that is found on the boles is an open system whereby arthropods move between the litter/soil layer and the tree boles. Therefore, it appears that an appropriate fire management schedule would control not just encroaching mid-story vegetation, but also would have a beneficial effect on the prey base.

As Red-cockaded Woodpeckers do not migrate, the availability of suitable prey throughout the year is important. Skorupa and McFarlane (1976) speculated that prey was readily available to the Red-cockaded Woodpecker at the SRS in the summer but was limited in winter. However, results of the extensive arthropod study conducted recently at the SRS described above suggest that Red-cockaded Woodpeckers do not experience periods of low arthropod availability on the bole portion of the trees (Hanula and Franzreb 1998). In fact, Hanula and Franzreb (1998) found that arthropod biomass was highest in the fall and winter.

To manage foraging habitat of the Red-cockaded Woodpecker effectively, it is essential to understand the habitat needs of the arthropods on the bark that constitute the major prey items for the woodpecker. Because arthropods now are known to move readily between the bark surface and the forest floor or understory vegetation, the habitat requirements of the prey species in these areas as well as on the bark surface should be considered in the interest of providing adequate Red-cockaded Woodpecker foraging habitat.

HOME RANGE

During a 5-month study in 1976–1977 of two groups of Red-cockaded Woodpeckers at the SRS, Skorupa (1979) found that territory size (the defended area) was smaller in the summer than winter, with a minimum size of 15.8 ha in the summer and 16.0 ha in the winter. Skorupa (1979) speculated that the younger forest at the SRS provides lower quality foraging habitat than older habitat available elsewhere and that the effects of habitat quality are significant in the winter. The mean home range size (defined as the area used by the group, but not necessarily defended) of the Red-cockaded Woodpecker is variable (129 ha in Florida, Porter and Labisky 1986; 70.3 ha in coastal South Carolina, Hooper et al. 1982; and 148.1 ha for Florida; DeLotelle et al. 1983). One must be cautious when comparing home range sizes obtained by different estimators as not all estimation techniques provide similar results.

Home ranges were delineated for 7 groups of Red-cockaded Woodpeckers at the SRS to determine size, configuration, and temporal (annual and seasonal) changes. Data were collected from May 1992 through May 1995 by following the birds and recording locations every 15 minutes using a Pathfinder Professional Global Positioning System unit. Locations were differentially corrected and interfaced with GIS using ARC/INFO (for details see Franzreb and Barnhill 1995). Preliminary home range analyses using the minimum convex polygon and bivariate normal ellipse home range estimators as described in the computer program HOME RANGE (Ackerman et al. 1990) indicate that home range sizes vary from 46.5 to 128.6 ha (K. E. Franzreb, unpubl. data). Selection of a home range estimator for each group was determined using the HOME RANGE program, which evaluates each data set to assess which, if any, of the included estimators are appropriate for a particular data set. In depth analysis of the home range data is underway.

INTEGRATION OF RED-COCKADED WOODPECKER RESEARCH AND MANAGEMENT ACTIVITIES

The Southern Research Station has been responsible for the monitoring, translocation, and overall research endeavor for the Red-cockaded Woodpecker at the SRS since 1985. As part of this effort, the research staff prepared reports on an annual basis that thoroughly summarized all Red-cockaded Woodpecker related activities that had been undertaken on the site that year, and provided a current estimate of the overall population size, sex ratio, number of active groups, number of southern flying squirrels removed, and information on reproduction and mortality. Throughout the years there have been numerous meetings held to address the status of the Red-cockaded Woodpecker on the site, discuss research findings, review the outcomes of ongoing management actions, and plan for future activities. This successful partnership is chronicled in Gaines and co-workers (1995).

In 1991–1992, when SRI staff prepared the management plan for the Red-cockaded Woodpecker on the site (G. D. Gaines, Savannah River Site Red-cockaded Woodpecker Management Plan, unpubl. report), research staff provided input into its development and extensive technical review. This management plan is in the process of being revised. The draft results of the foraging behavior and home range studies of the Red-cockaded Woodpecker on the site were provided to SRI for consideration in reformulating the management plan.

The U.S. Fish and Wildlife Service guidelines (USFWS 1989) for managing Red-cockaded Woodpeckers include providing foraging habitat within 800 m of an active Red-cockaded Woodpecker cluster that contains a minimum of 6,350 live pine stems with a dbh ≥ 25.4 cm and a pine basal area of at least 804 m^2. Anything less than this would require data to substantiate that the birds would not be adversely affected under Section 7 of the Endangered Species Act of 1973, as amended. SRI envisions using the foraging data that research has provided to propose including some of the live pine stems that are 20.3–24.4 cm dbh within 800 m of active clusters to meet the overall requirement of 6,350 live pine stems (J. Blake, pers. comm.). Moreover, the U.S. Fish and Wildlife Service is now working on revising the Red-cockaded Woodpecker Recovery Plan (USFWS 1985), and the guidelines for foraging may be modified pending the completion and approval of this plan.

Regardless of the outcome of the new recovery plan and possible modifications in the existing U.S. Fish and Wildlife Service guidelines, the foraging data, long-term reproductive and population data, and home range information obtained at the SRS will be instrumental in helping define a more appropriate conservation strategy for this species at the site. Moreover, the model described below relies on site-specific information in its development. Although some of this information, such as that on foraging ecology, home range size, and population dynamics, is available from elsewhere in the range, it is rare to find all these data from one site and obtained over such a prolonged period of time. Use of such information should strengthen the reliability of the model.

A GIS-BASED MODEL FOR RED-COCKADED WOODPECKER HABITAT AT THE SAVANNAH RIVER SITE

Our discussion to this point has focused on research designed either to understand Red-cockaded Woodpecker biology or to develop management options that can be used in a population recovery strategy. A major obstacle to the application of these research results is a lack of analytical tools to evaluate and to track over time the spatial interconnectedness of Red-cockaded Woodpecker recovery strategies, forest stand management actions (in the form of thinning and regeneration harvests), and forest growth dynamics. In response to this need, we initiated a research project designed to link Red-cockaded Woodpecker demographics and habitat needs with a spatially referenced model of forest structure. Forest structure is defined here as the within-stand, unit-area distribution of tree diameter classes based on measurements at breast height. Change in forest structure is modeled by tracking harvesting actions over time as to type, location, amounts removed, and/or residual densities, and by modeling the growth of the trees that remain.

A primary product of the research is a spatial simulator of forest structure that integrates existing and planned geographic databases, Red-cockaded Woodpecker demographics, and forecasting of forest growth. The simulator allows a resource manager to choose specific stands for thinning or clearcutting at given times over multi-year planning cycles and then simulate the effects on the Red-cockaded Woodpecker population. Alternatively, the resource manager may permit the simulator to select stands for thinning or clearcutting using target harvest volume goals, harvest decision rules (such as the residual basal area left in thinned stands), and constraints arising because of Red-cockaded Woodpecker needs. The simulator has the capacity to evaluate the interacting impacts of Red-cockaded Woodpecker habitat requirements and the harvesting of trees. This is accomplished by running the simulator in two modes. One mode specifies a given amount of harvesting activity, the level of which is set by a harvesting target, and then evaluates over time the maximum number of Red-cockaded Woodpecker foraging areas that the resulting forest structure can support. A second mode identifies a desired number of Red-cockaded Woodpecker breeding groups, and then simulates harvesting actions (over time) that will not compromise the Red-cockaded Woodpecker population goal.

CONCEPTUAL APPROACH USING SRS DATABASES

Present stand inventory data for the SRS consists of spatial information in the form of a GIS layer of stand boundaries, with associated data on the stand's forest type, age, and merchantability class (e.g., sapling, pole, mature, or saw timber). A major shortcoming of this data set is that it lacks complete information on productivity and stocking (the amount of basal area per unit-area). For example, many stands lack the basic measure of productivity (referred to as site index), only a few have basal area stocking estimates, and none have diameter distributions per unit area (our selected measure of forest structure).

The scope of the simulation is constrained to the pine and mixed pine-hardwood forest types on the SRS because this is where the harvesting activity occurs and where the Red-cockaded Woodpeckers nest and forage. Because the diameter distributions are the basic data needed to drive the forest growth simulation, we developed a way to generate unbiased estimates of tree diameter distributions ("tree lists") for each stand. To approximate the diameter distributions for the pine and mixed pine-hardwood forest types, we used an approach that approximates diameter distributions from a network of permanently located and periodically remeasured forest inventory plots established on the SRS land base. These data were obtained under contract by the Forest Inventory and Analysis (FIA) unit of the USDA Southern Research Station.

Approximately 800 inventory plots are distributed uniformly across the SRS land base. There are 2,225 stands within the area covered by the model. Therefore, even with this very dense set of inventory plots, not every one of the 2,225 stand polygons has an inventory plot associated with it. We developed the tree list assignments for each stand by relating the empirical diameter distributions from the permanent plots to the variables of forest type and stand age.

The estimated species-specific tree diameter list is used as input to a distance-independent, individual-tree growth simulator. Bolton and Meldahl (1990) used this kind of model form in developing SETWIGS for southern forest types using growth measurements from permanent-plot forest inventory data located throughout the South. Furthermore, SETWIGS has been incorporated into a growth model delivery system maintained by the USDA Forest Service called FVS (Forest Vegetation System). We decided to use FVS because it has a permanent technical support and development staff who provide help with fitting, maintaining, and/or modifying the models in the system.

Although the simulator is for pine dominated stands, may of these stands still have hardwood mid-stories that need to be included in the forest structure description because they can be present in significant enough quantities to negatively affect the suitability of the habitat for Red-cockaded Woodpecker nesting and foraging. Two data sources are being used to estimate the quantity and location of this mid-story component. One source is GIS-based orthoimagery (Sumerall and Lloyd 1995) developed from 1951 panchromatic aerial photography taken when the SRS was acquired by the Federal government. The value of these data lies in the spatial identification of two broad land use conditions (forested and agriculture) present at the time the area was purchased and replanted. It turns out that these two land use conditions are related to current mid-story structure differences. The quantity of hardwood mid-story is being estimated from the FIA permanent plot inventory data, and the location of the mid-story over the entire landscape is being determined using the orthoimage land use classification.

Since the model simulates a dynamic forest, the simulator needs a way to mimic change in the location and aerial extent of management and Red-cockaded Woodpecker usage areas. Mimicking change is accomplished by breaking the GIS-depicted land base into small, contiguous, hexagonally shaped land units (polygons). These land units are small enough to be relatively uniform as to topography and soil type, and when aggregated, are capable of accurately approximating the larger forest stand polygons from which they are derived. Spatial objects such as Red-cockaded Woodpecker foraging areas, stand boundaries, burned areas, and treatment locations (for examples, areas that have been thinned) are represented in GIS data bases as closed polygons. In the real world these boundaries are not static over time. For example, only a portion of a stand might be burned, or a Red-cockaded Woodpecker foraging area can change over time as the result of harvesting activity or from competition for foraging habitat needed by newly established Red-cockaded Woodpecker groups. Our approach to providing this dynamic quality to our simulator is to approximate stands by aggregating these small, hexagonal polygons. By modeling the effects of silvicultural activities and Red-cockaded Woodpecker usage, we gain the dynamic quality we seek. As we decrease the size of these small, uniform, hexagonal polygons, the accuracy of using contiguous aggregations to approximate stands, foraging areas, etc., increases. However, at the same time, computation time and data storage needs increase.

To determine the most appropriate size for the new, hexagonal units, we experimented using a number of possible cell sizes. We did this by overlaying grids of different cell sizes on the stand boundary GIS data layer. When any particular hexagonal polygon encompassed more than one stand, it was assigned the attributes of the stand with the most area within it. After testing a range of cell sizes, we selected a 3-ha unit. Only a few small, linearly shaped stands were lost in this conversion process. Our analysis suggested that a 3-ha sub-area was an appropriate compromise between computation time and minimizing the loss of stands in the conversion. We also chose to use a hexagonal polygon rather than the usual square shape implied by the normal grid process built into GIS software because all polygon center points are equally distant to their neighbors, and it allows the demographics model to simulate fledgling dispersal in six directions instead of only the four that would have been accommodated by a square polygon.

The bird dispersal model is not yet developed, but it will be probability-based and will use habitat information from the forest structure simulator to predict availability of Red-cockaded Woodpecker foraging areas. All foraging areas will be formed around "seed" cells that contain trees suitable for natural cavity construction or installation of artificial cavity inserts. New groups will be formed either by artificial cavity creation (with or without translocation of birds into the new nesting sites), or by natural dispersal from established breeding pairs into neighboring or distant areas using a probabilistic prediction. New foraging areas will be created by aggregating hexagonal cells into areas that meet minimum foraging requirements. Red-cockaded Woodpecker research on foraging requirements will be used to delimit foraging areas. Foraging area associated with a given group is changed by the model over time as the population grows and adjusts to the changing competition from nearby groups and the accumulated effects of timber harvesting.

A management scenario builder will be developed that either accepts user-supplied actions and translates policies and user-supplied goals (e.g., a fixed annual harvest target, burning targets, or artificial cavity installation rates) into year-by-year events occurring in specific stands. This module uses standards and guidelines that deal with the full array of management actions. It allows unconstrained implementation, that is, ignoring standards and guidelines, or constrained implementation. Priority can be given to either the harvesting goal or the Red-cockaded Woodpecker population goal. When the simulator selects stands for harvesting as opposed to user-selection, the scenario management builder will only harvest in compliance with guidelines.

SIGNIFICANCE OF THE SIMULATOR

Some elementary examples of applications can help illustrate the significance of this research. The resource manager can evaluate the effect of a user-supplied, time-sequenced set of harvesting actions on the Red-cockaded Woodpecker population expansion. In this case, the management scenario builder is instructed to give priority to the harvesting activities. A second example could use the same simulations to track effects of the harvesting plan on the total number of potential (as opposed to actual) nesting/roosting sites for the Red-cockaded Woodpecker over time. A third application example could switch the priority for actions from harvesting to establishment of new breeding groups at specific places. In this case, the potential nesting sites identified could be used to develop a time-sequenced plan of artificial cavity creation by identifying suitable locations for new nesting sites. Using the location of new groups as input, a follow-up simulation would allow only harvesting that does not compromise the location-specific Red-cockaded Woodpecker objective.

The general significance of this simulator is its value as a decision aid that uses spatial data as the vehicle for capturing the interconnected effects of multiple resource management actions on outputs from the same land base. It will more fully and effectively use the foraging behavior, home range, and population demographics research results for the Red-cockaded Woodpecker that have been developed for the SRS. The simulator has application potential beyond the SRS and provides a major step in developing decision tools that will evaluate more than the two resource goals considered here.

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STUDYING WILDLIFE AT LOCAL AND LANDSCAPE SCALES: BACHMAN'S SPARROWS AT THE SAVANNAH RIVER SITE

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Abstract. In the late 1980s and early 1990s, mutual research interests between land managers at the Savannah River Site and biologists at the University of Georgia resulted in a landscape-ecology study of the Bachman's Sparrow (*Aimophila aestivalis*). This species had been declining throughout its range for several decades and was considered a species of management concern by the U.S. Forest Service. The reasons for its decline were obscure, but the distribution of suitable habitat across complex landscapes was a possible factor. Thus the species seemed well suited for a pioneer study on landscape influences on avian population dynamics. A cooperative research program developed from these mutual interests, including quantifying the landscape and local habitat patterns shown by the sparrow, spatially explicit modeling of population response to landscape change, and demographic field studies of reproductive success, survivorship and dispersal. These studies are summarized, and the value of the research to both management and research interests is discussed.

Key Words: *Aimophila aestivalis,* Bachman's Sparrow, BACHMAP, demography, habitat distribution, landscape ecology, management impacts, spatially explicit modeling.

Ecologists, wildlife biologists, and land managers have seen the importance of expanding the spatial scale of research and land-use planning from the traditional focus on local, site-specific phenomena to those that operate over landscape scales (Haas 1995, Turner et al. 1995, Villard et al. 1995). Active land management is one anthropogenic force that changes the distribution and quality of habitat patches across large, complex areas (i.e., "landscapes"). Land managers are interested in how organisms and populations respond to landscape change, because such responses are critical to understand if managers are to consider how wildlife will be affected by regional land management. Ecologists, on the other hand, have expanded the spatial and temporal scales of population biology and community ecology to create the relatively new field of landscape ecology. The study of impacts of experimental changes in the distribution or quality of habitats across a landscape is often a desired goal of landscape studies. However, landscapes are difficult to manipulate experimentally for all but the smallest organisms (Forman and Godron 1986, Wiens and Milne 1989, Johnson et al. 1992). In managed landscapes, such changes occur regularly, are predictable (in fact, are planned well in advance), and are roughly replicated in space at scales that are normally hard to manipulate experimentally. Thus, the needs and interests of managers and basic ecologists coincide to make managed lands an excellent opportunity for studies in landscape ecology.

In 1988, when students and associates of Dr. H. Ronald Pulliam at the University of Georgia began studies of Bachman's Sparrows (*Aimophila aestivalis*) at the Savannah River Site (SRS), it quickly appeared that the species might be a good candidate for landscape-level studies. The sparrow was found in pine stands managed by the U.S. Forest Service for threatened and endangered species, native communities, and timber production. Timber management changed the within-stand characteristics of individual stands on a semi-annual basis, and therefore the locations of suitable habitat for a given species were temporally dynamic. Thus, the management strategy at SRS could potentially have a strong impact on species that occupy pine woodlands. Little was known locally about Bachman's Sparrow at the time our studies began; published reports even seemed to disagree about what habitat the species occupied and whether it was migratory or a permanent resident (Hardin and Probisco 1983). Most importantly, throughout its range Bachman's Sparrow was often described as being absent from seemingly suitable habitat (Nicholson 1976, Hall 1983). Our initial surveys (described below) indicated that the bird was often absent from stands that were isolated from other occupied habitat patches. This suggested to us that landscape effects could be important—"suitable" patches might be unoccupied if they were located in disjunct or unsuitable landscapes.

The Savannah River Natural Resources Management and Research Institute (SRI) was also interested in gaining more information about the sparrow because the species had declined throughout its range since the 1930s, and was absent from large portions of its former range (Brooks 1938, Haggerty 1988, Dunning 1993, Sauer et al. 1997). In the southeastern United States, Bachman's Sparrow was one of the highest ranking "species of management concern" for the U.S. Forest Service (a classification that includes species not on the official list of threatened and endangered species). The sparrow was classified as a "Category 2" species by the U.S. Fish and Wildlife Service (USFWS) in the 1980s. This ranking suggested that the species might warrant listing under the U.S. Endangered Species Act, but too little information existed to make such a determination. (The list of Category 2 species was eliminated by the USFWS in 1996, but the species formerly on the Category 2 list are still of management concern to the USFWS [Crystal 1997].)

Thus, our interest in Bachman's Sparrow as a study organism for landscape studies coincided with the SRI's need for better local information on how this species might be affected by timber management. We began a study of the sparrow's habitat use, both on a local and landscape scale, with funding from the Savannah River Ecology Laboratory (University of Georgia) and the SRI (U.S. Forest Service), with additional support in later years from the National Science Foundation and the U.S. Environmental Protection Agency. Studies ran from 1988–1997, with some continuing studies planned for the future.

Our work has included (1) local-scale habitat analysis; (2) landscape-scale analyses; (3) theoretical analyses linking spatially explicit population models to dynamic landscapes created by a geographic information system (GIS); and (4) demographic field studies in different habitats, emphasizing demographic variables found to be important in model simulations. In this paper, we briefly summarize these integrated studies, emphasizing the benefits we have seen from working in these rapidly changing landscapes.

LOCAL SCALE STUDIES

Bachman's Sparrow is associated with various age classes of pine forest throughout the southern portion of its range (Dunning 1993). In fact the subspecies found in South Carolina was long called the "Pine Woods Sparrow." But at the start of our study, it was not clear what kinds of pine woods were used. Some published sources described sparrow habitat as old-growth pine forest (Allaire and Fisher 1975, Meanley 1988), while other sources emphasized open habitat such as the edges of fields, old pastures and clearcuts (Burleigh 1958, Hardin et al. 1982, Hardin and Probisco 1983). Our initial study in 1988 therefore focused on the local-habitat characteristics that have been emphasized in traditional avian ecology: we surveyed sparrows across a spectrum of age classes and pine species to determine which habitats were occupied (Dunning and Watts 1990). We found that Bachman's Sparrows occupied the youngest (1–5 year old clearcuts) and oldest (open mature pine at least 80 years old) age classes, but not pine stands of intermediate age. The occupied age classes shared a suite of vegetation characteristics, including a relatively dense layer of grasses and forbs in the ground layer and few tall shrubs or understory trees (Dunning and Watts 1990).

We confirmed these local-habitat patterns by examining habitat occupancy in other South Carolina regions where management practices differed from those on the SRS. For the most part, the sparrows occupied stands whose ground vegetation had the same characteristics as occupied sites on the SRS. For instance, at the Francis Marion National Forest, near Charleston, South Carolina, sparrows were present in middle-aged (30–80 year old) pine forest, an age class that was not occupied at the SRS (Dunning and Watts 1990, 1991). At Francis Marion National Forest, middle-aged and mature pine stands are managed similarly and have the same vegetation characteristics.

In some regions, the density of suitable habitat patches was much lower than at either the SRS or the Francis Marion National Forest. In these regions, our ability to identify occupied sites by their vegetation characteristics was much poorer. For instance, at the Sumter National Forest in the Piedmont of South Carolina, most patches of clearcut habitat were scattered in small portions of National Forest land, which were themselves distributed over a matrix of privately owned farmland and forest. In spite of what appeared to be suitable vegetation in many of these clearcuts, few sparrows were found. For example, only 8 of 38 clearcuts surveyed in 1990 were occupied (Dunning et al. 1995a). This further suggested that sparrows might not occupy isolated clearcuts even if the local site characteristics were suitable.

LANDSCAPE-LEVEL STUDIES

During our initial 1988 surveys, sparrows were not present in all patches that appeared to contain suitable vegetation characteristics. A wider set of surveys in 1989 confirmed that many clearcut patches of suitable age and condition were not occupied in the western half of the SRS. We surveyed 50 stands from 1989–1991 to determine if landscape characteristics helped explain this pattern of sparrow occupancy (Fig. 1). The 50 sites were stratified by clearcut age (1–2 yr old versus 3–5 yr old) and landscape quality (study site close to [<0.6 km] or far from [>0.6 km] other suitable habitat). A complex pattern emerged suggesting landscape variables were important. Young clearcuts close to other suitable habitat supported significantly

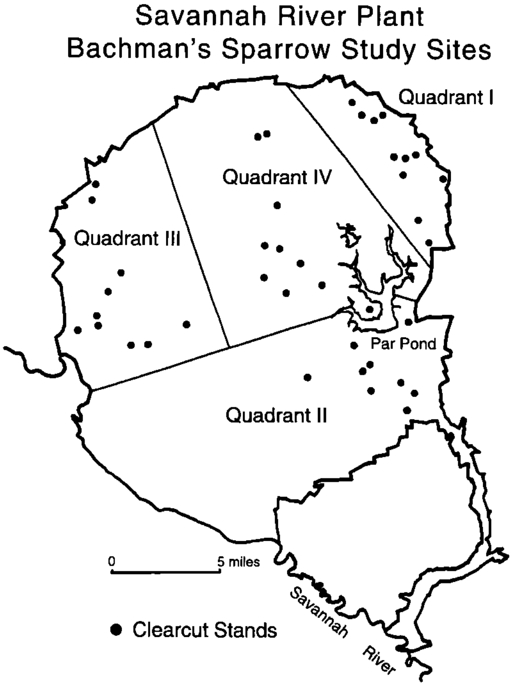

FIGURE 1. Locations of 1989 study sites on Savannah River Site. Grouping of study sites into four quadrants reflected differences in landscape characteristics among regions of the SRS.

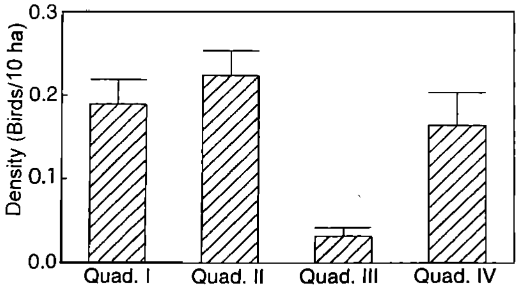

FIGURE 2. Effect of regional (quadrant) grouping of study sites on Bachman's Sparrow density in 1989. Density = number of singing male sparrows per 10 ha. Quadrants refer to regions numbered in Fig. 1. Error bars = 1 SE.

more sparrows than isolated clearcuts, and regions of the SRS dominated by older or more isolated clearcuts supported very few sparrows (Fig. 2). In particular, the western portion of the SRS had few sparrows in suitable habitat patches, which were mostly isolated, older clearcuts.

One factor that could account for decreased occupancy in isolated stands is poor dispersal ability by the sparrow. If sparrows did not disperse freely across unsuitable habitat, then the Forest Service policy of scattering clearcuts throughout the forest could create many landscapes where individual patches of suitable habitat are too distant from existing sparrow populations to be occupied readily. This problem would be exacerbated by the narrow time window during which most clearcuts were suitable. Due to rapid regrowth of planted pines on the SRS, many clearcuts had the open field characteristics that seemed most attractive to the sparrows for only 3–4 years post-planting. Thus, the sparrows may be dispersing across a landscape where suitable habitat exists only briefly and in unpredictable locations. This should put a premium on dispersal ability (Dunning and Watts 1990).

Unfortunately, Bachman's Sparrows proved difficult at first to catch, band, and follow in large numbers. Thus, documenting their dispersal ability directly was problematic, and we measured dispersal ability indirectly by monitoring the sparrow's colonization of patches of different isolation within small regions of the SRS (Dunning et al. 1995a). In these regions, we selected study sites that were different from one another in their degree of isolation. We hypothesized that if sparrows had poor dispersal ability, then newly available sites close to known sparrow populations should be occupied earlier and support larger populations than sites that were more isolated, but of the same age. We monitored sparrow occupancy in two regions that allowed this comparison from 1991–1993, and found strong support for the poor-dispersal hypothesis (Dunning et al. 1995a). Sparrows colonized the clearcuts closest to existing populations first. Most interestingly, the most isolated patches in one study region were never colonized during the 3–4 years in which their local (within-patch) characteristics appeared to be suitable. Thus, the hypothesis that patch isolation strongly affects sparrow distribution was supported (albeit indirectly). It should be noted that other bird species occupied all of the study sites in these regions, suggesting that the landscape was not as limiting to other species.

GIS/POPULATION MODELING

Although Bachman's Sparrows occupy both clearcuts and mature (>80 yr old) pine forest, the vast majority of the sparrow population on the SRS is found in clearcuts, primarily because mature forest is locally rare. Less than 200 ha (0.5%) of mature forest exists on the 770 km^2 SRS. For the most part, therefore, timber harvest by the U.S. Forest Service determines the landscapes in which the sparrows exist by creating clearcuts. Because an individual clearcut is suitable for only 3–8 years (most commonly 3–4 years during our study), regional landscapes change quickly. A portion of the SRS may lose most of its suitable habitat within 5 years if new clearcuts are not generated. This rapidly changing landscape is tailor-made for landscape ecology, since researchers can expect a population response to a specific landscape design within a short time period (e.g., Dunning et al. 1995a).

On a more practical level, the SRI was interested in how their management strategies affected the status of the sparrow within the SRS. The SRI adopted a new management plan for plant and animal populations in 1992 (SRFS 1992). This plan proposed many changes in forest management over a 50-year period, with the probable result of substantially changing forest structure during that period (Liu 1992, 1993). The SRI was interested in assessing how species of management interest such as the sparrow might respond to changes in landscape structure proposed in the management plan. Because the management plan covers a 50-year period, field experiments were not a practical way to answer this question. Instead, we developed a spatially explicit population model to simulate landscape change and sparrow population dynamics at the required spatial and temporal scales (Pulliam et al. 1992, Liu et al. 1995).

Spatially explicit models incorporate the exact spatial locations of objects of interest in the landscape (Dunning et al. 1995b). These objects can include individual organisms, populations, habitat patches, barriers to dispersal, and other relevant factors. In our spatially explicit population model, individual organisms were placed on a grid representing a specific landscape (Pulliam et al. 1992). The individuals gained habitat-specific demographic traits (reproductive success, survivorship, estimated from published literature sources) associated with the habitat patch in which they were located. Individuals moved across the landscape according to specific dispersal algorithms. The model we developed (called BACHMAP) followed individuals through an annual cycle of reproduction, mortality and dispersal, and then derived population characteristics such as population size or time to extinction by summing over all individuals. Population characteristics can be estimated annually during a simulation period, projected over an entire simulation, or averaged among replicate simulations (Liu 1993, Liu et al. 1995). Spatially explicit models are extremely data-intensive and subject to error if initialized or structured poorly (Conroy et al. 1995), but when used carefully, the models provide a means of examining possible population responses to long-term management over large spatial scales (Dunning et al. 1995b, Turner et al. 1995).

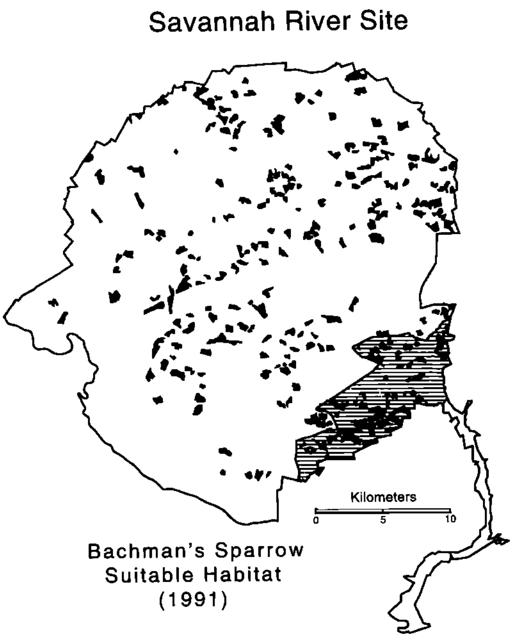

FIGURE 3. Locations of suitable patches of clearcut habitat (as defined by stand age) in 1991. Hatched area in lower right corner represents the SE corner region used in BACHMAP modeling.

We built a spatially explicit model by linking a sparrow population model to a landscape map of the southeast corner of the SRS (Fig. 3). The landscape map included about 6000 ha, and was created from the stand-and-compartment timber database maintained by the SRI (CISC database; see Hamel and Dunning *this volume*). The map of stands was digitized into ARC/INFO, and a grid of hexagons was overlaid onto the original map. Each hexagon cell represented 2.5 ha, which is the size of a Bachman's Sparrow territory (Haggerty 1988, Stober 1996), and, thus, could be occupied by a single reproductive female. Characteristics of the original stands were assigned to the associated hexagonal cells in the grid data layer. The result was a hexagon grid of cells whose habitat characteristics and spatial distributions were similar to the original landscape (Liu et al. 1995).

BACHMAP placed individuals on this landscape grid to match known patterns of habitat occupancy in 1989, and followed individuals and their progeny for 50 simulated years. At the start of each simulation year, the ages of habitat in all cells were increased by 1 yr, and management options were applied. For instance, under a 30-yr forest rotation, all 30-yr-old stands

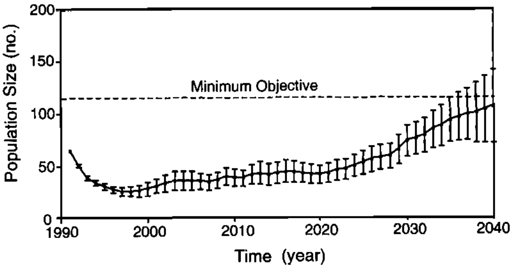

FIGURE 4. Typical BACHMAP population trajectory using forest management options outlined in SRFS (1992). Error bars = 1 SE. Adapted from Liu et al. (1995), reprinted by permission of Blackwell Science, Inc.

would be harvested, creating new clearcuts. Stands were selected for harvest based on the broad guidelines of the management plan (SRFS 1992). Dispersing sparrows settled in 1–5 yr old clearcuts and mature stands, and gained a habitat-specific reproductive success depending on the age of the stand in which they settled. For more details on the model structure and parameterization see Liu (1993).

Our simulations suggested that the population of Bachman's Sparrows in the southeastern region would decline sharply during the first decade of the 50-yr management plan, then eventually increase slowly (Fig. 4). The simulations suggested that the sparrow population would meet or exceed the Forest Service management goals for this species, but only during the final decade of the management plan. Liu et al. (1995) simulated several modifications of the plan to see how the management goals could be met more quickly. One such modification was to change management in the middle-aged stands (especially 40–80 yr stands) to provide the same ground-cover characteristics found in mature pine forest.

This suggestion from the simulations is being field tested by a pilot program adopted by the SRI in the early 1990s. To provide more habitat for the endangered Red-cockaded Woodpecker (*Picoides borealis*), which also uses older forest with the same vegetation structure associated with the sparrows, the SRI is thinning and burning middle-aged forest stands. These modified sites (referred to as "woodpecker recruitment stands") have the potential for providing more suitable habitat for the sparrow in middle-aged stands, as suggested by the sparrow model simulations and field studies (Gobris 1992, Liu et al. 1995, Wilson et al. 1995). In April 1997, a male Bachman's Sparrow was heard singing on territory in a woodpecker recruitment stand, two years after treatment (J. B. Dunning, pers. obs.); this particular stand had not been occupied by sparrows prior to modification. Demographic studies (see below) have also established that sparrows will occupy the woodpecker recruitment stands (Stober 1996, Christie 1997). If implemented throughout the SRS, our simulations suggest that the woodpecker recruitment program will provide enough habitat to stabilize the sparrow population and meet or exceed management goals through most of the 50-yr extent of the current plan (Liu et al. 1995).

DEMOGRAPHIC FIELD STUDIES

One of the important uses of spatially explicit population models is to identify the demographic variables that may have the greatest impact on populations in a given landscape (Dunning et al. 1995b). Once identified, field researchers can concentrate their field studies on the most important demographic and life history traits. Since there is never enough time, personnel, or money to study all possible aspects of a species of interest, field research will be most effective if focused on a limited number of critical variables likely to be affecting a population. Modeling can help identify these most critical variables through sensitivity analyses (Jørgensen 1986, Pulliam et al. 1992).

In sensitivity analyses, a series of simulations are run where input values for a single parameter in the model are varied within a predetermined range (i.e., a percentage of nominal values) while other model parameters are held constant. Output from the model is monitored to determine how sensitive model performance is to the nominal value used for the parameter under study. If the model output does not vary substantially despite large changes in input value, the model is said to be relatively insensitive to the nominal value used for that parameter. If small changes in the initial parameterization yield large changes in model output, then the model is relatively sensitive to that parameter. Care must be taken that accurate initial values be used for sensitive parameters, because parameterization errors may be magnified during model performance (Conroy et al. 1995). In the most complex sensitivity analyses, values for combinations of parameters can be varied in a factorial experimental design, to test for sensitivity to interaction effects between model parameters (see Pulliam et al. 1992).

Pulliam et al. (1992) and Liu et al. (1995) examined model sensitivity to reproductive success, survivorship, dispersal, and landscape characteristics. The BACHMAP model proved to be most sensitive to demographic traits, especially survivorship and reproductive success. In response to these results, we initiated field demographic studies in 1994 (Stober 1996, Christie 1997). While we had collected data on reproductive success and other demographic traits since the beginning of this project, this kind of data was extremely hard to gather in sufficient samples, because the sparrows are difficult to follow in the field, and nests are hard to find. Survivorship data are even scarcer, because the species is relatively difficult to capture, mark, and relocate (Dunning 1993). In the absence of local field data for these traits, we depended on published information (especially Haggerty 1986, 1988) for model parameterization.

Starting in 1994, David G. Krementz and colleagues initiated a series of studies on survival rates, reproductive rates, habitat use, and home-range size. Using an intensive mark-recapture study, they were able to capture many sparrows (~150 individuals). A subsample of these were marked with radio transmitters during the 1994–1997 breeding seasons. Sex-, habitat- (clearcut versus mature forest), and year-specific patterns in breeding-season survival rates were estimated. Comparisons of survival rates between sexes, habitats, or among years failed to reveal any significant differences. However, statistical power of these tests were low, ranging from 20–60%. Point estimates suggested habitat-specific differences for all factors.

Reproductive rates were comparable to those determined by Haggerty (1988, 1998) for Arkansas populations. Differences in daily nest-survival rates were determined for early- versus late-initiated nests, egg versus nestling periods, and between years (1995–1996; Stober 1996). All monitored females made multiple nesting attempts, and one female attempted to triple brood. Sparrows proved to be persistent nesters through a long breeding season (April–August).

Home ranges were estimated using radiotelemetry locations. Again, these estimates were comparable to those by Haggerty (1986, 1998) estimated from Arkansas. Home-range size was significantly larger in mature than in younger stands. We hypothesize that differences in food availability and abundance between forest age classes might cause these differences. Typical daily sparrow movements were restricted to a core area of ~1 ha within the home range. In most cases, all activities were confined to the home range, although we documented dispersal movements most often associated with failed nesting attempts. In addition, we documented large scale (>1 km) movements in response to prescribed summer burns. To the best of our knowledge, these dispersing individuals did not obtain mates during the remainder of the breeding season.

WHAT HAS BEEN GAINED?

The research has proven beneficial in a number of ways, spanning the information needs of both basic researchers and land managers. First, we have a better ecological understanding of a species that has undergone a dramatic population decline in the last 50 years, and which is of management concern in the southeastern United States. More fundamentally, the research program has explored how a species of apparently limited dispersal ability (compared to most passerines found in the same study sites) is affected by rapid landscape change. This knowledge has given us a better understanding of the importance of monitoring habitat change at different spatial scales, and a working system for studying landscape ecology with birds. Parts of the research program have profitably explored new techniques for studying small passerines, including miniaturized radio transmitters for the study of dispersal and demography, and spatially explicit models for population and landscape studies. Comparison of our demographic studies and published values from other parts of the species' range is an important part of validation of the BACHMAP model.

The research also yielded results that support the mission of the Savannah River Institute on the SRS. We believe our results give managers a better appreciation of how timber management affects target species, especially by modifying the landscape through which these birds disperse and breed. By linking our population model to the stand-and-compartment database that the SRI compiled for timber management purposes, we increased the value of SRI data and thus increased the value of their research and data collection programs. Finally, our research created new databases that can be used by other researchers within the SRI for other purposes. For example, the distributional and density data collected during field work has been used to parameterize a new set of bird/habitat models by U.S. Forest Service researchers (J. C. Kilgo, pers. comm.). Thus, this collaboration between researchers and the SRI has increased the value of the research done by both parties.

ACKNOWLEDGMENTS

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EFFECTS OF LONG-TERM FOREST MANAGEMENT ON A REGIONAL AVIFAUNA

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Abstract. We compared breeding bird populations on and off of the Savannah River Site (SRS), South Carolina, to determine whether management practices on SRS have affected abundance and composition of the resident avifauna. We assessed relative abundance by comparing Breeding Bird Survey (BBS) data from six routes off SRS with three surrogate routes generated using point-count data from four research projects on SRS. Total number of species per route did not differ on- and off-site. Total number of birds per route was greater off SRS than on. Twenty-three species were more abundant on than off SRS, and 33 species were more abundant off than on SRS. Species more abundant off SRS primarily were those that prefer agricultural or urban habitats, whereas those more abundant on SRS primarily prefer mature forest habitat. We conclude that management practices on SRS have resulted in a landscape that supports many species not otherwise common in the region.

Key Words: Breeding Bird Survey, forest management, landscape effects, point counts, Savannah River Site, South Carolina.

The Savannah River Site (SRS) is a 78,891-ha tract in Aiken, Barnwell, and Allendale counties in the upper coastal plain of South Carolina. Prior to acquisition by the U.S. Department of Energy in the early 1950s, the land was largely in agricultural production. Subsequent to acquisition, open areas were reforested by plantings and natural succession (White and Gaines *this volume*). Forest resources currently are managed by the U.S. Forest Service (USFS) for timber production and wildlife habitat needs (see White and Gaines *this volume* for more detailed discussion of SRS management). Approximately 89% of SRS is in closed canopy forest, primarily managed pine (loblolly, longleaf, and slash; see Table 1 for scientific names) and bottomland hardwood (Table 1). In contrast, only 62% of the southern portion of South Carolina's coastal plain is forested, whereas 23% is in agriculture and 9% is urban (Tansey and Hutchins 1988). Thus, the degree of forest cover, and therefore overall landscape structure, differs considerably between SRS and the surrounding lands. We compared breeding bird populations on and off of SRS to determine whether management practices on SRS have affected abundance and composition of the resident avifauna. If those practices have not affected bird populations, off-site monitoring programs should be sufficient to track populations on-site. However, if SRS management practices have affected bird populations, on-site monitoring also may be necessary.

METHODS

The North American Breeding Bird Survey (BBS) is the most comprehensive bird census database available for nearby off-site areas. The BBS, a program of the Biological Resources Division of the U.S. Geological Survey, uses volunteer labor to survey permanently established routes once per year during the breeding season in early June (Robbins et al. 1986). An observer drives a 39.4-km route (24.5 mi), stopping every 0.8 km (0.5 mi) for a total of 50 stops. At each stop, all birds detected within 0.4 km (0.25 mi) of the observer during a 3-min count are recorded. Surveys begin at 0.5 h before official sunrise and are conducted only during acceptable weather (good visibility, little or no precipitation, and no more than light winds). We used data from the six BBS routes that at least partially fell within 80 km of the SRS boundary and were in the same physiographic province; three were in Georgia and three were in South Carolina.

No BBS routes existed on SRS. Therefore, we used point-count census data from four recent studies conducted on SRS (Kilgo 1996, Buffington et al. 1997; K. E. Franzreb, unpubl. data; S. A. Gauthreaux, Jr., unpubl. data) to generate three surrogate "BBS" routes. Although objectives and habitat types sampled in each study differed, all used standard point-count methodology (Ralph et al. 1995). Sampling occurred between 5 May and 25 June. Counts were conducted from sunrise to 3.5 h post-sunrise. For this reason, night birds were less likely to be detected on point counts than on BBS routes, which began at 30 min before sunrise. Therefore, we eliminated the goatsuckers (Common Nighthawk, *Chordeiles minor,* Chuck-will's-widow, *Caprimulgus carolinensis,* and Whip-poor-will, *C. vociferus*) and the Barred Owl (*Strix varia*) from analysis (no Eastern Screech-Owls, *Otus asio,* were recorded). All birds detected from a point were recorded in distance intervals of <50 and >50 m. Birds flying over the point were recorded separately by Franzreb (unpubl. data) and Gauthreaux (unpubl. data) but were not recorded by Kilgo (1996) or Buffington et al. (1997). Consequently, birds such as crows and vultures, most commonly recorded when flying over a point, may be slightly underrepresented in the SRS data. Buffington et al. (1997) and Kilgo (1996) conducted 5-min point counts, subdivided into intervals of 1–3 min and 4–5 min, whereas Franzreb (unpubl. data) and Gauthreaux (unpubl. data) conducted 10-min counts, subdivided

TABLE 1. HABITAT TYPES ON THE SAVANNAH RIVER SITE AND THE U.S. FOREST SERVICE CODES FROM WHICH THEY WERE DERIVED

Habitat type	USFS forest type code	Code description
Longleaf pine	21	Longleaf pine (*Pinus palustrus*)
Loblolly-slash pine	22	Slash pine (*P. elliottii*)
	31	Loblolly pine (*P. taeda*)
	32	Shortleaf pine (*P. echinata*)
	34	Sand pine (*P. clausa*)
	35	Eastern red cedar (*Juniperus virginianus*)
Pine-hardwood	12	Shortleaf pine-oak (*Quercus* spp.)
	13	Loblolly pine-hardwood
	14	Slash pine-hardwood
	26	Longleaf pine-hardwood
	44	Southern red oak (*Q falcata*)-yellow pine (*P.* spp.)
	46	Bottomland hardwood-yellow pine
	47	White oak (*Q. alba*)-black oak (*Q velutina*)-yellow pine
Upland hardwood	53	White oak-red oak (*Quercus* spp.)-hickory (*Carya* spp.)
	56	Yellow poplar (*Liriodendron tulipifera*)-white oak-red oak
	57	Scrub oak (*Quercus* spp.)
	82	Black walnut (*Juglans nigra*)
Bottomland hardwood	58	Sweet gum (*Liquidambar styraciflua*)-yellow poplar
	61	Swamp chestnut oak (*Q. michauxii*)-cherrybark oak (*Q.f.* var. *pagodaefolia*)
	62	Sweet gum-Nuttall oak (*Q. nuttallii*)-willow (*Salix* spp.)
	63	Sugarberry (*Celtis laevigata*)-American elm (*Ulmus americana*)-green ash (*Fraxinus pennsylvanica*)
	64	Laurel oak (*Q. laurifolia*)-willow oak (*Q. phellos*)
	67	Bald cypress (*Taxodium distichum*)-water tupelo (*Nyssa aquatica*)
	68	Sweet bay (*Magnolia virginiana*)-swamp tupelo (*N.s.* var. *biflora*)-red maple (*Acer rubrum*)
	72	River birch (*Betula nigra*)-sycamore (*Platanus occidentalis*)

into intervals of 1–3, 4–5, and 6–10 min. We included all birds detected from each point, regardless of distance, during the first 3-min period. No point counts were conducted along roadsides.

Although some studies sampled multiple points per stand, we randomly selected only one point from each stand. Buffington et al. (1997) sampled one stand in each of three successional stages of bottomland hardwood forests during 1994. Kilgo (1996) sampled 20 upland hardwood sawtimber stands, 20 pine sawtimber stands, and 20 bottomland hardwood sawtimber stands, all during 1994. Franzreb (unpubl. data) sampled all stands within Red-cockaded Woodpecker (see Table 3 for scientific names) buffer zones (N = 86 points) during 1995. Gauthreaux (unpubl. data) sampled 75 points during 1994–95 that were established by the USFS Forest Inventory and Analysis program using an approximately 1,000 × 2,000-m grid overlaid on the site. Thus, 224 stands of all major forest types and ages occurring on SRS were sampled.

We classified habitats on SRS using the USFS Continuous Inventory of Stand Condition (CISC) database, which contains information on the entire land base of SRS, by stand. This information includes forest type, according to USFS codes, and age of each forest stand. We condensed the USFS forest types into five habitat types: (1) longleaf pine forest; (2) loblolly and/or slash pine forest; which also included insignificant acreages of shortleaf pine and Eastern redcedar; (3) mixed pine-hardwood forest; (4) upland hardwood forest; and (5) bottomland hardwood forest (Table 1). Six percent of the area of SRS was classified as nonforested. Nonforested areas, which included industrial facilities, rights-of-way, and bodies of water, were excluded from consideration in determining proportional area of habitats on site because no census data were available for those habitats. For this reason, we eliminated wetland birds (waterfowl, wading birds, and kingfishers) from the analysis. We used stand age to subdivide the six types into four successional stages similar to the procedure developed by USFS Region 8 biologists for use in the BIRDHAB GIS program, which is based on Hamel (1992). These types were regeneration (0–2 yr), seedling/sapling (3–9 yr), pole timber (10–30 yr), and sawtimber (>30 yr). We included with the regeneration stage the small amount of acreage classified as grass (USFS forest type 96) and brush (USFS forest type 99). Thus, 20 habitats were delineated: four successional stages of five habitat types.

We selected 50 point counts from SRS databases for each surrogate BBS route. To produce routes representative of habitat conditions occurring on SRS, we used the proportional area of each habitat type on site as the expected proportion of the routes (i.e., 50 points) that each habitat type should occupy. We used a random number generator to determine number of points expected in each habitat type for each route if 50 points were randomly located on SRS based on the expected proportions (Table 2). This approach simulated the expected composition of a randomly placed 39.4-km section of road (or BBS route) on SRS. We randomly selected from the datasets the number of point counts needed for each habitat type. When an insufficient number of point counts were available for a habitat type, we substituted point counts from the most similar habitat type with excess points. For example, three point counts from longleaf pine regeneration stands were substituted for three point counts from loblolly pine regeneration stands, because the bird communities of these types did not differ (J. B. Dunning, unpubl. data).

We compared the total number of individuals of each species counted per route (i.e., summed over the

TABLE 2. NUMBER OF POINT COUNTS WITHIN EACH HABITAT TYPE ON THE SAVANNAH RIVER SITE USED TO GENERATE THREE "BREEDING BIRD SURVEY" ROUTES

Forest type	Successional stage	Area (ha)	Percent	Number of points		
				Rt 1	Rt 2	Rt 3
Longleaf pine	Regeneration	858	1.1	2	0	1
	Seedling/Sapling	4,364	5.8	2	2	1
	Poletimber	2,070	2.7	3	0	1
	Sawtimber	9,235	12.4	8	4	6
Loblolly/slash pine	Regeneration	2,788	3.7	2	3	2
	Seedling/Sapling	7,962	10.6	3	7	8
	Poletimber	5,781	7.7	2	2	3
	Sawtimber	20,315	27.2	15	12	18
Pine-hardwood	Regeneration	0	0.0	0	0	0
	Seedling/Sapling	189	0.2	0	1	0
	Poletimber	289	0.4	0	0	0
	Sawtimber	2,105	2.8	3	2	0
Upland hardwood	Regeneration	0	0.0	0	0	0
	Seedling/Sapling	55	0.1	0	0	0
	Poletimber	724	1.0	0	0	2
	Sawtimber	1,740	2.3	0	1	2
Bottomland hardwood	Regeneration	126	0.2	0	0	0
	Seedling/Sapling	1,675	2.2	1	2	0
	Poletimber	2,615	3.4	0	2	0
	Sawtimber	11,877	15.9	9	12	6
Total		74,768	100.7	50	50	50

50 stops or points) between the SRS routes and the BBS routes using two-sample t-tests. We tested the assumption of equal variances using the F-test for equality of variance. When this test indicated that variances were not equal ($P < 0.05$), we used unequal variance t-tests. We felt justified in comparing BBS data (i.e., roadside counts) with point count data (i.e., off-road counts) because the detection of forest species is similar between roadside and off-road counts (Keller and Fuller 1995). Small roadside openings apparently are not avoided by area-sensitive birds (Keller and Fuller 1995).

A potential bias inherent in our approach may exist because habitat conditions along the BBS routes might not have represented those in the region. For example, if more forested habitat existed in the region than occurred within the detection distance from roads, forest interior species would be under-represented and edge species would be over-represented on the BBS routes. However, if the habitat conditions along the BBS routes did not differ from overall habitat conditions in the off-site areas (i.e., on- and off-road), an accurate assessment of birds occurring off-site was achieved by the BBS methodology.

To address that potential bias, we used satellite imagery and a Geographic Information System to compare the landscape composition of areas surrounding the BBS routes. Habitat-classified data (LANDSAT Multi Spectral Scanner, 80 × 80 m pixels) were available for portions ($\bar{x}$ = 82.4% coverage) of the three routes in east-central Georgia. Five cover types were defined from the data: open water, pine forest, hardwood forest, scrub forest (including turkey oak, successional [5–15 yr old], and residential open forests), and open habitats (including bare soil, row crop agriculture, and herbaceous fallow fields and pastures). We superimposed buffer strips of two widths (140 m [Bart et al. 1995] and 1 km) along the portions of the routes covered by the satellite image and tallied the total number of cells of each type that fell within or were intersected by the strips. We calculated percent composition by type for each route and averaged over the three routes.

RESULTS

Eighty species that were detected among the six BBS routes in Georgia and South Carolina and the three constructed routes on SRS were included in analysis. Total number of species per route did not differ ($t = 0.84$, $P = 0.21$) on ($\bar{x} = 53.0$, SE = 1.9) and off SRS ($\bar{x} = 55.5$, SE = 1.7). Eight species were detected on SRS that were not detected off SRS, whereas 20 species were detected off SRS that were not detected on SRS (Table 3).

Total number of birds per route was greater ($t = 3.77$, $P = 0.004$) off SRS ($\bar{x} = 661.2$, SE = 50.6) than on SRS ($\bar{x} = 372.0$, SE = 31.2). Including species that were detected only on SRS, 17 species were more abundant on SRS than off ($P < 0.05$; Table 3). Including those detected only off SRS, 32 species were more abundant off SRS than on ($P < 0.05$; Table 3). Thirty-one species did not differ in abundance ($P > 0.05$) on and off SRS.

Distribution of habitat types near (within 140 m) the three BBS routes in Georgia generally was similar to that in the larger landscape (within 1 km of BBS routes; Table 4). Forested types

TABLE 3. COMPARISON OF BIRD ABUNDANCE (MEAN ± SE) ON THE SAVANNAH RIVER SITE (SRS) AS INDEXED USING THREE "BREEDING BIRD SURVEY" (BBS) ROUTES GENERATED FROM POINT COUNT DATA, WITH BIRD ABUNDANCE OFF THE SRS, AS INDEXED USING SIX ACTUAL BBS ROUTES

	Abundance[a]		
Species	On SRS	Off SRS	t-test (P)
Species detected only on SRS			
Wild Turkey (*Meleagris gallopavo*)	2.0 ± 0.6	0.0 ± 0.0	0.074[b]
Ruby-throated Hummingbird (*Archilochus colubris*)	0.7 ± 0.3	0.0 ± 0.0	0.184[b]
Red-cockaded Woodpecker (*Picoides borealis*)	2.0 ± 1.0	0.0 ± 0.0	0.184[b]
White-breasted Nuthatch (*Sitta carolinensis*)	0.3 ± 0.3	0.0 ± 0.0	0.423[b]
American Redstart (*Setophaga ruticilla*)	1.3 ± 0.7	0.0 ± 0.0	0.184[b]
Ovenbird (*Seiurus aurocapillus*)	1.7 ± 0.3	0.0 ± 0.0	0.038[b]
Louisiana Waterthrush (*Seiurus motacilla*)	1.7 ± 0.3	0.0 ± 0.0	0.038[b]
Hooded Warbler (*Wilsonia citrina*)	7.0 ± 1.5	0.0 ± 0.0	0.045[b]
Species more abundant on SRS			
Pileated Woodpecker (*Dryocopus pileatus*)	6.0 ± 0.6	1.2 ± 0.3	0.000
Tufted Titmouse (*Baeolophus bicolor*)	24.7 ± 5.8	9.5 ± 1.6	0.011
Brown-headed Nuthatch (*Sitta pusilla*)	5.3 ± 1.9	1.2 ± 0.7	0.031
Yellow-throated Vireo (*Vireo flavifrons*)	1.3 ± 0.3	0.2 ± 0.2	0.009
Red-eyed Vireo (*Vireo olivaceus*)	7.7 ± 1.7	2.0 ± 0.7	0.008
Northern Parula (*Parula americana*)	8.7 ± 1.2	2.0 ± 0.8	0.002
Pine Warbler (*Dendroica pinus*)	27.3 ± 5.9	8.0 ± 2.3	0.007
Prairie Warbler (*Dendroica discolor*)	4.7 ± 0.3	0.5 ± 0.2	0.000
Kentucky Warbler (*Oporornis formosus*)	1.7 ± 0.3	0.3 ± 0.2	0.010
Species detected only off SRS			
Turkey Vulture (*Cathartes aura*)	0.0 ± 0.0	4.2 ± 1.6	0.050[b]
Mississippi Kite (*Ictinia mississippiensis*)	0.0 ± 0.0	0.2 ± 0.2	0.363[b]
Killdeer (*Charadrius vociferus*)	0.0 ± 0.0	3.0 ± 1.1	0.058[b]
Rock Dove (*Columba livia*)	0.0 ± 0.0	1.8 ± 1.5	0.278[b]
Chimney Swift(*Chaetura pelagica*)	0.0 ± 0.0	11.2 ± 3.2	0.017[b]
Eastern Phoebe (*Sayornis phoebe*)	0.0 ± 0.0	0.7 ± 0.5	0.235[b]
Horned Lark (*Eremophila alpestris*)	0.0 ± 0.0	0.8 ± 0.8	0.363[b]
Purple Martin (*Progne subis*)	0.0 ± 0.0	19.3 ± 8.7	0.077[b]
Rough-winged Swallow (*Stelgidopteryx serripennis*)	0.0 ± 0.0	0.2 ± 0.2	0.363[b]
Barn Swallow (*Hirundo rustica*)	0.0 ± 0.0	5.7 ± 2.4	0.065[b]
American Robin (*Turdus migratorius*)	0.0 ± 0.0	2.8 ± 0.9	0.030[b]
Gray Catbird (*Dumetella carolinensis*)	0.0 ± 0.0	2.5 ± 0.9	0.037[b]
Loggerhead Shrike (*Lanius ludovicianus*)	0.0 ± 0.0	2.7 ± 0.6	0.007[b]
European Starling (*Sturnus vulgaris*)	0.0 ± 0.0	12.7 ± 6.6	0.115[b]
Yellow-throated Warbler (*Dendroica dominica*)	0.0 ± 0.0	1.0 ± 0.6	0.175[b]
Eastern Meadowlark (*Sturnella magna*)	0.0 ± 0.0	7.0 ± 2.6	0.044[b]
Boat-tailed Grackle (*Quiscalus major*)	0.0 ± 0.0	0.2 ± 0.2	0.363[b]
Common Grackle (*Quiscalus quiscula*)	0.0 ± 0.0	44.8 ± 15.8	0.036[b]
House Finch (*Carpodacus mexicanus*)	0.0 ± 0.0	1.3 ± 0.6	0.082[b]
House Sparrow (*Passer domesticus*)	0.0 ± 0.0	12.8 ± 7.0	0.126[b]
Species more abundant off SRS			
Northern Bobwhite (*Colinus virginianus*)	5.7 ± 0.7	24.7 ± 3.6	0.003[b]
Mourning Dove (*Zenaida macroura*)	15.0 ± 4.0	66.0 ± 7.1	0.002
Eastern Kingbird (*Tyrannus tyrannus*)	1.3 ± 1.3	14.7 ± 1.4	0.001
Blue Jay (*Cyanocitta cristata*)	10.3 ± 1.8	30.3 ± 3.7	0.009
Northern Mockingbird (*Mimus polyglottos*)	1.0 ± 1.0	44.0 ± 9.6	0.007[b]
Brown Thrasher (*Toxostoma rufum*)	1.0 ± 0.0	9.8 ± 2.9	0.030
Northern Cardinal (*Cardinalis cardinalis*)	14.0 ± 4.5	47.5 ± 4.7	0.003
Indigo Bunting (*Passerina cyanea*)	9.3 ± 1.8	18.7 ± 1.8	0.014
Blue Grosbeak (*Guiraca caerulea*)	3.3 ± 1.2	14.5 ± 2.0	0.008
Red-winged Blackbird (*Agelaius phoeniceus*)	0.7 ± 0.7	14.2 ± 4.6	0.031[b]
Brown-headed Cowbird (*Molothrus ater*)	1.3 ± 0.3	8.1 ± 1.7	0.009[b]
Orchard oriole (*Icterus spurius*)	0.3 ± 0.3	11.8 ± 2.7	0.008[b]
Species for which abundance did not differ on and off SRS			
Black Vulture (*Coragyps atratus*)	0.7 ± 0.7	7.3 ± 3.5	0.117
Red-shouldered Hawk (*Buteo lineatus*)	1.3 ± 0.7	0.8 ± 0.5	0.598
Red-tailed Hawk (*Buteo jamaicensis*)	0.3 ± 0.3	0.8 ± 0.3	0.351
Common Ground-Dove (*Columbina passerina*)	0.3 ± 0.3	2.2 ± 1.4	0.411

TABLE 3. CONTINUED

Species	Abundance[a] On SRS	Abundance[a] Off SRS	t-test (P)
Yellow-billed Cuckoo (*Coccyzus americanus*)	3.3 ± 0.3	2.7 ± 0.9	0.640
Red-headed Woodpecker (*Melanerpes erythrocephalus*)	6.7 ± 2.3	1.0 ± 0.5	0.133[b]
Red-bellied Woodpecker (*Melanerpes carolinus*)	15.0 ± 1.5	15.5 ± 2.4	0.894
Downy Woodpecker (*Picoides pubescens*)	2.3 ± 0.7	4.2 ± 0.9	0.247
Northern Flicker (*Colaptes auratus*)	3.0 ± 1.5	0.8 ± 0.5	0.119
Eastern Wood-Pewee (*Contopus virens*)	7.7 ± 1.8	3.8 ± 0.9	0.066
Acadian Flycatcher (*Empidonax virescens*)	6.7 ± 1.5	1.5 ± 0.3	0.067[b]
Great Crested Flycatcher (*Myiarchus crinitus*)	23.0 ± 4.0	6.5 ± 1.0	0.051[b]
Fish Crow (*Corvus ossifragus*)	3.0 ± 1.5	15.0 ± 8.7	0.228[b]
Carolina Chickadee (*Poecile carolinensis*)	9.0 ± 1.0	6.8 ± 1.3	0.318
Carolina Wren (*Thryothorus ludovicianus*)	17.7 ± 1.9	18.8 ± 5.5	0.890
Blue-gray Gnatcatcher (*Polioptila caerulea*)	7.3 ± 0.9	3.8 ± 1.1	0.076
Eastern Bluebird (*Sialia sialis*)	3.3 ± 1.2	4.7 ± 1.1	0.486
Wood Thrush (*Hylocichla mustelina*)	4.3 ± 0.9	4.0 ± 1.3	0.873
White-eyed Vireo (*Vireo griseus*)	7.3 ± 3.0	4.7 ± 1.0	0.471
Black-and-white Warbler (*Mniotilta varia*)	1.0 ± 0.6	0.2 ± 0.2	0.106
Prothonotary Warbler (*Protonotaria citrea*)	0.6 ± 0.3	1.8 ± 0.9	0.398
Swainson's Warbler (*Limnothlypis swainsonii*)	0.3 ± 0.3	0.2 ± 0.2	0.626
Common Yellowthroat (*Geothlypis trichas*)	3.7 ± 1.2	2.2 ± 0.5	0.222
Yellow-breasted Chat (*Icteria virens*)	2.0 ± 2.0	4.7 ± 2.0	0.435
Summer Tanager (*Piranga rubra*)	12.0 ± 2.0	7.2 ± 1.4	0.084
Painted Bunting (*Passerina ciris*)	0.3 ± 0.3	1.8 ± 0.8	0.244
Eastern Towhee (*Pipilo erythrophthalmus*)	14.0 ± 4.7	25.3 ± 3.3	0.090
Bachman's Sparrow (*Aimophila aestivalis*)	5.0 ± 1.5	0.3 ± 0.3	0.089[b]
Chipping Sparrow (*Spizella passerina*)	2.3 ± 0.3	1.0 ± 0.7	0.234
Field Sparrow (*Spizella pusilla*)	1.7 ± 0.9	5.8 ± 1.7	0.147
American Goldfinch (*Carduelis tristis*)	0.7 ± 0.3	0.7 ± 0.5	1.000

[a] Expressed as number of individuals detected per route.
[b] Unequal variance t-test.

(pine and hardwood) accounted for a slightly greater proportion of the area within 1 km (36.4%) than within 140 m (32.5%) of the routes. Conversely, open habitats accounted for a slightly greater proportion of the area within 140 m (58.6%) than within 1 km (55.3%).

DISCUSSION

The relative abundance of birds in the region surrounding SRS was nearly twice that of birds on SRS. The most probable explanation for the greater abundance of birds detected off SRS is that a greater diversity of land use practices, including agriculture and urban/suburban development, was present off-site. Areas under these land uses provided habitat for more species. For example, Killdeer, Horned Lark, Eastern Meadowlark, Eastern Kingbird, Blue Grosbeak, and Brown-headed Cowbird commonly are associated with field, pasture, or edge habitats, and Rock Dove, Chimney Swift, Purple Martin, House Finch, and House Sparrow commonly are associated with urban or residential habitats. Developed areas were present on SRS that were not sampled, and these areas supported populations of urban birds; all of the above-mentioned species have been documented to occur on SRS (Mayer and Wike 1997). Developed areas comprised <5% of the area of SRS, so their impact on abundance comparisons likely would have been minimal had we data to include them in analysis. However, inclusion of these areas may have impacted the species richness estimates for SRS, and the number of species detected only off SRS may have been reduced considerably. Additionally, J. B. Dunning (unpubl. data),

TABLE 4. COMPARISON OF RELATIVE DISTRIBUTION (% COMPOSITION) OF HABITAT TYPES NEAR (WITHIN 140 M) THREE BREEDING BIRD SURVEY ROUTES WITH THAT IN THE BROADER LANDSCAPE (WITHIN 1000 M OF THE ROUTES) IN EAST-CENTRAL GEORGIA

Cover type	Distance from road 140 m	Distance from road 1,000 m
Open water	0.6	0.8
Pine forest	6.4	7.6
Hardwood forest	26.1	28.8
Scrub forest[a]	8.2	7.6
Open ground[b]	58.6	55.3

[a] Includes turkey oak (*Quercus laevis*), successional, and residential open forest.
[b] Includes bare soil, row crop agriculture, herbaceous fallow field, and herbaceous pasture.

working in forest regeneration stands on SRS, documented the presence of several species reported herein as occurring only off SRS. These species, present but only locally common or uncommon on SRS, included Mississippi Kite, Rough-winged Swallow, Barn Swallow, Gray Catbird, Loggerhead Shrike, and Common Grackle, in addition to some of the urban birds mentioned above. As with any sampling methodology, species were missed. For this reason, Table 3 should not be viewed as a comprehensive list with regard to SRS birds, but rather as a representative sample of the species occurring in non-developed habitats on SRS. Similarly, species recorded off SRS likely are only a representative sample.

The difference in land-use patterns on- and off-site also explains the greater abundance of forest birds on SRS. Of the species that were more abundant on-site, most were species that preferred mature forested habitats of either bottomland hardwood or longleaf pine. These included Red-cockaded Woodpecker and Prairie Warbler in longleaf pine forest, and American Redstart, Louisiana Waterthrush, Hooded Warbler, and Kentucky Warbler in bottomland hardwoods. Both mature longleaf pine and bottomland hardwood forests are more prevalent on SRS than off. Both are considered by Partners In Flight to be ecosystems of high priority for bird conservation (W. C. Hunter, in prep.). Furthermore, many species more abundant on SRS were forest-interior species (e.g., Pileated Woodpecker, Red-eyed Vireo, American Redstart, Kentucky Warbler; Robbins et al. 1989, Kilgo et al. 1998). Apparently, the continuously forested landscape of the SRS increased the effective size of suitable habitat patches (i.e., stands) for these species, and thus supported greater densities (Kilgo et al. 1997).

A potential bias that may have contributed to the differences we observed relates to the different sampling methodologies of the BBS and point counts. When compared with off-road counts, roadside counts such as the BBS may over-represent species that prefer edge habitats (Keller and Fuller 1995), apparently because of the greater amount of edge habitat (i.e., that created by the right-of-way) that is sampled. However, such a bias was not a concern in our study if the roadside counts sampled the habitat actually available in the region. That is, if the region was dominated by edge or brushy habitat, more of these habitats were expected to be sampled by the BBS routes, and therefore more edge or brush birds were expected. Our GIS analysis of landscape composition indicated that the strip within 140 m of the BBS routes generally was similar to the larger landscape in both forested habitat (32.5 vs. 36.4%, respectively) and open habitat (58.6 vs. 55.3%, respectively). If these differences are not merely attributable to sampling error, the relative abundance of birds in the off-site areas that prefer open or brushy habitat may be slightly over-estimated, whereas that of forest birds may be slightly under-estimated. However, we believe that, due to the magnitude of the differences in bird populations on and off of SRS, this bias had minimal impacts on our analysis.

We conclude that SRS provides the habitat conditions necessary to support a large suite of forest birds not otherwise common in the region. Eleven of the species that were either more abundant or occurred only on site are ranked as "high priority" or higher for the area by the Partners In Flight prioritization scheme (Hunter et al. 1993; W. C. Hunter, in prep.), and one, Red-cockaded Woodpecker, is an endangered species whose population on site is increasing (Franzreb and Lloyd *this volume*). This situation exists because of the presence of rare habitats on SRS (longleaf pine and bottomland hardwood forest) and the overall landscape composition and configuration of SRS. However, forest management conducted at the expense of other land uses (agriculture and urban development) also precludes the presence of habitat conditions for many species. The conservation needs of each group (i.e., forest versus non-forest birds) should be considered in large-scale land use planning.

The differences in bird populations on and off SRS necessitate a monitoring program on site to supplement ongoing regional monitoring programs such as the Breeding Bird Survey. However, we demonstrated that if such on-site information is lacking, long-term research projects may provide useful comparative information in lieu of standard monitoring programs if the research data are collected following standardized guidelines such as those of Ralph et al. (1995) for point counts.

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FIFTY YEARS OF ORNITHOLOGICAL COVERAGE AT SRS: WHAT SPECIES AND GROUPS HAVE FALLEN THROUGH THE CRACKS?

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Abstract. Over the past 50 years, SRS has been the site of numerous ornithological studies, both applied and basic. Although monitoring the entire avifauna has never been the goal of these studies, the spatial, temporal, and taxonomic coverage have nevertheless been extensive. In this paper, we attempt to distill published review papers and others in this volume into a single assessment of coverage. In addition to showing the successes of this body of work, our compilation shows the temporal periods, species, and higher taxonomic groups that have received little or no coverage. We found that waterfowl and other waterbirds have been well-covered throughout the half-century. Three endangered species (Wood Stork, *Mycteria americana,* Bald Eagle, *Haliaeetus leucocephalus,* and Red-cockaded Woodpecker, *Picoides borealis*) have received considerable attention for the past 2–3 decades. Upland gamebirds were a focus principally during the early years, and landbirds in general received little attention between the 1950s and the early 1990s, when extensive terrestrial censusing was initiated. Two groups that are frequently singled out for study, raptors and cavity nesters, have not been studied at SRS as guilds, and aerial foragers and nocturnal species have received little attention. While overall coverage has been good, we suggest that the status of SRS as a National Environmental Research Park calls for a more proactive attempt at comprehensive long-term monitoring of the avifauna on and off site, which could be accomplished through partnerships already in place.

Key Words: bird populations, contaminants, Department of Energy (DOE), Forest Service, long-term monitoring, National Environmental Research Park (NERP), radionuclides, Savannah River Ecology Laboratory (SREL), Savannah River Institute (SRI), Savannah River Site (SRS), silvicultural impacts, South Carolina, thermal impacts.

Seen from space, the Savannah River Site (SRS) is a vast patch of nearly continuous forest green in a surrounding matrix of agricultural fields, ditches, woodlots, and human residences (White and Gaines *this volume*). The current distribution of habitats on the SRS was created through the long-term land management of the SRS by the U.S. Forest Service, funded through the Department of Energy (DOE), and in response to the DOE's programmatic goals. One result of this management is that the avifauna on the SRS differs from that found in the agricultural lands and human residential areas that dominate the landscape matrix off-site (Kilgo et al. *this volume*). For instance, the SRS has a higher proportion of forest than do private lands in the region, and therefore supports more forest birds. The SRS offers at least potential source habitat for many forest-dwelling species that are uncommon in the surrounding landscape. Conversely, species typical of agricultural fields or other open habitats may be under-represented on the SRS (Kilgo et al. *this volume*).

Research on the birds of the SRS has been dominated by studies required to meet programmatic goals of DOE or the Forest Service. Thus, the research done to date is not completely representative of the whole avifauna. Programmatic emphases have varied since the creation of the SRS; thus different species have been studied at different times over the past 40-plus years. The emphasis on certain species has been diminished somewhat by additional studies conducted for reasons extrinsic to the mission of SRS (e.g., by visiting faculty and students), and explicit attempts to monitor the entire avifauna (e.g., the annual Christmas Bird Count). Some species and higher taxa, however, remain poorly known on the site.

The purpose of this paper is to document how intensively and extensively this avifauna has been studied since the establishment of the site. The major focus is to identify those species and higher taxa that have fallen through the cracks in the extensive floor of coverage on the site. We address this goal by documenting in tabular form the species that have received coverage, both intentional and coincidental. Both published sources (from this volume and the open literature) and unpublished in-house reports have been consulted. The result is a compilation of taxa and ecological associations that allows us to identify which groups have been studied least and are not currently under study.

METHODS

Our data were species listed in tables or text in formal reports, both published in the open literature and in-house. These included journal articles, Savannah River Ecology Laboratory (SREL) documents, and SRS documents. Theses were not consulted, but were reviewed recently by Mayer et al. (1997). Original analysis of raw data, such as field notes, banding records, and museum specimens was beyond the scope of this study. We did, however, use raw Christmas Bird Count data compiled by K. F. Gaines, C. Eldridge, and L. L. Eldridge (unpubl. data).

We constructed a spread-sheet in which the rows were all the species recorded on SRS (Mayer et al. 1997), and each source document was represented by a column. To add some temporal depth to the tabulation, each decade since 1950 was represented in the appropriate cell by a numeric code (e.g., 50 for 1950–59, 60 for 1960–69, etc.). To save space, we combined data from studies that covered only one or a few species into a single column (Table 1, column 10). We used this coverage table to identify species and higher taxonomic groups that have received no or little coverage. We complemented the table with results of a discussion group at the symposium to identify, in a second table, taxa that may need more intensive coverage in the future (Table 2).

RESULTS AND DISCUSSION

Table 1 shows 254 species recorded by Mayer et al. (1997) as occurring on SRS. We found 192 species (99 nonpasserine, 93 passerine), representing 50 families (26 nonpasserine, 24 passerine) and 17 orders (following the taxonomy of Post and Gauthreaux 1989) that have received some coverage (Table 1). Despite the large number and percentage (76% of site list from Mayer et al. 1997) of species tabulated as covered, inspection of the table reveals strong taxonomic and temporal biases in coverage. Noteworthy omissions are listed in Table 2 and discussed below.

SRS has always had a programmatic interest in impoundments and wetlands (Table 1, columns 3, 4). The coverage of open-water habitats, and the mostly nonpasserine birds using them, has been extensive temporally and intensive methodologically. In winter, waterfowl and American Coots (scientific names of all species appear in Table 1) have been the main subjects of these studies (Brisbin et al. 1973, Brisbin 1974, Mayer et al. 1986, Brisbin and Kennamer *this volume*; R. A. Kennamer, unpubl. data); while the major breeding anatid, the Wood Duck, has been studied continuously from 1981 to the present (Kennamer and Hepp *this volume*). Ciconiiform waders were studied as their habitat was being flooded by the impoundment of L Lake in the 1980s (Table 1, column 2; Bildstein et al. 1994) and during the drawdown of Par Pond in 1991 (Bryan et al. 1996). Two endangered species that use aquatic habitats, the Bald Eagle and particularly the Wood Stork, have been the subjects of study (Table 1, column 2; Bryan et al. 1996, *this volume*).

Terrestrial birds, on the other hand, have received much less attention. Upland habitats were not a major programmatic concern, and following the pioneering studies of E. P. Odum and students on old-field succession in the 1950s (Table 1, column 1; Meyers and Odum *this volume*), these birds received little attention until neotropical migrants became a focus of conservation efforts in the 1980s. In the early 1990s the Forest Service's Savannah River Institute (SRI) initiated extensive annual breeding bird censusing effort in terrestrial habitats (Table 1, columns 6–8; Kilgo et al. *this volume*). This added considerably to the scope of previously existing studies of forest birds, which were mostly associated with management of the endangered Red-cockaded Woodpecker (Franzreb and Lloyd *this volume*). Terrestrial coverage focused on communities was supplemented by intensive work on the Bachman's Sparrow and its associates in mature pine forest and early successional habitats (Table 1, column 5; Dunning et al. *this volume*).

Because of the conversion of the landscape from agricultural to forested land uses (White and Gaines *this volume*), coverage of open-country birds declined after the initial studies of succession directed by Odum (Meyers and Odum *this volume*). As the short-rotation pine plantations responsible for most of the increase in forest coverage matured, clear-cuts offered open-country birds, at least the ones with small home ranges (mostly passerines), extensive if temporary footholds throughout the site. Dunning et al. (*this volume*) have studied the impacts of this landscape-level ephemerality on Bachman's Sparrows and other open-country passerines (Table 1, column 5).

Falling under the rubric of open-country birds are two gamebirds (Mourning Dove and Northern Bobwhite), which were studied intensively in the 1950's. The Northern Bobwhite has declined drastically because of habitat conversion, on SRS as well as in the piedmont of the state (J. Cely, pers. comm.). Recently, the Mourning Dove has become the subject of intensive metal uptake and radioecology studies (Burger et al. 1997, 1998; Kennamer et al. 1998), but its basic biology was not studied during the shift from open to forested habitat, 1960–1990.

Another gamebird, the Wild Turkey, was present in small numbers in the Savannah River Swamp in the 1950s. In 1973–1974 the South Carolina Department of Natural Resources introduced 48 turkeys to SRS for propagation and, as of 1997, 728 turkeys had been relocated to other areas in the state and beyond (Halverson et al. 1997). Turkeys have been the subject of telemetry studies in the 1990s (I. L. Brisbin, pers. comm.; J. C. Kilgo, pers. comm.).

Given the intensive silvicultural management of the site, the lack, until recently, of explicit coverage and/or management of upland cavity-

TABLE 1. Bird Species of SRS, with Those Which Have Received Some Coverage and Assessment Indicated in Bold Type

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Common Loon, *Gavia immer*		80, 90		50, 60, 70, 80					70, 80, 90	
Red-throated Loon, *Gavia stellata*									70, 90	
Pied-billed Grebe, *Podilymbus podiceps*	50	80, 90	70	50, 60, 70, 80				70, 90		
Horned Grebe, *Podiceps auritus*		80, 90	70	50, 60, 70, 80					70, 80, 90	
Double-crested Cormorant, *Phalacrocorax auritus*		80, 90							70, 80, 90	
Anhinga, *Anhinga anhinga*		80, 90							70, 80, 90	
American Bittern, *Botaurus lentiginosus*		80, 90							90	
Least Bittern, *Ixobrychus exilis*	50	80, 90								
Great Blue Heron, *Ardea herodias*		80, 90				90			70, 80, 90	
Great Egret, *Ardea alba*		80, 90							70, 80, 90	
Snowy Egret, *Egretta thula*		80, 90								
Little Blue Heron, *Egretta caerulea*		80, 90							80, 90	
Tricolored Heron, *Egretta tricolor*		80, 90								
Cattle Egret, *Bubulcus ibis*									80	
Green Heron, *Butorides striatus*	50	80, 90				90			70, 80	
Black-crowned Night-Heron, *Nycticorax nycticorax*		80, 90							70, 80	
Yellow-crowned Night-Heron, *Nycticorax violaceus*	50									
White Ibis, *Eudocimus albus*									80	
Wood Stork, *Mycteria americana*		80, 90								80, 90[10]
Tundra Swan, *Cygnus columbianus*				50, 60, 70, 80					80, 90	
Greater White-fronted Goose, *Anser albifrons*										
Snow Goose, *Chen caerulescens*				50, 60, 70, 80						
Canada Goose, *Branta canadensis*	50			50, 60, 70, 80					80, 90	
Wood Duck, *Aix sponsa*	50	80, 90		50, 60, 70, 80		90			70, 80, 90	80, 90[11]

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Green-winged Teal, *Anas crecca*				50, 60, 70, 80					70, 80, 90	
American Black Duck, *Anas rubripes*		80, 90		50, 60, 70, 80					70, 80, 90	
Mallard, *Anas platyrhynchos*		80, 90		50, 60, 70, 80					70, 80, 90	
Northern Pintail, *Anas acuta*		80, 90		50, 60, 70, 80					70, 80, 90	
Blue-winged Teal, *Anas discors*		80, 90		50, 60, 70, 80					70, 80, 90	
Northern Shoveler, *Anas clypeata*				50, 60, 70, 80					70, 80, 90	
Gadwall, *Anas strepera*		80, 90		50, 60, 70, 80					70, 80, 90	
American Widgeon, *Anas americana*		80, 90		50, 60, 70, 80					70, 80, 90	
Canvasback, *Aythya valisneria*				50, 60, 70, 80					70, 80, 90	
Redhead, *Aythya americana*				50, 60, 70, 80					70, 80, 90	
Ring-necked Duck, *Aythya collaris*		80, 90	70	50, 60, 70, 80					70, 80, 90	80, 90[12]
Greater Scaup, *Aythya marila*				50, 60, 70, 80					70, 80, 90	
Lesser Scaup, *Aythya affinis*		80, 90	70	50, 60, 70, 80					70, 80, 90	80, 90[12]
Oldsquaw, *Clangula hyemalis*				50, 60, 70, 80					80	
Black Scoter, *Melanitta nigra*										
Surf Scoter, *Melanitta perspicillata*										
White-winged Scoter, *Melanitta fusca*				50, 60, 70, 80					80	
Common Goldeneye, *Bucephala clangula*				50, 60, 70, 80					80, 90	
Bufflehead, *Bucephala albeola*		80, 90	70	50, 60, 70, 80					70, 80, 90	80, 90[12]
Hooded Merganser, *Lophodytes cucullatus*	50	80, 90		50, 60, 70, 80					70, 80, 90	
Common Merganser, *Mergus merganser*										
Red-breasted Merganser, *Mergus serrator*		80, 90		50, 60, 70, 80					80, 90	
Ruddy Duck, *Oxyura jamaicensis*		80, 90	70	50, 60, 70, 80					70, 80, 90	80, 90[12]
Black Vulture, *Coragyps atratus*						90	90	90	70, 80, 90	
Turkey Vulture, *Cathartes aura*	50					90	90	90	70, 80, 90	
Osprey, *Pandion haliaetus*		80, 90							90	
American Swallow-tailed Kite, *Elanoides forficatus*										

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Mississippi Kite, *Ictinia mississippiensis*						90	90			
Bald Eagle, *Haliaeetus leucocephalus*		80, 90								
Northern Harrier, *Circus cyaneus*									70, 80, 90	
Sharp-shinned Hawk, *Accipiter striatus*						90			70, 80, 90	
Cooper's Hawk, *Accipiter cooperii*									70, 80, 90	
Red-shouldered Hawk, *Buteo lineatus*						90	90	90	70, 80, 90	
Broad-winged Hawk, *Buteo platypterus*	50					90		90		
Red-tailed Hawk, *Buteo jamaicensis*					90	90	90		70, 80, 90	
Golden Eagle, *Aquila chrysaetos*									70, 90	
American Kestrel, *Falco sparverius*	50				90	90			70, 80, 90	90^{13}
Merlin, *Falco columbarius*									80	
Peregrine Falcon, *Falco peregrinus*										
Wild Turkey, *Meleagris gallopavo*						90	90	90	80, 90	70, 80, $90^{14,15}$
Northern Bobwhite, *Colinus virginianus*	50				90	90	90			90^{14}
King Rail, *Rallus elegans*	50			50, 60, 70, 80					80, 90	
Virginia Rail, *Rallus limicola*	50								90	
Sora, *Porzana carolina*									70	
Purple Gallinule, *Porphyrula martinica*		80, 90		50, 60, 70, 80						
Common Moorhen, *Gallinula chloropus*		80, 90	70	50, 60, 70, 80					70, 80, 90	
American Coot, *Fulica americana*		80, 90	70	50, 60, 70, 80					70, 80, 90	70, 80^{16}; 80, 90^{11}
Black-bellied Plover, *Pluvialis squatarola*									90	

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Killdeer, *Charadrius vociferus*	50	80, 90					90		70, 80, 90	
American Oystercatcher, *Haematopus palliatus*										
Greater Yellowlegs, *Tringa melanoleuca*										
Lesser Yellowlegs, *Tringa flavipes*		80, 90								
Solitary Sandpiper, *Tringa solitaria*										
Spotted Sandpiper, *Actitis macularia*		80, 90							70	
Sanderling, *Calidris alba*										
Western Sandpiper, *Calidris mauri*										
Least Sandpiper, *Calidris minutilla*									90	
White-rumped Sandpiper, *Calidris fuscicollis*										
Pectoral Sandpiper, *Calidris melanotos*										
Dunlin, *Calidris alpina*									90	
Short-billed Dowitcher, *Limnodromus griseus*										
Long-billed Dowitcher, *Limnodromus scolopaceous*									70	
Common Snipe, *Gallinago gallinago*									80, 90	
American Woodcock, *Scolopax minor*	50								70, 80, 90	
Red-necked Phalarope, *Phalaropus lobatus*										
Laughing Gull, *Larus atricilla*									70, 80	
Bonaparte's Gull, *Larus philadelphia*		80, 90							70, 80, 90	
Ring-billed Gull, *Larus delawarensis*		80, 90							70, 80, 90	
Herring Gull, *Larus argentatus*		80, 90							80, 90	
Caspian Tern, *Sterna caspia*		80, 90								

TABLE 1. CONTINUED

Species	Sources (see footnotes) 1	2	3	4	5	6	7	8	9	10
Common Tern, *Sterna hirundo*			70							
Forster's Tern, *Sterna forsteri*		80, 90							90	
Least Tern, *Sterna antillarum*		80, 90								
Sooty Tern, *Sterna fuscata*										
Black Tern, *Chlidonias niger*			70							
Rock Dove, *Columba livia*							90		70, 80, 90	
White-winged Dove, *Zenaida asiatica*										
Mourning Dove, *Zenaida macroura*	50				90	90	90	90	70, 80, 90	
Common Ground-Dove, *Columbina passerina*	50					90	90			
Black-billed Cuckoo, *Coccyzus erythrophthalmus*										
Yellow-billed Cuckoo, *Coccyzus americanus*	50				90	90	90	90		
Common Barn-Owl, *Tyto alba*										
Eastern Screech-Owl, *Otus asio*									70, 80, 90	
Great Horned Owl, *Bubo virginianus*	50								70, 80, 90	
Barred Owl, *Strix varia*	50					90			70, 80, 90	
Short-eared Owl, *Asio flammeus*	50									
Northern Saw-whet Owl, *Aegolius acadicus*										
Common Nighthawk, *Chordeiles minor*	50					90				
Chuck-will's-widow, *Caprimulgus carolinensis*										
Whip-poor-will, *Caprimulgus vociferus*									90	
Chimney Swift, *Chaetura pelagica*	50					90	90			
Ruby-throated Hummingbird, *Archilocus colubris*	50				90	90	90	90		
Belted Kingfisher, *Ceryle alcyon*		80, 90							70, 80, 90	
Red-headed Woodpecker, *Melanerpes erythrocephalus*	50				90	90	90	90	70, 80, 90	

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Red-bellied Woodpecker, *Melanerpes carolinus*	50				90	90	90	90	70, 80, 90	
Yellow-bellied Sapsucker, *Sphyrapicus varius*									70, 80, 90	
Downy Woodpecker, *Picoides pubescens*	50				90	90	90	90	70, 80, 90	
Hairy Woodpecker, *Picoides villosus*	50				90	90		90	70, 80, 90	
Red-cockaded Woodpecker, *Picoides borealis*	50				90	90	90		70, 80, 90	70[14]; 80, 90[17]
Northern Flicker, *Colaptes auratus*	50				90	90	90	90	70, 80, 90	
Pileated Woodpecker, *Dryocopus pileatus*	50				90	90	90	90	70, 80, 90	
Eastern Wood-Pewee, *Contopus virens*	50				90	90	90	90		
Acadian Flycatcher, *Empidonax virescens*	50					90	90	90		
Willow Flycatcher, *Empidonax traillii*										
Least Flycatcher, *Empidonax minimus*										
Eastern Phoebe, *Sayornis phoebe*							90	90	70, 80, 90	
Great Crested Flycatcher, *Myiarchus crinitus*	50				90	90	90	90		
Western Kingbird, *Tyrannus verticalis*										
Eastern Kingbird, *Tyrannus tyrannus*	50				90	90	90			
Gray Kingbird, *Tyrannus dominicensis*										
Horned Lark, *Eremophila alpestris*							90		80, 90	
Purple Martin, *Progne subis*						90	90			
Tree Swallow, *Tachycineta bicolor*									90	
Northern Rough-winged Swallow, *Stelgidopteryx serripennis*							90		90	

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Bank Swallow, *Riparia riparia*										
Barn Swallow, *Hirundo rustica*	50					90	90			
Blue Jay, *Cyanocitta cristata*	50				90	90	90	90	70, 80, 90	
American Crow, *Corvus brachyrhynchos*	50				90	90		90	70, 80, 90	
Fish Crow, *Corvus ossifragus*	50					90	90	90	70, 80, 90	
Carolina Chickadee, *Poecile carolinensis*	50				90	90	90	90	70, 80, 90	
Tufted Titmouse, *Baeolophus bicolor*	50				90	90	90	90	70, 80, 90	
Red-breasted Nuthatch, *Sitta canadensis*						90			80, 90	
White-breasted Nuthatch, *Sitta carolinensis*						90	90		80, 90	
Brown-headed Nuthatch, *Sitta pusilla*	50				90	90	90	90	70, 80, 90	
Brown Creeper, *Certhia americana*									70, 80, 90	
Carolina Wren, *Thryothorus ludovicianus*	50				90	90	90	90	70, 80, 90	
Bewick's Wren, *Thryomanes bewickii*	50									
House Wren, *Troglodytes aedon*	50								70, 80, 90	
Winter Wren, *Troglodytes troglodytes*									70, 80, 90	
Sedge Wren, *Cistothorus platensis*									90	
Marsh Wren, *Cistothorus palustris*	50								90	
Golden-crowned Kinglet, *Regulus satrapa*								90	70, 80, 90	
Ruby-crowned Kinglet, *Regulus calendula*								90	70, 80, 90	
Blue-gray Gnatcatcher, *Polioptila caerulea*	50				90	90	90	90	80, 90	
Eastern Bluebird, *Sialia sialis*	50				90	90	90	90	70, 80, 90	
Veery, *Catharus fuscescens*										
Gray-cheeked/Bicknell's Thrush, *Catharus minimus/bicknelli*										

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Swainson's Thrush, *Catharus ustulatus*										
Hermit Thrush, *Catharus guttatus*								90	70, 80, 90	
Wood Thrush, *Hylocichla mustelina*	50					90	90	90		
American Robin, *Turdus migratorius*						90	90	90	70, 80, 90	
Gray Catbird, *Dumetella carolinensis*					90	90	90	90	70, 80, 90	
Northern Mockingbird, *Mimus polyglottos*					90	90	90	90	70, 80, 90	
Brown Thrasher, *Toxostoma rufum*	50				90	90	90	90	70, 80, 90	
American Pipit, *Anthus rubescens*									80, 90	
Sprague's Pipit, *Anthus spragueii*										
Cedar Waxwing, *Bombycilla cedrorum*									70, 80, 90	
Loggerhead Shrike, *Lanius ludovicianus*	50					90	90		70, 80, 90	
European Starling, *Sturnus vulgaris*						90	90		70, 80, 90	
White-eyed Vireo, *Vireo griseus*	50				90	90	90	90	70, 80, 90	
Blue-headed Vireo, *Vireo solitarius*						90		90	70, 80, 90	
Yellow-throated Vireo, *Vireo flavifrons*	50					90	90	90	90	
Philadelphia Vireo, *Vireo philadelphicus*										
Red-eyed Vireo, *Vireo olivaceus*	50				90	90	90	90		
Blue-winged Warbler, *Vermivora pinus*										
Golden-winged Warbler, *Vermivora chrysoptera*										
Tennessee Warbler, *Vermivora peregrina*										
Orange-crowned Warbler, *Vermivora celata*									80, 90	

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Nashville Warbler, *Vermivora ruficapilla*										
Northern Parula, *Parula americana*	50				90	90	90	90		
Yellow Warbler, *Dendroica petechia*										
Chestnut-sided Warbler, *Dendroica pensylvanica*										
Magnolia Warbler, *Dendroica magnolia*										
Cape May Warbler, *Dendroica tigrina*										
Black-throated Blue Warbler, *Dendroica caerulescens*										
Myrtle Warbler, *Dendroica coronata*								90	70, 80, 90	
Black-throated Green Warbler, *Dendroica virens*										
Blackburnian Warbler, *Dendroica fusca*										
Yellow-throated Warbler, *Dendroica dominica*						90	90		70, 80, 90	
Pine Warbler, *Dendroica pinus*	50				90	90	90	90	70, 80, 90	
Kirtland's Warbler, *Dendroica kirtlandii*										
Prairie Warbler, *Dendroica discolor*	50				90	90	90	90		
Palm Warbler, *Dendroica palmarum*									70, 80, 90	
Bay-breasted Warbler, *Dendroica castanea*										
Blackpoll Warbler, *Dendroica striata*										
Cerulean Warbler, *Dendroica cerulea*										
Black-and-white Warbler, *Mniotilta varia*						90	90	90	70, 80, 90	

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
American Redstart, *Setophaga ruticilla*	50					90	90	90		
Prothonotary Warbler, *Protonotaria citrea*	50					90	90			
Worm-eating Warbler, *Helmintheros vermivorus*						90				
Swainson's Warbler, *Limnothlypis swainsonii*	50					90	90			80^{18}
Ovenbird, *Seiurus aurocapillus*						90	90	90		
Northern Waterthrush, *Seiurus noveboracensis*										
Louisiana Waterthrush, *Seiurus motacilla*	50					90	90			
Kentucky Warbler, *Oporornis formosus*	50					90	90			90^{18}
Connecticut Warbler, *Oporornis agilis*										
Common Yellowthroat, *Geothlypis trichas*					90	90	90	90	70, 80, 90	
Hooded Warbler, *Wilsonia citrina*	50				90	90	90			80, 90^{18}
Wilson's Warbler, *Wilsonia pusilla*										
Canada Warbler, *Wilsonia canadensis*										
Yellow-breasted Chat, *Icteria virens*	50				90	90	90	90		
Summer Tanager, *Piranga rubra*	50				90	90	90	90		
Scarlet Tanager, *Piranga olivacea*										
Northern Cardinal, *Cardinalis cardinalis*	50				90	90	90	90	70, 80, 90	
Rose-breasted Grosbeak, *Pheucticus ludovicianus*										
Blue Grosbeak, *Guiraca caerulea*	50				90	90	90	90		
Indigo Bunting, *Passerina cyanea*	50				90	90	90	90		

TABLE 1. CONTINUED

Species	Sources (see footnotes) 1	2	3	4	5	6	7	8	9	10
Painted Bunting, *Passerina ciris*	50				90		90			
Eastern Towhee, *Pipilo erythrophthalmus*	50				90	90	90	90	70, 80, 90	
Bachman's Sparrow, *Aimophila aestivalis*	50				90	90	90	90	90	80, 90[19]
Chipping Sparrow, *Spizella passerina*	50				90	90	90	90	70, 80, 90	
Field Sparrow, *Spizella pusilla*	50				90	90	90		70, 80, 90	
Vesper Sparrow, *Pooecetes gramineus*									70, 80, 90	
Savannah Sparrow, *Passerculus sandwichensis*	50								70, 80, 90	
Grasshopper Sparrow, *Ammodramus savannarum*	50									
Henslow's Sparrow, *Ammodramus henslowii*										
Le Conte's Sparrow, *Ammodramus leconteii*										
Fox Sparrow, *Passerella iliaca*									70, 80, 90	
Song Sparrow, *Melospiza melodia*	50							90	70, 80, 90	
Lincoln's Sparrow, *Melospiza lincolnii*										
Swamp Sparrow, *Melospiza georgiana*									70, 80, 90	
White-throated Sparrow, *Zonotrichia albicollis*								90	70, 80, 90	
White-crowned Sparrow, *Zonotrichia leucophrys*									70, 80, 90	
Dark-eyed Junco, *Junco hyemalis*								90	70, 80, 90	
Bobolink, *Dolichonyx oryzivorus*										
Red-winged Blackbird, *Agelaius phoeniceus*	50					90	90	90	70, 80, 90	
Eastern Meadowlark, *Sturnella magna*	50				90	90	90		70, 80, 90	
Western Meadowlark, *Sturnella neglecta*										

TABLE 1. CONTINUED

Species	Sources (see footnotes)									
	1	2	3	4	5	6	7	8	9	10
Rusty Blackbird, *Euphagus carolinus*									70, 90	
Brewer's Blackbird, *Euphagus cyanocephalus*									90	
Common Grackle, *Quisculus quiscula*					90	90	90		70, 80, 90	
Brown-headed Cowbird, *Molothrus ater*	50				90	90	90	90	70, 80, 90	
Orchard Oriole, *Icterus spurius*	50				90	90	90	90		
Baltimore Oriole, *Icterus galbula*										
Purple Finch, *Carpodacus purpureus*									70, 80, 90	
House Finch, *Carpodacus mexicanus*							90		90	
Pine Siskin, *Carduelis spinus*									70, 80	
American Goldfinch, *Carduelis tristis*					90	90	90	90	70, 80, 90	
Evening Grosbeak, *Coccothraustes vespertinus*									80	
House Sparrow, *Passer domesticus*							90			

Notes: Digits in rows indicate decades of twentieth century in which studies were executed. For Christmas Bird Count data (column 9), these digits indicate that the species was recorded once in the decade. Column 10 collates studies that recorded a small number of species, but coverage may have been intensive.

[1] Meyers and Odum *this volume*.

[2] Bildstein et al. 1994, Bryan et al. 1996.

[3] Brisbin et al. 1973.

[4] Mayer et al. 1986.

[5] Unpubl. species list compiled by Dunning et al. in pine and clearcut habitats in connection with studies of Bachman's Sparrow (Dunning et al. *this volume*).

[6] Unpubl. species lists compiled by J. C. Kilgo, K. E. Franzreb, and S. A. Gauthreaux.

[7] Kilgo et al. *this volume*.

[8] J. B. Dunning, unpubl. data from New Production Reactor site.

[9] Christmas Bird Count data.

[10] Bryan et al. *this volume*.

[11] Kennamer and Hepp *this volume*.

[12] R. A. Kennamer unpubl. data.

[13] Beheler and Dunning 1998.

[14] White and Gaines *this volume*.

[15] M. Caudell, pers. comm.; Mayer et al. 1997.

[16] Brisbin and Kennamer *this volume*.

[17] Franzreb and Lloyd *this volume*.

[18] Moorman *this volume*.

[19] Dunning et al. *this volume*.

TABLE 2. ECOLOGICAL GUILDS AND TEMPORAL PERIODS THAT ARE UNDER-REPRESENTED IN PAST AND CURRENT RESEARCH, AND PROBABLE REASONS FOR THEIR UNDER-REPRESENTATION

Under-represented group	Probable reason
Night birds (owls, goatsuckers)	Require specific census techniques
Aerial foragers (swifts, swallows)	Require specific census techniques
Raptors (hawks, owls, shrikes)	Spatial scale too large for point counts
Cavity nesters (except Wood Ducks)	Current focus is on neotropical migrants
Stopover populations	Current focus is on breeding populations
Winter populations	Current focus is on breeding populations

nesters is surprising. Short rotations may prevent the build-up of an inventory of snags, which are used by eight primary cavity-nesters (Table 1: seven woodpeckers and Brown-headed Nuthatch) for excavation of new cavities. These cavities are then used by up to twelve species of small secondary cavity nesters found on the SRS species list (Table 1: Eastern Screech-Owl, Chimney Swift, Great Crested Flycatcher, Purple Martin, Carolina Chickadee, Tufted Titmouse, White-breasted Nuthatch, Carolina Wren, Eastern Bluebird, European Starling, Prothonotary Warbler, and House Sparrow). Recent comparisons of chemical and mechanical site preparation (Kilgo et al. *this volume*) begin to address silvicultural impacts on these small cavity-nesters. Additionally, a large-scale experimental study of the role of coarse woody debris in structuring communities of cavity-nesting birds in loblolly pine forests was initiated by SRI just prior to this symposium (J. C. Kilgo, pers. comm.).

Short rotations also prevent the buildup of an inventory of large and old trees that eventually would provide natural cavities for larger, facultative cavity-nesters such as vultures and owls. These species are probably limited to bottomland situations, where large trees persist, or nest in alternative sites such as buildings.

Studying the impacts of the site's shifting landscape pattern on metapopulation dynamics of cavity nesters could be even more productive than studies of non-cavity nesters in clearcuts have been, because the former's nests are so much easier to find than cup nests in shrubs and on the ground. Moreover, the site's limited human access also makes it seemingly ideal for studies of the mitigative effects of nest boxes on secondary cavity nesters in managed environments. The feasibility of the latter suggestion is compromised somewhat by the failure of American Kestrels (Beheler and Dunning 1998) and small passerines (D. A. McCallum, pers. obs.) to use boxes erected for their use. On the other hand, boxes erected for Wood Ducks have been used repeatedly, by nontarget as well as the target species (Kennamer and Hepp *this volume*). Erection of boxes for barn-owls in developed parts of the site could be especially effective.

A surprising omission in explicit coverage, given the level of interest on other federal lands, is raptors, both diurnal (falconiforms, shrikes) and nocturnal (strigiforms) (Table 2). Because of their large size and home ranges, many raptors require targeted surveys for adequate sampling. Fortunately, although raptors have not been studied as a group, several species have been studied individually. Once-a-year estimates of winter populations of all diurnal raptors (Christmas Bird Counts) and of Bald Eagles (Bryan et al. 1996) help identify trends. The SRI has augmented nesting structures for both Bald Eagles and Ospreys (W. L. Jarvis, pers. comm.). The American Kestrel was studied intensively for two years, 1995–1996 (Beheler and Dunning 1998). Loggerhead Shrikes were covered in studies of clearcuts (Dunning et al. *this volume*), and in urban areas (Mayer and Wike 1997).

Other nocturnal birds, primarily caprimulgiforms, are likely to be under- or undetected with the point count methodology used in many research and monitoring projects (Table 2; Kilgo et al. *this volume*). Swallows (Hirundinidae) and swifts (Apodidae) are aerial foragers whose numbers are not well estimated without methods specific to their habits, but nests of species that breed locally (Purple Martin, Barn Swallow, Northern Rough-winged Swallow) are monitored in the developed/urban areas (J. B. Dunning, unpubl. data; J. J. Mayer, unpubl. data). Purple Martins may be valuable as sentinel species around waste sites, but attempts to establish colonies have met with only limited success (I. L. Brisbin, pers. comm.).

The focus on breeding birds has left terrestrial birds largely unstudied during winter and migration for the entire half century of SRS's existence (Table 2). This is an unfortunate omission, because several resident or wintering species recorded in the 1950s (Meyers and Odum *this volume*: Table 8) are no longer present on the site (e.g., Short-eared Owl) or in the state (e.g., Bewick's Wren). The major exception to the absence of winter landbird coverage is the annual Christmas Bird Count (Table 1, column 9), sponsored by the National Audubon Society (with recent co-sponsorship by the American Birding Association). This one-day count of all species in a 15-mi diameter circle is in fact the major winter population monitoring scheme in North America, and the SRS count has provided invaluable data since 1979. But, this is a volunteer effort, with variable participation. A more rigorous and extensive approach to winter population monitoring is desirable. Data obtained in the pre-operational monitoring study for the proposed New Production Reactor (Ercolano 1992) provided a limited survey of these species. The inclusion of winter bird studies in recent master's theses (Kilgo et al. *this volume*) is a step in the right direction.

Winter studies are needed because the effect of land management practices may be just as significant for the many short-distance migrants that winter in South Carolina as it is for breeding species. For example, declines in populations of sparrows and other species that breed in mid-continent grasslands have recently aroused concerns. These are mostly "short-distance" migrants, some of which, e.g., Henslow's Sparrow, winter in South Carolina. Henslow's Sparrow is a species of concern for most land-management agencies in South Carolina and Georgia.

The importance of stopover sites for migratory species should also be recognized (Table 2). SRS, which lies athwart the northward route of many neotropical migrants, may be a stopover site of immense value for these dwindling populations, but the use of the site by migratory passerines has only recently received attention. A study of spring and fall migrant use of early successional bottomland hardwood habitat was initiated just prior to this symposium (J. C. Kilgo, pers. comm.).

CONCLUSIONS AND RECOMMENDATIONS

SRS was the first National Environmental Research Park, and the presence of a DOE operation on the site seems likely well into the future. The opportunity afforded by this tenure for comprehensive monitoring and study of all bird populations on the site has not, however, been exploited fully. The programmatic emphasis on wetlands has resulted in excellent coverage of nonpasserine aquatic birds, and many publications in the open, peer-reviewed literature. A recent emphasis on risk assessment has resumed an early focus on upland game birds, and additional work in this area may expand coverage somewhat. Indeed, the programmatic emphasis on fate and effects of contaminants seems to have led to underutilization of terrestrial birds as subjects by SREL, DOE's chief provider of ecological research (Meyers and Odum *this volume*).

Another contractor, the USDA Forest Service, has begun to fill this void in the past decade with a variety of census projects. Although many of these have specific applied goals, Kilgo et al. (*this volume*) show how such results can be amalgamated into an approximation of comprehensive basic research on the breeding birds of forested lands. Nevertheless, comparison of census results on and immediately off the site show that onsite bird communities are not representative of the regional matrix (Kilgo et al. *this volume*), and suggest that SRS is a regional center of abundance for 13 species of neotropical migratory passerines, some of which are experiencing range-wide population declines. These authors conclude that the differences in bird populations on and off SRS necessitate a monitoring program on site to supplement ongoing regional monitoring programs such as the Breeding Bird Survey. As Forest Service research and policy emphases understandably change over time, we conclude that unless DOE makes long-term monitoring of bird populations on SRS a programmatic emphasis, coverage will continue to be piecemeal, and the opportunity to acquire a priceless data set on avifaunal change may well be lost.

Moreover, despite the excellent coverage of terrestrial breeding bird populations fostered by Forest Service initiatives in the past decade, nonbreeding populations of terrestrial birds have received no intensive study. A 78,000-ha site with controlled access and a managed landscape has high potential as a major wintering and stopover site for nonbreeding birds. Assessing and maintaining this potential should go hand in hand with maintenance of breeding bird populations.

During the first half century of SRS's existence, DOE's environmental mission for SRS focused on minimizing and mitigating impacts caused by local operations. Although this mission will remain important in perpetuity, the next 50 years will see great changes in industrial focus at the former "bomb plant." A more inclusive mission could make this NERP a world leader in adaptive management for biodiversity, which would compliment its well-deserved reputation in contaminant studies and environmental monitoring. This potential leads us to recommend that DOE undertake the following programmatic goals and objectives for the next half-century:

Explicit commitment to 50 years of year-round monitoring of bird populations in upland, bottomland, aquatic, and urban habitats on site, and in the off-site matrix. This will permit correlation with global as well as local environmental variation.

Continued focused study on the impact of industrial operations and silviculture on these bird populations.

Restoration and maintenance at sustainable levels of populations of endangered and threatened species; maintenance at sustainable levels of populations of species with declining global habitat availability.

Specific objectives that would help implement these goals include: continuation of excellent studies of Wood Ducks and Wood Storks; continued encouragement and study of Bald Eagle and Osprey nesting on site; initiation of intensive study of cavity-nester metapopulation dynamics under stand-level, short-rotation timber management (including a site-wide nestbox program); continuation and expansion of intensive study of early-successional-species metapopulation dynamics under stand-level, short-rotation timber management; continuation and expansion of study of migratory forest-nesting birds; initiation of year-round monitoring of visiting and resident bird populations; active management of industrial fringes, rights-of-way, and early successional forest compartments for wintering sparrows and other regionally declining open country birds, such as Northern Bobwhite and Loggerhead Shrike.

Expand leadership in the field of contaminant uptake and fate in birds by focusing on impacts on unexploited populations, in addition to impacts on humans.

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PEOPLE AND DECISIONS: MEETING THE INFORMATION NEEDS OF MANAGERS

JOHN BLAKE AND ELIZABETH LEMASTER

Abstract. The process of identifying management information needs, providing credible results, and incorporating those results into land management decisions has been essential for the effective conservation of avian communities. The Savannah River Institute funded 18 avian studies as part of a Biodiversity Program started in 1989. The factors that influenced the success of the management-research collaboration include an effort to understand the land manager's decision making environment, land use alternatives, and a close working relationship among scientists and managers that built trust and ownership in the projects. Broad research needs identified include ecological restoration, key species and resources, landscape patterns and processes, and monitoring. Individual research studies evaluated avian community responses to silvicultural manipulations, landscape vegetation patterns, and potential influence of key resources such as soft mast and coarse woody debris. Geographic Information Systems technology provided a means to develop two important decision support tools. The first was a quantitative assessment of community habitat models, and the second was the application of spatially explicit modeling of sensitive or endangered species.

Key Words: biodiversity, decision making, environmental assessments, geographic information systems, habitat modeling, land management.

In an early assessment of management information needs, Ackoff (1967) found that "most managers suffer from an over-abundance of irrelevant information." Yet, we find ourselves asking for more information to make decisions about the conservation and management of avian communities on public and private lands. Why does this apparent contradiction exist? A significant part of the problem results from the type of information that is being provided. People and organizations also have their own personalities and cultures that affect the utility of information. Given the concern for sustainable management of native communities and viable populations, it is important to refocus scientific efforts to generate information of greater utility. Management organizations also must provide a process for evaluating scientific information, and incorporating reliable results into land management decisions.

In 1989, the Manager of the Savannah River Institute (SRI) proposed a biodiversity research program at the Savannah River Site (SRS). The Institute management staff decided on a mission oriented, problem solving approach. It was evident to us that: (1) many land management paradigms in conservation are influenced directly or indirectly by the behavior of avian groups; (2) there had been few systematic observations of avian communities in forested areas at SRS since the 1950s; and (3) genuine concerns existed as to the impact of harvesting and silvicultural activities, land management policies, and facilities construction. Over the succeeding years, the Institute funded a total of 18 avian-related studies. This paper addresses general factors that influence the success of the management-research collaboration at SRI, how research needs at SRI were developed, and how the resulting information might affect changes in land management at SRS.

MANAGEMENT-RESEARCH COLLABORATION

THE DECISION MAKING ENVIRONMENT

The primary responsibility of the Institute's staff is to make land management decisions consistent with the objectives of the Department of Energy, and then to implement those decisions given the resources and technology available. A key to identifying useful information is understanding the decision making environment. Failure to appreciate this simple fact often results in scientific studies with little relevance to management issues, and in results that are ignored by practitioners.

Managers contribute to the problem by having objectives that are ill-defined, e.g., "enhance naturalness." We sometimes develop goals to manage and monitor species with little consideration of the metrics and costs involved. Our plans must be dynamic, but often are not, resulting in conflicts over time. Frequently, spatial scale is not appreciated. We have a difficult time articulating science questions beyond the classic "we need more information on . . . ," but offer no specifics. Rarely do we take a complex issue and break it into tractable questions that can be addressed through systematic studies. The important questions may include the need to test assumptions in existing relationships, or to establish the mechanistic bases for empirical observations. The need for the latter can be difficult for managers to appreciate. Scientists can help translate our information needs into research questions by using a parsimonious scientific approach.

From a manager's perspective, answers to science questions that do not distinguish among alternative land management activities will not be valued. If the alternatives are too politicized, good science is not likely to impact choices either. If the scientists fail to appreciate the larger context of the management problem, particularly other impacts that may result from the alternatives being considered, the information will be discounted. For example, social forces can significantly constrain alternatives. Serious health or liability problems may arise from ecological fire management strategies, or from restoring endangered species that impair adjacent landowner activities. It is technically difficult, particularly with biodiversity issues, to test alternative strategies directly, and to select a winner based upon a single variable. This requires that scientists often apply some mental gymnastics, involving consistency with other data, and a few assumptions, to extrapolate results to various management scenarios. However, the preference, when feasible, will be for more direct empirical tests contrasting alternative actions, and using simple metrics like richness, relative abundance, density, reproduction, or survival. The dilemma for scientists is the willingness to allocate time to improve communications and trust, and to develop the necessary perspective on decision making, including objectives, alternatives, technology, regulations, logistics, and costs.

As a starting point, scientists might ask themselves some simple questions. What decisions are being made by whom and at what level? Decision making authority often is delegated depending on perceived risks and technical demands. Decisions may be left to a committee whose members have competing agendas and little accountability. Some individuals are more adaptive to new information, others are not. What level of information is needed to distinguish among alternative actions? The purpose, in theory, of new information is to improve predictability by increasing precision or reducing bias in specific actions. Those actions may be broad land use decisions, or specific ones about whether, when, or how to harvest a single stand. What technology and resources are realistically available? Managers are frequently limited by regulations or budget authorizations with the consequence that the ability to implement certain alternatives is questionable. Are there regulatory requirements, such as an environmental impact statement or a forest plan, involved? When biological assessments are done at the SRS, regulators want data sets comparing impacted vs. un-impacted areas. How will information be used? It is important to anticipate whether results will contribute to a formal process such as a quantitative model, qualitative guidelines, or to convince one individual to change his or her mind.

MANAGERS AS PEOPLE

A few axioms about human nature and the process of change include: (a) that stress is an important factor in the process of innovation; (b) that you generally get what you reward and what is most important to an organization may have nothing whatsoever to do with resource management; and (c) individuals often see what they want to see, and hear what they want to hear. We all have our preconceived notions or favorite paradigms that are difficult to abandon in light of new information.

At the personal level, an essential step in identifying research needs is establishing a dialogue. Unfortunately, managers often see scientists as elitist and reluctant to treat them as equal partners in evaluating conservation strategies. Nevertheless, getting managers involved by defining their concerns, working together to establish the science questions, and in reviewing proposals is essential. The latter helps to build ownership in the results, and confidence that the scientists are largely free of bias associated with advocacy. This approach runs counter to the belief that collaboration with management will taint or compromise the science. Given the previous statements, effective communication may not be easy. For example, managers may be reluctant to criticize a scientific proposal, even one with obvious flaws, and they can be overwhelmed by unfamiliar literature and methodology.

Finally, many managers are not as analytical as scientists, and may not trust analytical-mechanistic models. Many multi-million dollar decisions are based upon a significant amount of intuitive gestalt. Some managers prefer the personal responsibility associated with using intuitive judgments, while others prefer to avoid rational analysis altogether. Government agencies like to institutionalize decision-making as standards and guidelines to avoid personal culpability, and to have something that will hold up in court.

IDENTIFYING RESEARCH NEEDS AT SRS

THE PROBLEM

When established in 1951, the SRS was a highly "domesticated" landscape dominated by farming, livestock, forestry, and hunting. Almost fifty years of federal management has transformed SRS from open habitats of agricultural fields and cut-over forests to a closed forest environment. Prescribed burning was aggressively re-introduced in 1977 to assist in the recovery of the Red-cockaded Woodpecker (*Picoides borealis*), and later to restore pre-settlement fire dependent communities. All these activities have without doubt altered vegetative conditions and wildlife populations to the extent that there are no truly un-impacted communities remaining. Despite past land use, the SRS currently supports a remarkably species-rich flora and fauna, although their relative abundance and distribution probably differs significantly from pre-settlement conditions.

The Atomic Energy Commission sponsored an inventory of the entire flora and fauna in the early 1950s, and subsequently supported research on ecological processes. Over the intervening decades, public values changed as evidenced by the amount of environmental legislation passed in the 1970s. People saw native plants, animals, and their communities as non-market "resources" that they wanted restored and sustained. What was once an innovative idea, i.e., inventory and monitoring, became an essential task. And whereas scientists historically set the direction of scientific studies, regulatory compliance demanded a more deliberate research agenda than just increasing our knowledge of ecological processes.

By 1989, the prospect of new legislation or directives aimed specifically at biodiversity and ecosystem management suggested the need to be proactive. However, the potential mandates were too subjective ("ecosystem management"), intangible ("naturalness"), unmeasurable ("integrity"), or unamenable to study (whole ecosystems) to adequately define research questions. In the simplest sense, we had to know what species were here in the past, what species could potentially be here based on range and habitats, and how to restore those species. It was important to establish which species were utilizing the site, and whether they were resident, summer migrant, winter migrants, or transients. We needed to develop long-term monitoring that provided accurate and unbiased estimates, and which was relatively easy and inexpensive to perform. We had to refine and test expected relationships between vegetation types, successional stages, landscape variables, structural variables, silvicultural activities, and species occurrence or abundance in order to predict possible impacts or benefits from manipulations. Were there source vs. sink habitats for sensitive species? Were there trends occurring over time and how were species distributed across SRS? We need to provide for all species, yet give particular attention to certain rare species, which incurs risks in that decisions are based on limited information about a few.

THE SOLUTION

The strategic solution was to target simple measurable objectives that could be more directly related to the public's perception of the issues. After some struggle, a document evolved that defined the biodiversity objective for SRS as "sustaining and restoring native species in structurally and functionally desirable communities" (SROO 1993). The definition recognized the long history of human influence at SRS, the need to minimize the amount of technology involved in sustaining and restoring species, and that goals would be determined by human perceptions of a diverse landscape, not just technical indices.

The SRI research program was delineated into broad themes: ecological restoration studies, key species and resources, landscape patterns and processes, and monitoring. Ad hoc groups of managers and scientists met formally and informally to develop and delineate specific research questions. Within the broad areas, major questions were identified that addressed areas of "tension" between alternative competing hypothesis. Some of these questions had implications for establishing the pattern and distribution of potential vegetation types across the SRS landscape, such as pre-settlement vegetation, land use history, and ordination of remnant natural communities. Others were targeted at the effects of specific silvicultural manipulations and their effects on community richness and abundance. Development of restoration strategies obviously was important given past land use, but also important were answers to questions about key resources, such as soft fruit or large woody debris, and their influence on the viability and distribution of native species. Research on landscape patterns and processes tested landscape and population processes that might significantly improve more traditional wildlife habitat models. The latter included a large experimental study of corridors.

Under these broad themes, a number of avian studies were initiated. In many research projects, the avian community was seen as a response variable to various large scale experimental treatments, such as creation of bottomland hardwood canopy gaps, removal of large woody debris, tree thinning, and site preparation. One study was directed at the importance of soft fruit to fall and winter migrants. The variation in community and species characteristics also were measured along gradients of successional stage, clear-cut size, hardwood patch size in agricultural and forested landscapes, and patch isolation. More intensive individual species studies were implemented only when a species could serve as a model for a process or mechanism (predation, dispersal, etc.), or was sufficiently rare or sensitive to justify more detailed studies of population behavior. The SRI developed an avian monitoring effort using breeding bird census methodologies across the site during the nesting season to complement the Christmas bird count data collected during winter. Finally, several modeling projects were supported. In all, these have generated a considerable understanding of the avian community at SRS.

EFFECTING CHANGES IN SRS LAND MANAGEMENT

THE PROCESS

The process for effecting change is an evolving one. To begin with, a series of seminars for the SRI staff was implemented at their request. Reports, theses, and papers submitted to journals by students and scientists were copied and distributed. These approaches affect mangers individually, that is, they can influence decisions made by each individual when and where they believe it is relevant. They work well with a stable staff, and when one is testing fundamentals (e.g., How do corridors influence population processes?), or when straightforward results to interpret an experiment are available (e.g., Does leaving woody debris affect density of certain species?). In these cases, it is frequently better if scientists do not make management recommendations per se, but make a clear convincing case, in light of all available research, that the science is sound. Let the managers determine the implications and the level of acceptable risk.

The more difficult problem is institutionalizing new information without precluding subsequent change. On federal lands, managers are obligated by law to address environmental impacts of their activities. Specifically, what will be the impact to flora and fauna from certain manipulations, and can we manipulate an area to improve conditions for a certain species without detrimentally affecting other species at a larger scale? Results from research at SRS that clearly relate to specific activities can be incorporated into an environmental impact statement or assessment. The results, along with other studies, can influence the preferred alternative. Research also can be incorporated into more detailed operational management guidelines. A habitat matrix, which is a simple tabular way of expressing the relationship between a species attribute (occurrence, nesting, foraging, etc.) and habitat attributes (type, age, stand size, snags, mast species, edge, distance to water), can be developed as a tool for analyzing impacts. However, the matrix rarely expresses the uncertainty in the relationships or weights variables quantitatively.

The advent of Geographic Information Systems (GIS) has provided a means for testing and using matrix relationships that includes uncertainty, quantitative parameters, variable scales, landscape attributes, and dynamic processes. The current status or future state in response to a specific alternative can be predicted on a "real" landscape. The SRS has been working with scientists to implement "spatially explicit" GIS modeling as a means for integrating research and institutionalizing results (Dunning et al. 1995). An approach underway is to test and refine the basic habitat matrix of Hamel (1992) using the SRS data sets (Kilgo 1996). Another approach for individual species is to construct dynamic meta-population models. The latter is being applied to the Red-cockaded Woodpecker, and "model" species, such as the Bachman's Sparrow (*Aimophila aestivalis*), where population parameters are available, and when a more detailed analysis is required.

WHAT CHANGES ARE OCCURRING?

It is difficult to determine the impact from the studies because we are at the stage where the information is used individually, although some results are making their way into formal biological assessments. The SRI is incorporating the results into a GIS habitat model, and we are continuing to develop spatially explicit models for a few species. There has been a realization of the enormous variability in existing habitat models as well as some counter-intuitive results, such as the occasional use of open habitat by forest interior birds. One side benefit has been a revision of the forest inventory system to emphasize structural measures of avian habitat. However, we still have not quantified winter migrant use, and we need to quantify reproduction and survival for various species in various habitats. It also is perplexing to try to obtain reliable data on rare species with low densities.

The primary tool for shaping habitat conditions for plant and animal communities has been and will continue to be manipulation of the structure, composition, and pattern of the vegetation through harvesting, silviculture and burning, and selective removal or re-introduction of species. Despite negative connotations, harvesting, silviculture, and burning (or lack thereof) are effective tools in sustaining and restoring some communities. It is not so much what is done, as how, when, and where it is done that can make the difference (snag and debris retention, choice of tree species, planting density, patch size, season of management activity, frequency, etc.). Ultimately, information from research will alter the extent to which we apply these tools, or alternatively, allow us to more precisely understand their impacts.

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DESIGNING AND PRESENTING AVIAN RESEARCH TO FACILITATE INTEGRATION WITH MANAGEMENT

CHRISTOPHER E. MOORMAN

Abstract. Both avian scientists and managers are responsible for the results of management decisions and the consequent effects that field applications have on bird communities. However, communication gaps arise between management and research as the two disciplines continue to specialize. Researchers must make an effort to bridge these gaps by designing studies with management utility and presenting results in a form that will reach a wide audience including managers. Basic research increasingly is shifting towards applied problems and applied research has moved towards basic ecological theory, thereby diminishing distinctions between the two. Avian scientists should continue to use the hypothetico-deductive method when performing research, but should emphasize scales and problems relevant to management. Once projects are completed, researchers should present results as quickly as possible, especially at meetings where scientists and managers interact. Adaptive resource management represents a new opportunity for the integration of research and management because, by definition, it requires that the two endeavors work together. I include a case study of an interdisciplinary and coordinated research effort conducted on the Savannah River Site in South Carolina. The research is developed in a theoretical framework designed to answer broad ecological questions but retains its applicability to avian management.

Key Words: adaptive resource management, avian, bottomland forest, communication, group selection, management, research, scale, scientific method.

Natural resource managers must integrate use of forest resources with changing ecological values (Sharitz et al. 1992). Natural resource scientists must apply sound scientific principles to solve problems that arise during management of natural resources, and, therefore, should be judged by how well their efforts increase manager success. Interaction between scientists and managers is required for the problem identification and resolution process to be effective and complete. However, poor communication between researchers and managers is a common phenomenon that leads to inefficiency in both endeavors (Stoltenberg et al. 1970, Hanley 1994).

Communication gaps between researchers and managers arise from a lack of mutual understanding of the other's responsibilities and goals (Macon 1967). Resource managers point out that researchers often are narrowly focused, impractical, slow to arrive at solutions, and difficult to understand. In contrast, researchers object that managers do not use research results effectively and expect oversimplified solutions to complex problems, and that research is chronically underfunded relative to manager expectations (Hanley 1994). Researchers and managers have different functions and goals, and as each continues to specialize, the number of people with both research and management experience will continue to dwindle. Effective communication between researchers and managers becomes increasingly important as management decisions become more complex and research continues to specialize (Macon et al. 1970).

Avian scientists increasingly are working with forest and wildlife managers to improve understanding of the relationships between forest management practices and avian ecology. Birds are a diverse and readily sampled group and avian habitat specialization based on physical characteristics of the environment is well documented (e.g., MacArthur and MacArthur 1961, Anderson and Shugart 1974, Holmes et al. 1979). These characteristics of bird communities and recent declines of some bird species in association with human influences (e.g., Terborgh 1989) have made applied avian research a priority topic. Consequently, avian scientists must strengthen communication with land managers and design research that facilitates integration with management operations.

RESEARCH DESIGN

Fretwell (1972) stated that scientists adept at both theory and field work were most likely to make advances in ecology. However, opportunities for these types of scientists have been rare because of the substantial gap between applied and basic research. The primary function of applied science is to provide knowledge to manage species for commercial, ecological, and/or aesthetic value, while basic science strives to understand nature for understanding's sake (Romesburg 1991). Purely basic research, because it is so specialized, appears narrow and often has no direct utility to management (Stoltenberg et al. 1970). Recently, many natural resource scientists have attempted to narrow the gap between basic and applied research. Sources of funding for basic research have dwindled and scientists are increasingly required to justify their research in terms of its applicability (Brown 1992). Basic researchers have moved to applied problems and applied problems have shifted toward more basic ecological questions (Hanley 1994). Distinctions between basic and applied science are diminishing and increasingly irrelevant (Nudds 1979, Sharitz et al. 1992, Wiens 1992, Hanley 1994, Moffat 1994). Research that advances theory applicable to management is ultimately the most useful research for management.

Applied-basic science is basic science conducted in an applied area (Romesburg 1991). In this transition zone, basic information is screened for possible application (Macon et al. 1970). Historically, applied research and management have worked together closely, while each benefited from basic research peripherally (Hanley 1994). Basic and applied researchers should work jointly in developing scientific knowledge of ecological processes, while managers benefit from advances in science by revising their analytical tools accordingly (Hanley 1994). Increased competition for limited numbers of positions, advanced education requirements, and diversification of job applicants in the resource manager's field have raised the qualifications of managers occupying existing positions. Therefore, managers should be able to understand relevant ecological theory and handle the additional responsibility of implementing sound research into management practice. However, this should not free scientists from responsibility to apply sound scientific principles to solve problems and perform research that is applicable to real-world situations.

A priori decisions regarding problem selection, experimental design, and site selection should be made with the manager's needs in mind. There is a long time span between research and implementation, so research problems should be timely and contemporary. The problems must have important application to management and also be favorable to developing predictive theory. Scientists funded by management institutions often take on broad and ambiguous problems and those funded by basic research institutions investigate more specialized problems (Hanley 1994). The most useful research is a compromise between these extremes.

The present needs of management and the shortcomings of the management status quo can be identified through communication with field personnel and/or inventory and population monitoring. For example, field personnel might have pertinent information concerning which bird species are declining locally and theories relating to the causes of the declines. Regional and larger-scale population trends can be obtained from long-term monitoring programs like the Christmas Bird Count, Breeding Bird Survey, and Breeding Bird Census. Using retroduction, asking questions about these trends and/or examining the results of previous research, especially qualitative studies (Romesburg 1981), scientists can identify pressing research needs.

Unless natural resource scientists use rigorous scientific procedures following the hypothetico-deductive method (Romesburg 1981), our understanding of the processes underlying the relationships between birds and management will stagnate. Once management decisions are made and implemented, they cannot be retracted. Therefore, decisions based upon poorly designed research could be detrimental to the wildlife meant to be conserved. Researchers must develop and test several alternative hypotheses (Chamberlain 1897). Testing of a single alternative model may lead scientists to become attached to the "pet hypothesis," resulting in incomplete and biased conclusions. Induction, which is based on observations of associations and correlations, cannot give knowledge about the processes that drive nature (Romesburg 1981). Instead, during hypothesis formulation scientists must ask *Why?* and *How?* rather than *What?*. Applied-basic research should be done in a theoretical framework because it aids proper application of the scientific method (Nudds 1979).

However, the scientific method is difficult to apply in ecology because stochasticity, complexity, and unobserved or uncontrollable variables are common (Loehle 1987). Temporal variation in avian habitat selection can be annual or seasonal and spatial variation can occur at the territory, stand, or landscape level. Individual variation can interact with both spatial and temporal variation to compound errors. Predictions defined in ways that can be tested unambiguously (Hanley 1994) and proper replication and controls aid in efficiently accounting for variability.

The utility that research has to management is partially determined by the scales, both temporal and spatial, at which it is performed. Historically, wildlife management decisions targeted individual species rather than the entire community and its system (Wagner 1977). However, the present trend is toward management of ecosystems and the maintenance of biological diversity (Sharitz et al. 1992). In practice, managers must continue to manipulate at spatial scales equal to or larger than the size of existing stands and plan at temporal scales equal to the rotation lengths of those stands. Stand sizes and rotation lengths can be changed, but this usually takes time. Conversely, manipulative experiments, in which replication and control are important, usually are carried out on a small scale because the scientific method becomes increasingly difficult at larger scales (Hanley 1994). Logistics, especially the effort required to measure habitat variables and the difficulty of accounting for variability at larger scales, limit the scale of experiments.

The species or community in question may limit the scales that can be used in experimental approaches. For example, a landscape that is heterogeneous to a Prairie Warbler (*Dendroica discolor*) may be contained within a homogeneous patch from the perspective of a Cooper's Hawk (*Accipiter cooperii*). Research that documents characteristics of Hooded Warbler (*Wilsonia citrina*) nest substrates (e.g., substrate height and number of limbs at point of nest placement), while providing valuable knowledge concerning the ecology of the species, has little practical value to large-scale land management. Although managers continue to advance their ability to manipulate habitats at multiple scales, it may be impractical to control the height or growth patterns of a single substrate species. Instead, managers would have to adjust these fine-scale results to a more coarse-grained scale (i.e., % cover of substrate species). Because results of small-scale experiments may not be relevant to larger systems (Carpenter 1996), scientists increase the utility of their research by targeting the scales at which management issues will be addressed and the habitat variables controllable by managers when they formulate hypotheses, make predictions, and develop an experimental design. Results from studies conducted at multiple scales will more likely identify patterns of change between scales (Wiens 1989) and may be more easily incorporated into management prescription.

Unless dealing with game species (e.g., harvest regulations), managers manipulate bird communities by manipulating their habitats. Therefore, research that provides direct linkages to habitat creation and manipulation will have the most relevance to management operations. Scientists also can increase the utility of their research by making linkages to previous research or ongoing research projects. A series of short-term projects with a common tie can partially substitute for long-term research projects (e.g., Kilgo et al. *this volume*). Coordination of several specific studies may be used to answer a larger, more general question (Stoltenberg et al. 1970).

ADAPTIVE RESOURCE MANAGEMENT

Scientists can address large-scale questions by using management or natural manipulations as scientific experiments (Macnab 1983, Walters 1986, Walters and Holling 1990, Sinclair 1991, Lancia et al. 1996). This approach, termed Adaptive Resource Management (ARM), integrates learning about a system and its mechanistic processes with ongoing management operations (Walters 1986, Lancia et al. 1996). ARM encourages that research and management be conducted simultaneously as one coordinated endeavor and that the two collaborate to take better advantage of planned management actions and manipulations (Lancia et al. 1996). Within a landscape, several alternatives are tested simultaneously and as inferior alternatives are replaced by more proven ones, the direction of management is altered coincidentally (Irwin and Wigley 1993). By definition, ARM promotes increased communication and collaboration between researchers and managers. Rewards are shared equally by ecological science and wildlife management and distinctions between managers and researchers blur as the two are compelled into closer working associations (Macnab 1983). Lancia et al. (1996) suggested an interdisciplinary approach to adaptive management and the forging of partnerships among professional societies with conservation interests. Such a coordinated effort could stimulate more creative hypothesis development by researchers (Romesburg 1991) and operation on a more challenging professional level by managers (Macnab 1983).

Researchers may have to accept some compromise in the development of experiments in coordination with ongoing management, especially because of constraints on randomization and replication (Lancia et al. 1996). Additionally, scientific monitoring at such large scales may be limited by common logistical problems such as shortages of manpower and funding. Two main challenges to the design of adaptive management experiments are the development of technical advancements and imaginative methods to sample ecological processes at large scales, and the establishment of administrative arrangements that would allow for long-term investigations by researchers (Walters and Holling 1990).

Scientists and managers responsible for setting waterfowl harvest regulations already have begun implementation of ARM (Johnson et al. 1993, Williams and Johnson 1995) with some initial success (Williams et al. 1996). Due to the uncertainty of the effects that harvests have on waterfowl populations, establishment of these regulations is a difficult task. Uncertainties arise from the complexity of regulatory options offered, the inconsistencies of regulations from year to year, and the large geographic range covered by waterfowl populations during the annual cycle (Williams and Johnson 1995). Williams and Johnson (1995) described the general process used by waterfowl managers and researchers to implement ARM. First, the objectives for harvest management are established through communication between several cooperating groups, including state wildlife agencies, the U.S. Fish and Wildlife Service, Canadian and Mexican governments, and the public. The status of waterfowl populations is determined with monitoring programs, and the effect harvests have on populations from year to year is assessed. Data acquired from harvest surveys and population monitoring are used to update models that predict optimal harvest regulations. Eventually, uncertainty is reduced to the point that the most appropriate model for describing population dynamics is identified. Despite potential obstacles, active adaptive harvest management offers considerable benefits, including stronger links between migratory bird management and research (Williams and Johnson 1995).

PRESENTATION AND RECOMMENDATIONS

Managers depend on researchers for solutions to problems (e.g., species declines) that arise during management applications. Although researchers may directly address problems and develop potential solutions, most results are presented as scientific publications, which most managers cannot translate into relevant prescriptions. However, there are steps that natural resource scientists can take to make results more available and applicable to wildlife management.

Once research projects are finished, results should be published or packaged for managers as quickly as possible. This usually is mandatory if the funding agency is management oriented. If results and recommendations do not reach the management sector until after the often long and drawn out publication process, their applicability to management may be outdated. It is best to package the results in a form that will reach managers at all levels including government, private industry, and private landowners. Examples of such publications include experimental forest bulletins and Cooperative Extension Service pamphlets. Managers can exhibit publications, reports, and maps resulting from research activities as proof of their dedication to scientific advancement.

Understandably, most research scientists are driven by performance evaluations based primarily on quantities of refereed publications in high quality journals. Time spent producing bulletins and pamphlets would detract from researcher ability to reach goals required for tenure or professional advancement. Goals established by administrators or upper-level management may not be in the best interest of natural resource management. Institutions and agencies that presently do not reward scientists that publish manager-oriented publications should reconsider such a policy or provide personnel specifically funded to link managers with research publications.

When preparing results to be presented specifically to managers, researchers should make recommendations that are cost effective, logistical, and practical. Hanley (1994) stressed that management should be left to translate ecological knowledge into the analytical tools needed for application. However, efforts by researchers to present recommendations in a relevant form will facilitate the process. Researchers should take special care to consider the manager's time and spatial constraints. Economic constraints, beauracratic hurtles, or planning requirements can impede changes in management policy for decades. Researchers must plan for these time lags when making recommendations. During presentations to managers, scientists should be specific with objectives, hypotheses, alternatives, and recommendations. Researchers should reduce the clutter of mathematical jargon present in most scientific publications, but remain careful not to overstep the limits of significance that statistics erect. If research does not have direct applicability to management, scientists should not attempt to assign management utility to results. Invalid conclusions that overstep the boundaries of research applicability can retard the advancement of science and management.

Scientists must actively engage in the logical flow of information (Stoltenberg et al. 1970). Attendance at professional meetings and project planning conferences where researchers and managers interact promotes idea transformation and translation. Written reviews and project progress reports, consulting services to managers, advisory committees to management organizations (e.g., Ducks Unlimited, National Wild Turkey Federation, Partners in Flight), and liaisons also help maintain information flow between scientists and managers. Very little, if any, professional advancement may come from the extra effort taken to create these special pathways between management and research. However, the long-term benefits to avian ecology and conservation may provide more career satisfaction than one more technical publication.

CASE STUDY: THE GAP PROJECT AT SAVANNAH RIVER SITE (SRS)

Several individual research studies, covering diverse taxa, were initiated on SRS in a bottomland hardwood stand in which experimental canopy gaps were created by group selection timber harvest. Six replicates of six gap sizes (0.015, 0.031, 0.062, 0.126, 0.264, 0.503 ha) were created in the stand, and portions of the stand that were left unharvested were used as control replicates. Although the study was originally designed to examine the effects of gap size on herbivory rates on woody and herbaceous plants by white-tailed deer (*Odocoileus virginianus*) and swamp rabbits (*Sylvilagus aquaticus*), the rigorous experimental layout provided the opportunity to study a variety of other ecological processes and species groups.

THEORETICAL FRAMEWORK

Upon learning that Savannah River Institute (SRI) managers were interested in the relationships between the artificial gaps and bottomland bird communities, several local researchers proceeded to identify the important ecological questions and what utility they had to management. Previous studies have documented increased bird use (e.g., species richness and abundance) in natural gaps relative to the surrounding forest (Schemske and Brokaw 1981, Willson et al. 1982, Blake and Hoppes 1986, Martin and Karr 1986, Wunderle et al. 1987). Blake and Hoppes (1986) and Martin and Karr (1986) attributed the increases to higher resource abundance in the disturbed areas. Forest-interior, area-sensitive species such as Kentucky (*Orporornis formosus*) and Hooded Warblers are adapted to internal forest disturbances such as tree-fall gaps (Thompson et al. 1993, Kilgo et al. 1996). Researchers sought to investigate whether these relationships were similar in artificially created gaps, and, if so, for what reasons.

MacArthur and MacArthur (1961) documented a positive relationship between bird species diversity and foliage height diversity (FHD). Runkle (1982) determined that with increased gap size, vegetation within gaps increased in woody species diversity, total basal area, and total number of stems. Resource levels (i.e., fruit and insects) also might be higher in gaps because of greater primary productivity associated with increased light levels (Halle et al. 1978). Consequently, habitat heterogeneity and FHD should be greater in the artificially created gaps, especially larger ones, than forested areas without gaps; thereby providing niches for a wider range of species as well as a greater abundance of individuals. Researchers developed two testable predictions from this hypothesis: (1) species richness and individual species abundance will be greater in and around the artificial gaps, especially the larger gaps, than the control areas; (2) species richness and individual species abundance in the gaps will increase with any temporal increase in the structure of the vegetation.

JUSTIFICATION

Between 2000 and 2030, annual hardwood timber removals from southern bottomland hardwood forests are projected to increase from about 22.1 million m^3 to about 36.3 million m^3 (U.S. Forest Service 1988). Group selection is a method commonly used to harvest bottomland timber, and it may adequately simulate the natural disturbances that provide canopy openings and an uneven-aged structure (Pashley and Barrow 1992). Forest fragmentation, resulting from stand-level disturbances, causes declines of some forest-interior species and local extinctions of others (Finch 1991). However, Hamel (1989) determined that Swainson's (*Limnothlypis swainsonii*) and Hooded warblers, both forest-interior species, occurred at higher densities in selection harvests than in clearcut or uncut areas. Therefore, it is possible that there is an area-related threshold where gap-phase disturbances such as those in selection harvesting operations begin to have similar effects as stand-level disturbances. With the relatively continuous range of gap sizes present in the study, the gap size in which early-successional species first appear (low-end threshold) and the size in which forest-interior species begin to disappear (high-end threshold) could be identified. Any information relating to these thresholds and results from the original predictions could be used to provide recommendations on the optimal opening sizes to be used in selection harvest operations.

PRESENTATION

To maintain constructive interaction with managers, researchers presented annual progress reports to SRI personnel and periodic updates at local symposia. Study recommendations were made part of the logical information flow by making presentations of preliminary results at national conferences with both managers and researchers attending and presenting practical and clearly-stated management recommendations in a final report. Hopefully, all conceptual aspects of the research will be published in scientific journals in the future.

The gap project is an exceptional example of an interdisciplinary approach to investigate a broad range of specific research questions and a coordinated effort to address a few general problems. Among the scientists performing research on the gap site are botanists, ecologists, ornithologists, herpetologists, and mammalogists. Among the managers based at SRI are computer specialists, silviculturalists, foresters, and wildlife biologists. The simultaneous presence of the

SRI personnel and the gap-project scientists provides a unique opportunity for productive interaction before, during and after each research project.

CONCLUSION

Avian ecologists have a great responsibility to the future of wildlife management. The success of future management decisions rests as much with scientists as it does with managers. The greatest challenge to research scientists is to conduct research that is developed in a theoretical framework and answers broad ecological problems but also has utility and application to avian management. Adaptive resource management is the potential solution to the problem of integrating research with management in the future. It ensures that managers and scientists jointly make decisions regarding management direction and uses ongoing management to answer research questions. However, ARM will require willingness of basic researchers to operate in a more applied realm and compliance by managers to adjust field prescriptions to meet demands of experimental design. This increased cooperation should reduce the information swamping that managers currently undergo and provide pertinent, unambiguous answers to contemporary management problems.

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INTEGRATING LONG-TERM AVIAN STUDIES WITH PLANNING AND ADAPTIVE MANAGEMENT: DEPARTMENT OF ENERGY LANDS AS A CASE STUDY

JOANNA BURGER

Abstract. Ornithologists in many regions have initiated long-term studies to examine trends in populations, reproductive success, and chemical contamination that are aimed at understanding the status of avian populations, and in predicting the health and stability of future populations. Yet, the design of such biomonitoring studies often does not include a management component, and may not be based on basic ecological knowledge. Thus the data from such studies are often ignored by planners and managers, either because they are unaware of the studies or because the studies do not meet their needs. I suggest that avian researchers would profit from understanding the data needs of planners and managers, and that cooperation in the early phases of study design would increase the usefulness of long-term avian studies to both managers and basic researchers. The integration of basic biological data into management decisions requires both the researcher and the manager, working in concert. Certain types of data gathered routinely for long-term studies will be extremely useful for all phases of remediation (including restoration) and management of degraded lands, while others will be less useful. While data from endangered birds are useful for a single management approach, long-term data sets that include population or community aspects will be most useful to managers in determining whether to preserve, and what size to preserve. Such data will also be useful in determining variation in assemblage structure, which is important in detecting impacts. Contaminants data will be most useful for decisions concerning whether to remediate, restore, or allow the land to remain a preserve, as well as determining the causes of biological impacts. For all types of data, the appropriate assessment of reference sites is critical to understanding human impacts. The Department of Energy sites serve as an important case study because many of these sites are associated with ecological laboratories that have long-term data sets on resident and migratory birds, as well as contaminant loads.

Key words: avian studies, biomonitoring, Department of Energy, environmental planning, long-term studies, public policy, restoration, stewardship.

For many years different academic disciplines have developed in relative isolation. Integration, when it occurred, often involved either closely related disciplines, or different levels of organization. There has been a split between what is perceived as applied and basic research, rather than the realization that there is a continuum in research objectives. Yet solving many of our most pressing environmental problems on a national scale will involve not only scientists that have either applied or basic expertise, but scientists with both aspects (Meffe and Viederman 1995) or who are willing to work with scientists or managers with a different perspective. Conservation biology and related disciplines are maturing to encompass economic, legal, and political issues as well (Meffe and Viederman 1995).

Stewardship of natural resources is an important national priority, necessary to sustainability goals for the U.S. (Buzzelli and Lash 1996). Ecosystem integrity is an integral part of sustainable agriculture, fisheries, forestry and conservation. Likewise, environmental quality is intimately bound with conservation of natural resources (Buzzelli and Lash 1996). In national polls, concern for the environment ranks very high (Dunlap 1991), along with other environmental and health-related problems. Ornithologists can contribute to such stewardship of environmental resources by providing the necessary data to make knowledgeable management decisions.

In this paper I examine the need for integration between long-term avian studies, public planning, and adaptive management. I discuss avian studies and ecological risk, Department of Energy (DOE) sites as case studies for integration of long-term avian studies and management, the usefulness of different types of long-term avian research for planning and management activities, and suggestions for optimizing the usefulness of long-term avian studies for decision-making about remediation or management.

Although this chapter uses the Savannah River Site (SRS) in South Carolina as a case study, the generality of the observations and suggestions apply to other DOE sites, as well as to Department of Defense sites, Superfund sites, and a variety of other contaminated sites that are being considered for public use. The amount of public land that is being considered for alternate land uses or is being decommissioned as a result of the ending of the Cold War is very large, and ecological data from avian studies can be used in both cleanup and future land use decisions. Cleanup is referred to by DOE personnel as remediation (DOE 1991), although the resultant ecosystem may not mimic natural conditions.

AVIAN STUDIES AND ECOLOGICAL RISK

Risk assessments examine the potential risk to target organisms (or populations, communities or ecosystems) from chemical, physical, or biological hazards. The National Research Council (NRC) (1983) formalized the human health risk assessment paradigm to include four parts: hazard identification, dose-response assessment, exposure assessment, and risk characterization. This basic paradigm has remained the same, and has been extremely useful in providing consistency in methods for identifying the risks to human health (NRC 1993).

Risk assessment is not strictly an academic discipline, but relates to managing risk in the public interest (Nathwani and Narveson 1995). Agencies such as the Environmental Protection Agency are focusing on setting priorities for what they can solve (Morgenstern and Sessions 1988), and dealing with the complicated issue of their own evaluation of risk compared to that of the public. The public clearly places hazardous waste sites as a very serious environmental problem (Morgenstern and Sessions 1988, Kunreuther 1991), and they hold the preservation of the ecosystems on those sites equally high (Burger 1998). One important aspect of hazardous waste is to understand the risk they pose to ecosystems and their component parts.

Several disciplines have studied or evaluated risks to non-human populations and the environment, including ecology, wildlife and land management, ecotoxicology, and more recently, restoration ecology and ecological engineering (Odum 1957, Paine 1966, NRC 1986, Hoffman et al. 1990; Cairns 1991, 1993; Mitsch 1993). Ecological risk assessment has developed from the convergence of human health risk assessment, ecology, and ecotoxicology to provide data for environmental management and decision-making (NRC 1993). Ecological systems are much more complex than the single-species/single lifetime approach used in human health risk assessment, requiring modifications of the risk assessment paradigm for particular uses (Norton et al. 1992, Burger and Gochfeld 1996).

Ecological risk assessment has emerged as an important discipline because it fulfills three needs: it can be used to assess the general health and well-being of animal and plant populations, communities and ecosystems; it can be used to evaluate competing risks (past, present or future); and it can inform decisions about future use of contaminated land. Long-term avian studies can contribute necessary data for all of these objectives, and the existence of such data sets for DOE sites such as the SRS make them particularly useful for assessing current damage, for designing remediation plans, and for evaluating remediation and management actions. Understanding these risks involves developing a holistic biomonitoring plan that uses long-term data as a firm basis (Burger 1999).

For example, long-term data sets on the population levels and reproductive success of endangered species, such as Red-cockaded Woodpeckers (*Picoides borealis*) on SRS, can help determine which forests should be preserved, and the logging regime within that forest (Franzreb and Lloyd *this volume*). Information on reproductive success and contaminants of Wood Ducks (*Aix sponsa*) and other species can be used as indicators of environmental health and well-being (Kennamer et al 1993, Kennamer and Hepp *this volume,* Brisbin and Kennamer *this volume*). These studies can then be used as baselines for comparison both to other areas within SRS or to other DOE sites. These types of studies can be used to evaluate the health of DOE ecosystems, to measure changes in contaminants that pose human and ecological risks, and to inform managers about preservation of habitats.

Ecologists may need to develop expedited risk assessments that will allow more cost-effective answers that are less science-intensive (Cranor 1995). But in some cases, such as at SRS, the presence of long-term data sets for birds will provide some of the necessary data for expedited assessments. The presence of long-term data sets from many of the DOE sites provides a unique opportunity to integrate avian studies in management. For example, having long-term data on the habitat needs of Wood Storks (*Mycteria americana*) provides necessary data for any risk assessment involving cleanup of habitats these species use (Bryan et al. *this volume*). Having long-term data on contaminants of American Coots (*Fulica americana*) from Par Pond on SRS allows managers to quickly examine risks associated with any changes in water levels that expose sediments (Brisbin and Kennamer *this volume*).

Long-term studies on birds can contribute markedly to risk assessments by providing data on population sizes and levels of reproductive success necessary to maintain healthy viable populations in existing habitats. Although the data from long-term studies were not specifically collected for risk assessments, they can contribute because they allow analysis of the types of stressors with associated effects (hazard identification). Another advantage of using birds is that they integrate over fairly large geographical regions, depending upon the choice of bird; recently Cairns (1995) and Suter (1990) noted the importance of using larger scales in ecosystem evaluations. For example, studies with Bachman's Sparrow (*Aimophila aestivalis*) have included large segments of SRS, leading to the opportunity for management on a landscape scale, necessary for a species that has such specific requirement for forest stands of a particular successional stage (Pulliam et al. 1992, Dunning 1993, Dunning et al. *this volume*).

DOE SITES AS CASE STUDIES

Many environmental problems involve contaminated sites such as landfills, Comprehensive Environmental Response Compensation and Liability Act (CERCLA, or "Superfund") sites, nuclear facilities, the siting of waste storage facilities and nuclear power plants, and finally, dealing with the toxic legacy of the Cold War (Kunreuther et al. 1990; Slovic et al. 1991a,b; Barke and Jenkins-Smith 1993, Kivimaki and Kalimo 1993; Flynn et al. 1994a,b). For many years federal regulators and managers focused on point-source pollution and on Superfund sites (Russell 1991, Mones 1991), but recently the realization of the magnitude of contamination on DOE and Department of Defense sites has shifted the focus to federal lands. In the United States, many of the DOE sites that were formerly involved in nuclear weapons production require clean-up before these lands can be used for recreational, industrial, or residential purposes, or placed in long-term stewardship.

The DOE is involved in a massive cleanup, and the Office of Environmental Restoration within the Office of Environmental Management must manage the budget among programs based on considerations of site-specific health risks, ecological risks, regulatory requirements, and costs (Jenni et al. 1995). Grumbly (1996) noted that the DOE has contaminated sites in 34 states, with over 600 billion gallons of contaminated groundwater. The DOE complex houses over 3000 tons of spent nuclear fuel, some of which is in pools that are now corroding, threatening to contaminate groundwater supplies. There are 710 million gallons of radionuclide mixed waste at Hanford (in Washington), SRS, and Oak Ridge (in Tennessee) alone. Clearly the problem of remediation of DOE sties is a national priority. Restoring these sites to a pristine state will be extremely costly, and the degree of cleanup will depend partly on future land use. Stakeholder views are critical to considerations of future land use (NRC 1995, Wernick 1995, DOE 1996b, Commission on Risk Assessment and Risk Management 1996, Nakayachi 1998), and thus to the methods and types of cleanup required (Fig. 1).

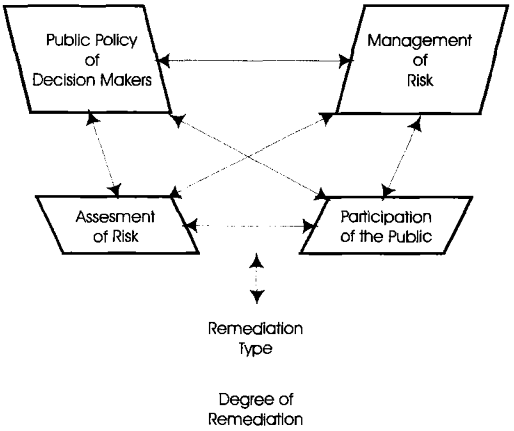

FIGURE 1. Relationship of public policy, management, risk assessment, and the public at the Department of Energy as envisioned by the National Research Council (NRC 1994).

Having decided to clean up these sites, several other considerations follow: (1) how much should they be cleaned up; (2) what ecological constraints should apply to cleanup; and (3) what metrics shall be used to determine the success of clean up? An additional question germane to ecologists is whether the cleanup itself will do more damage to the ecosystem, and its component organisms, than leaving the contamination alone (human health considerations aside; Dale and Parr 1998). The DOE must decide both the type of remediation and the degree of remediation (NRC 1994). Data from long-term studies can contribute to all four of these aspects, at least with respect to ecological issues.

The job of cleanup on DOE sites is estimated to take until the year 2070, and although no similar estimate has been made for the large number of Department of Defense sites, the process will take many years. Thus, this is not a small problem that will disappear in a few years. Further, the creation of new hazardous wastes makes it imperative to develop ecological risk methodologies that managers can use for years to come, and avian data sets can provide useful information for the process.

One important aspect ornithologists should bear in mind when considering the role of long-term avian studies in public planning and management is that the DOE, and perhaps other federal agencies as well, must take into account future land uses when making remediation and restoration decisions. DOE is committed to multiple use of their lands where appropriate, including recreation and industrialization (DOE 1996b). DOE is also committed to natural resource management, with biodiversity as a ma-

TABLE 1. Types of Data Useful for Making Decisions About Preservation of Land, Regardless of Current Contamination or Degradation

Biological Level	Parameter	Decision to preserve	Size to preserve	Landscape issues
Individual	Habitat preferences	X	X	
	Changes in preferences		X	X
	Morphological changes			
Population	Population size and trends	X	X	X
	Age and sex ratio changes			X
	Reproductive success trends	X	X	X
	Contaminant trend	X		
Community/ Ecosystem	Species diversity changes	X	X	X
	Successional changes		X	X
	Endangered species	X	X	X
	Trends in guild populations	X	X	X

Notes: An X indicates the data that will be useful in that decision.

jor goal (DOE 1996b). These aspects should be considered in planning long-term studies.

In their recent future land use report (DOE 1996b), DOE acknowledged that inputs will be essential from a variety of stakeholder groups, including state and local governments, tribal governments, site-specific advisory boards, and other interest groups. DOE recognized seven land-use categories: agricultural, residential, recreational, industrial/commercial, open space, storage and disposal, and open space/recreational. Thus, open space and recreational (generally low level human use that can maintain the integrity of natural ecosystems) make up three of the seven categories. DOE completed detailed future use plans for the 16 largest or most-contaminated sites, using input from a variety of governmental, scientific, and stakeholder groups (DOE 1996b). They estimated that nearly 86% of the land acreage on these 16 sites should remain open space, 2.4% should be open space/recreational, and another 0.4% should be recreational. This suggests that a significant proportion of the land at DOE is slated to remain open space, and data from long-term avian studies could be critical to appropriate management of these sites, and to selecting which sites to maintain.

MANAGEMENT NEEDS AND LONG-TERM AVIAN STUDIES

Managers, whether they are dealing with Superfund, DOE, Department of Defense, or other hazardous waste sites, require certain types of data for adaptive management. Adaptive management includes maintaining on-going research to determine the effectiveness of management decisions, and altering management decisions when warranted. Since management goals often include preservation of healthy populations or communities, research involving managed and relatively pristine areas is needed to define "healthy" conditions. Adaptive management provides an opportunity for ornithologists to conduct basic research at reference sites while directly playing a role in adaptive management. Existing long-term data sets provide the basis for adaptive management.

Since it is not possible to have data on all aspects of the life histories of all organisms in an ecosystem, indicators are essential (Hunsaker et al. 1990, Suter 1990). Birds are ideal indicators because they are diverse with respect to trophic level and life history strategies, some are long-lived and at the top of food chains, they are diurnal and highly visible, they are responsive to a variety of stressors, and they are of interest to the public (Burger and Gochfeld 1995).

Currently, long-term studies on birds deal with aspects of individuals, populations, communities, and ecosystems (Table 1). Individual parameters measured include habitat preferences, changes in habitat preferences, and anatomical abnormalities. Population parameters measured in long-term studies include population numbers and trends (the most popular of the long-term studies with birds), trends in reproductive success, changes in age or sex ratios, and trends in contaminant levels. Community or ecosystem parameters recorded in long-term studies include changes in species diversity, changes in numbers and distribution of endangered species, and successional changes in bird communities or guilds, among others (Sheehan 1984, Burger and Peakall 1995, Linthurst et al. 1995). When researchers and managers work together to determine the types of data to be gathered before the initiation of a study, then the necessary data will be available to maximize ecosystem integrity and restoration goals.

One of the important aspects of designing experiments and observations is the opportunity for both managers and researchers to refine and select reference sites for comparison with potentially impacted sites. Recently Reynoldson et al. (1997) defined reference conditions as "the conditions that are representative of a group of minimally disturbed sites organized by selected physical, chemical, and biological conditions." Implicated in this definition is an understanding of natural variation, both temporally and spatially. Natural variation can encompass population size or growth rates, community structure, or ecosystem assemblages. Reference sites can be particularly useful on DOE sites because many of the sites are extremely large, with several square miles, providing minimally disturbed areas as well as those impacted by physical, chemical or biological disturbances.

In most cases, long-term studies are conducted on individual species, and concentrate on individual and population parameters. These include studies on Black-legged Kittiwake (*Rissa tridactyla*; Coulson 1968), Black Skimmer (*Rynchops niger*; Burger and Gochfeld 1990), Common Tern (*Sterna hirundo*; Burger and Gochfeld 1991), Florida Scrub-jay (*Aphelocoma caerulescens*; Woolfenden and Fitzpatrick 1984), Great Tit (*Parus major*; Perrins and McCleery 1985), Red-billed Gull (*Larus novaehollandiae*; Mills 1989), Sparrowhawk (*Accipiter nisus*; Newton 1986), and White Ibis (*Eudocimus albus*; Bildstein 1993; see also Newton 1989).

The decisions that planners and managers have to make relate to current or future land use. The first decision, if land is disturbed or undeveloped, is whether the site (or part of the site) should remain as a preserve. Data from long-term avian studies can be particularly useful in making this initial decision since the presence of viable, healthy populations of endangered species and species or assemblages of concern (i.e., forest interior-nesting neotropical migrants), will contribute to justification of this land use (Table 1). But such data are only useful if they contain information on specific habitat requirements, viable population sizes, and territory requirements such that managers can determine what needs to be preserved. On SRS, data on Red-cockaded Woodpeckers and Bachman's Sparrows has proven particularly useful to managers in determining logging regimes, as well as the matrix of forest types required to preserve the species (see Dunning et al. *this volume*).

If some of the land is to remain wild or relatively undisturbed, the following questions arise: what part of the land should be a preserve, what size should be preserved, and what landscape issues are critical for the target resources? All of these questions require data from long-term avian studies to make reasonable judgements (Table 1). Landscape-scale issues require the most detailed studies from all levels of biological organization. Further, long-term data sets dealing with birds are particularly useful for modeling population changes in a changing landscape (Pulliam et al. 1994), as would surely occur with either remediation or restoration.

Decisions concerning preservation of land are those with which ornithologists are most familiar, and in which they often participate. Further, ornithologists frequently become involved when currently wild land is being considered for development, and the types of data listed in Table 1 from long-term studies are often pivotal in the decision concerning whether to develop land or how much of it to develop. These data are frequently used extensively in environmental impact statements and in public hearings.

However, the nation now faces a large set of future land use decisions that relate to the DOE sites, as well as to Department of Defense lands, that cover far more land than do Superfund sites. Many of the DOE sites are contaminated with nuclear and chemical wastes, and decisions must be made regarding cleanup. Although initially the U.S. Congress and the general public wanted to see these sites cleaned up to pristine conditions, the cost of such cleanup is prohibitive (Grumbly 1996). It is now clear that decisions must be made about what areas to clean up, and how clean they must be. Future land use and ecological considerations will drive such decisions since the degree of human health risk can be managed by controlling access and future land use. If there is no off-site migration of contaminants, then human risk (and in many cases off-site ecological risk) can be reduced or eliminated, if people are kept out of the site.

The decisions that DOE must make regarding their lands include (1) whether to maintain the National Environmental Research Parks in their present state, (2) whether to remediate, (3) how much (amount of land) to remediate and to what contamination level, and (4) what to restore and to what degree. All four of these decisions depend on future land uses, which will be determined by DOE in collaboration with various stakeholders, including scientists (NRC 1995, Wernick 1995, DOE 1996b, Commission on Risk Assessment and Risk Management 1996). Both their immediate and long-term actions will depend on regulatory considerations since DOE must work toward compliance with existing environmental laws. In the 1970s several of the DOE sites that were large with much of their areas in natural ecosystems typical of their respective regions were declared National Environmental Research Parks and were devoted to the study of the effects of energy production on

TABLE 2. TYPES OF LONG-TERM DATA THAT WILL AID IN DECISIONS ABOUT MAINTENANCE OF DOE SITES AS NATIONAL ENVIRONMENTAL RESEARCH PARKS (NERPS) WHETHER TO REMEDIATE, WHETHER TO RESTORE ECOSYSTEMS, AND WHETHER REGULATORY CONSTRAINTS INFLUENCE THEIR MANAGEMENT DECISIONS

Biological Level	Parameter	NERP	Remediation	Restoration	Regulation
Individual	Habitat preferences	X	X	X	
	Changes in preferences	X		X	
	Morphological changes		X		X
Population	Population size and trends	X	X	X	
	Age and sex ratio changes	X		X	
	Reproductive success trends	X		X	
	Contaminant trends	X	X	X	X
Community/ Ecosystem	Species diversity changes	X	X		
	Successional changes	X	X		
	Endangered species	X	X	X	X
	Trends in guild populations	X	X	X	

Notes: An X indicates where the data will be particularly useful in making that decision.

the environment (Dale and Parr 1998). In 1972 the Atomic Energy Commission designated the SRS as America's first National Environmental Research Park (Gibbons 1993).

There are two important aspects to the land use question for researchers: what are the ecological resources that stakeholders wish to preserve, and what are the ecological risks of present disruptions (biological, radiological, and chemical) and cleanup operations? Biologists should enter the discussion about how ecosystems are used, or such decisions will be made without data on use of ecological resources. For example, interviews with both sportsmen and the general public living around SRS indicated that maintenance of SRS as a National Environmental Research Park, Preserve, or for recreation ranked the highest, and residential and industrial uses ranked the lowest (Burger et al. 1997a; Burger 1997, 1998).

It is in the arena of the DOE lands that long-term studies can contribute to all aspects of decision-making (Table 2). Having long-term data on endangered species, sensitive species, or vulnerable groups (such as neotropical migrants) will prove invaluable in making decisions about whether to maintain the NERPs in their current status, or to reduce their size (many of these decisions will be similar to those listed in Table 1).

Decisions to remediate will depend first on future land use, to which avian data can surely contribute. For example, the presence of functioning, interesting, unique ecosystems may suggest that some portion of the land should be used either for a preserve or for recreation. Decisions about what land to remediate, and the degree of remediation will depend also on the contaminant levels present. Trade-offs must occur between the presence of the current ecosystem (which may be functioning even though it is slightly contaminated), and the damage that the remediation will do to those systems. This damage, however, cannot be assessed without data on the existing ecosystems, and long-term data will be most useful since they will demonstrate not only current communities but their long-term viability.

Restoration decisions will profit markedly by data from long-term studies since, with knowledge about individual, population, and community structure, it will be possible to define the level of restoration possible for that parcel of land, and the possible trajectory of recovery given the avian assemblages that exist on the site prior to restoration. Restoration may be active or passive, and again, data from avian studies may contribute to the decision about whether to allow natural succession to occur or to speed it up by the process of restoration.

Lastly, there are regulatory constraints that must be addressed in any planning or management decision (Bilyard et al. 1993), and some data from long-term studies are useful for this mandate (Table 2). In most cases, such data relate to contaminant levels and the presence and status of endangered species. In both cases, long-term data sets with birds are particularly useful in establishing the current value of a site, in predicting its future value, in establishing management options, and in stewardship.

Many DOE sites have cleanup and remediation issues that revolve around the cooling ponds from their nuclear reactors that are no longer in operation. Continued maintenance of these ponds costs in the millions of dollars annually, and the question of no longer maintaining them is important. Data from long-term studies with contaminants can contribute to these decisions. For example, from September 1991 to December 1994 the water levels of Par Pond on SRS were lowered by 6 m. Par Pond had received the cooling water effluent that was periodically contaminated with radiocesium and smaller amounts of other contaminants from 1954 to 1964. During the drawdown, Mourning Doves (*Zenaida macroura*) feeding on the exposed sediments were collected for radiocesium and heavy metal analysis (Burger et al. 1997b, Kennamer et al. 1998). Levels of radiocesium in the muscle tissue of doves from Par Pond were sufficiently high as to pose a potential human health risk if hunters had been allowed to hunt there every day during the dove hunting season. These data could be compared to levels in the tissues of other birds from long before the draw-down of Par Pond. These data are useful to managers and regulators in their decisions about future drawdowns, and were important data for them when deciding not to allow L Lake (another cooling pond on SRS) to revert to its previous levels.

DESIGNING LONG-TERM RESEARCH FOR PLANNING AND LAND MANAGEMENT

Many long-term studies with birds at SRS, and elsewhere, were designed many years ago to provide data on behavior, ecology, and reproductive success of individual birds, or groups of birds (Newton 1989). Thus they were not designed with management and pubic planning in mind. This, however, does not mean that the data are not useful for management and planning, nor does it mean that the data that are gathered in the future cannot be even more useful, often with only minor tinkering.

Tables 1 and 2 indicate the types of data that would be useful to managers and planners, with the idea that some types of data can be gathered now, even if they were not part of the original protocol. For example, data from long-term studies can be used to design types of remediation and restoration, and can be used as measures of success of specific remediation or restoration plans. Evaluating the effectiveness of remediation and restoration is an important aspect of management. Without it we will be unable to determine which methods to use in the future (Burger 1994, White 1996).

Finally, risk assessors are defining a role for expert judgement in risk analysis (Otway and Winterfeldt 1992). While expert judgement has always played a role in risk assessment and management (Barke and Jenkins-Smith 1993), this role may increase in the future because good science may not always be able to provide the unambiguous facts necessary for decisions. In the context of avian research, the presence of scientists associated with long term-studies will provide a cadre of experts that are partially legitimized by these studies. An avian directory of long term studies, cross-referenced to species, types of studies, and contaminants or other anthropogenic stressors, could provide an invaluable stable of "experts" for aid in remediation, management, and planning decisions.

In summary, ornithologists have participated in many long-term studies designed to gather information on trends in populations, reproductive success, and chemical contamination. I suggest that avian researchers would profit from understanding the data needs of planners and managers, and that cooperation in the early phases of study design will increase the usefulness of long-term avian studies. Further, long term data sets can be used to evaluate the relative importance and uniqueness of habitat, contributing markedly to the initial decision of whether to remediate contaminated lands.

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AN APPROACH TO QUANTIFYING LONG-TERM HABITAT CHANGE ON MANAGED FOREST LANDS

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Abstract. Forest land managers must determine the effects of their management on nontarget resources, resources for which no current inventory is available, and for which no past trend information exists. The tools available to managers to make these determinations consist of the inventory information gathered for those commodities desired to be produced, i.e., the target resources. A method is proposed here, using available land use records and bird data sets for the Savannah River Site, to reconstruct past land use conditions and bird community composition and distribution. In addition to describing habitat change and resource response, the method can estimate the amount of uncertainty inherent in assessing implications of land management decisions for nontarget resources.

Key Words: bird-habitat relationships, forest history, forest management, habitat modeling, land management planning.

Forest land managers need to make rapid and accurate decisions to be effective natural resource stewards. The quality of these decisions depends upon several factors, one of which is the accuracy of inventory information available. Unfortunately, land managers rarely have the staff to inventory resources other than those they produce intentionally. Inventories that are completed focus on a few critical elements relevant to commodity production. Such inventory work is typically carried out in a cyclical fashion, in which managers return to individual forest stands on a regular basis.

Information available to the decision-maker often is only the current inventory. Unless this individual has a long history of management responsibility on the site, little information from the previous inventories will be available to them. Unfortunately, the details of earlier inventories often are not archived in a retrievable fashion. Because timber harvest rotation ages often are longer than the careers of managers, it is unlikely that managers will have much information on the history of a stand or its historical productivity.

If the absence of resource inventory information was the primary problem faced by managers, their tasks would be difficult enough. However, as conditions change over time, additional resources often are identified as important products of the forest. As these resources are identified, forest managers become responsible for producing and monitoring them.

This addition of resources to the targets of production is the problem of interest here. Academically trained to produce one set of resources, managers later in their careers find themselves required to produce other, nontarget resources as well. The managers cannot have been trained to produce these nontarget resources nor, more importantly, can they have adequate inventory information for these nontarget resources. The resource management nightmares that result from these circumstances are numerous. The Spotted Owl (*Strix occidentalis*; Thomas and Raphael 1993) of the Pacific Northwest; the Bachman's Warbler (*Vermivora bachmanii*; Evenden et al. 1977, Hooper and Hamel 1977, Remsen 1986), the pondberry (*Lindera melissifolia*; DeLay et al. 1993), and the Red-cockaded Woodpecker (*Picoides borealis*; Hunter et al. 1994, Conner et al. 1996) of the Southeast are all examples of such resource management nightmares. Ultimately, without an accurate understanding of the habitats for these species and others, creatures of considerable value economically, like the Passenger Pigeon (*Ectopistes migratorius*), aesthetically, like the Carolina Parakeet (*Conuropsis carolinensis*), or ecologically, like the Ivory-billed Woodpecker (*Campephilus principalis*), are lost to future generations.

In this brief paper, we propose a mechanism to address this problem using the lands of the Savannah River Site (SRS) managed by the Savannah River Natural Resource Management and Research Institute (SRI) as a model. We suggest exploring potential effects of land management planning by looking not for more sophisticated means to anticipate the future but by taking advantage of current technology and understanding of ecological processes to reinterpret the historical record of land use. The objectives of this paper are to (1) outline a process to retrofit current land-use information into a history of the SRS, and (2) suggest methods to apply existing bird-habitat relationships to develop predictions of past bird communities. A byproduct of this process will be a method for forest land management planners to evaluate consequences of decision-making processes on birds and to use those evaluations to guide future decision-making.

THE RECONSTRUCTION PROCESS

The proposed process involves a reconstruction of the past land use environment. The reconstruction uses available information projected back into the past, assesses the accuracy of those backward projections based upon examination of past records, makes predictions of later conditions of nontarget resources from the reconstructions of the past, and compares those predictions to subsequent measurements of those resources. We outline several methods to conduct the reconstructions. The several bird community studies presented by others in this volume provide the "nontarget resources" for which the projections can be made.

TECHNIQUES SUGGESTED FOR RECONSTRUCTING FOREST HISTORY

Three techniques are outlined for reconstructing forest history. They are (a) strict backtracking from present inventory coverage, (b) successive backtracking using past inventory coverage, and (c) re-evaluation of old aerial photographs. Each of these techniques is capable of projecting a past forest condition that can be mapped. The utility of using several of these techniques on the SRS is that with the extensive history of forests and bird communities maintained by researchers on the site, it will be possible to develop several depictions of the history and compare them with each other. The result of the comparison will be information useful to managers in other locations who may have only one of these methods at their disposal to reconstruct the history of the forest.

Strict backtracking from present inventory coverage

The most straightforward method of reconstructing the history of the forest on the SRS is to use the current inventory of existing tabular files and maps of stands. These data are maintained in a management information system, the Continuous Inventory of Stand Conditions (CISC), and a set of maps maintained in a geographic information system (GIS). By associating characters of age and composition with the mapped stands, it is possible to estimate the mosaic of forest conditions in approximately 10-yr intervals into the past from the present to the establishment of the SRS in the 1940s. This technique should be relatively easy to apply, and is limited only by the unavailability of information on the previous composition of stands recently harvested or otherwise modified, as by fire. Where stands are regenerated, the previous CISC data for that stand can be used to continue the projection of history in the stand. One important qualifier for this process will be the extent to which this stand information is actually available. Much of it may have been lost or destroyed as no longer relevant information. A second qualifier is the extent of the area that can be typed by this method. If the area that cannot be typed is large, this technique will be less useful than if that area is small.

The steps in this process are

1. Quantify age-condition-structure relationships using a cross-sectional approach, given the existing CISC data.
2. Backtrack in 10-year time intervals to estimate expected situation during each interval.
3. Overlay bird-habitat affinity information (e.g., Hamel 1992) onto the projected habitat situations for specific time periods.

The result of applying this process will be a set of maps of distribution of habitats for particular bird species, with associated suitabilities, for the entire SRS at specified times. From these maps can be derived summaries of extent of habitats believed to be present at the specified times. Empirical associations of relative abundance with habitat condition (e.g., Hamel 1992, Hamel et al. 1988) will indicate relative abundance of species at specified times. Comparison of the abundance and quality of habitats and relative abundance of the birds suggested by this process for the specified times will indicate the suggested trend in habitat availability and relative abundance for the species during the period of time since establishment of SRS. The individual snapshots of habitat availability and suggested relative abundance are the outcomes available for comparison among methods for projecting the past conditions on SRS.

Using past inventory coverage—successive backtracking

To the extent that they are available, historical CISC records also will permit construction of the forest for stands at particular times in the past. This is the equivalent of using the current CISC data base for depicting the forest at the present time. Although perhaps the most effective way to reconstruct the management view of the forest at some time in the past, this method likely suffers from lack of available records, an unfortunate casualty of the management focus on current conditions and the next management action. Useful for monitoring and managing intended resource uses, such a focus reduces the managers' ability to inventory and monitor the nontarget resources in their care.

From each of these sets of historical records, a past history can be developed as in the first technique. Comparison of these histories is a useful check on the use of management data to depict history. Differences between the maps projected from the first technique and actual past maps from this technique reflect at least two sorts of errors, both of which are relevant to predicting occurrence of nontarget resources from stand inventory information. The differences confound error introduced by the projection process with error introduced by the variation in individuals who did the initial inventories and prepared silvicultural prescriptions for the areas. Comparison of retrofit projections with actual past estimates, however, does provide an important measure of change, despite problems with observer variability in preparing stand maps from inventory information (stand typing).

As in the first technique, projections of bird communities can be overlain onto the projections of habitat conditions to estimate bird communities at particular times in the past. Comparisons of bird community estimates derived from retrofitting current stand information with estimates derived from using actual past estimates is again a measure of observer variability in typing. Until this sort of error can actually be measured, however, it will not be possible to ascertain whether it exists at an acceptable level.

A potentially appealing use of past inventory infor-

TABLE 1. SCHEMATIC OF USE OF CURRENT AND PAST VEGETATION AND BIRD DATA SETS TO RECONSTRUCT AND TEST LAND USE HISTORY

	Prediction data set (test data set)					
	CISC data gathered (air photos)					
		past				
Time Period	current	10	20	30	40	50
Current	A(T)[a]	P	P	P	P	P
10 yrs ago	F	A(T)	P	P	P	P
20 yrs ago	F	F	A(T)	P	P	P
30 yrs ago	F	F	F	A(T)	P	P
40 yrs ago	F	F	F	F	A(T)	P
50 yrs ago	F	F	F	F	F	A(T)

[a] Symbols in the table reflect whether the vegetation maps are A — actual, or F — forecasts of the future based upon actual measurements in the past, or P — historical projections into the past of measurements made later. (T) — indicates that aerial photographs can be used to test measurements made on the ground; they can also be used to evaluate both Projected and Forecast maps.

mation will be the use of earlier CISC inventories to project both backward and forward in time (Table 1). Each of the past CISC data sets can be used to project both forward and backward in time to establish a set of predictions of habitat conditions for all the time periods to be examined. The utility of this approach will be that it provides a method to compare the accuracy of predictions made with data of different lag times, i.e., in which the predictions are one, two, etc. re-entry cycles removed from the actual inventory information on which they are based.

Retyping old aerial photographs

A series of aerial photographs exists for the SRS, as they do for many areas. It is possible to conduct an inventory of forest resources from each of these sets of photographs, and to identify individual stands and map them. This method, called forest typing, involves interpretation of the photographs and determination of the extent of stands of similar conditions of composition (forest type) and structure or successional stage (stand condition class). Although a respected method of forest inventory and management work, it suffers in that it takes a great deal of time to retype old aerial photographs.

The strength of this approach is that it will allow comparison of the projections of CISC with replicable, objective data sets compiled from the aerial photos. Observer variation is potentially controllable by having a single individual conduct the silvicultural prescriptions from the photographs themselves. Ground-truthing of the old photographs obviously will not be possible. Bird data can be overlain onto the projections of the aerial photos as well, as in the other methods.

SRS—AN IDEAL CASE STUDY AREA

SRS is an ideal area on which to test this approach or apply this model. The size, forest mix, location, and forest management activity conducted by SRI on SRS are representative of National Forests or of other managed forest lands in the South. The advantage of SRS is the availability of relatively long-term investigations of resources other than timber. This array of biological data provides the opportunity to evaluate how well managers might anticipate effects of management activities on nontimber resources.

APPLICATION OF THE RECONSTRUCTION PROCESS

As an example of this process, we analyzed the 1988 CISC database for the SRS to estimate changes in habitat from 1950–1988. We used the 1988 CISC database because it was the oldest complete database available to us. As mentioned above, information on prior history is lost when stands are regenerated and data on new stand conditions are inserted into the CISC database. Thus use of more current databases would result in the loss of more information on prior history.

We selected 4–7 compartments in each of three regions of the SRS, regions devoted primarily to Forest Service management. We excluded heavily industrialized areas from this test. The selected compartments also were located away from the Savannah River floodplain, which has different soils, hydrology, and forest types than the upland portions of the SRS. We excluded areas within the compartments identified in the CISC database as deciduous forest because studies of these forest types have shown little temporal change in distribution on the SRS since the 1950s (J. Pinder, pers. comm.). The following amounts of pine forest and open habitats remained for analysis: northwest (NW) region (compartments 14–17, 2,227 ha), northeast (NE) region (compartments 24–29, 4,475 ha), and southeast (SE) region (compartments 76, 80–85, 4,812 ha) (Table 2). We classified the remaining pine forest and open habitat stands in these regions by 10-yr age class using the year of planting recorded in the CISC database.

We then made a series of assumptions to extrapolate 1950 habitat distributions from the current (1988) database. For all stands identified in 1988 as pine forest (including stands of forest types = loblolly pine, *Pinus taeda,* longleaf

TABLE 2. 1988 HABITAT DISTRIBUTIONS IN SELECTED SRS COMPARTMENTS, EXPRESSED AS PERCENTAGE OF TOTAL PINE/OPEN HABITAT WITHIN THE COMPARTMENTS

	Age Classes					
Region	pre-1945	1946–1950	1951–1960	1961–1970	1971–1980	1981–1988
Northeast	32	5	26	15	3	19
Northwest	13	7	52	3	15	10
Southeast	10	6	53	2	9	20

pine, *P. palustris,* and slash pine, *P. elliottii*) we assumed that:

1. Stands with year of planting of 1945 or earlier were forested in 1950. Current studies of forest maturation and avian response show that 5-yr-old pine stands (especially loblolly and slash pine stands) are likely to consist of 4–5 m tall trees, and be dominated by forest-associated birds (Dunning and Watts 1990; J. B. Dunning, unpubl. data).
2. Stands with a year of planting between 1946–1950 were in regeneration in 1950, and therefore consisted of old-field successional habitat.
3. Stands with a year of planting between 1951–1980 were active or fallow agricultural fields. Within these age classes the stands aged 1971–1980 are the most problematic. At this time, most of the initial conversion of farmland to planted forest was completed, and some harvest of older forest may have been occurring. We treat this age class as part of the agricultural conversion because we have found no sources indicating that substantial timber harvest took place in the compartments we used during this decade.
4. Stands with a year of planting between 1981–1988 represent potential error in the analysis, as the history of these stands prior to planting is unknown.

By this analysis the three regions differed substantially in their 1950 distributions of pine forest and open habitats (Table 2). At least 32% of the NE region was forested in 1950 (as identified by pre-1945 year-of-planting designations) while only 10–13% of the NW and SE regions were in pine forest. In all three regions, we estimate that 5–7% of the regions were in regeneration. Between 45–70% of each region was in agriculture in 1950, as indicated by planting years between 1951–1980 in the 1988 CISC database. The NE region had the lowest estimated proportion of farmland, and also the lowest proportion in the problematic 1971–1980 age class. Error rates in the 1950 habitat reconstruction varied from 10–20% as estimated by the 1981–1988 age class.

From this initial analysis, we estimate that 10–32% of the SRS was forested in 1950, while 50–70% was more open. If needed, a decade-by-decade portrait of the conversion from agriculture to managed forest could be developed. About 5% of the SRS was probably similar to regeneration stands today.

As loss of information in the CISC databases associated with the most recent habitat conversions totaled 10–20%, use of even older databases would likely improve confidence in this type of reconstruction. Thus the use of older CISC data as outlined in the second technique would build upon the process we have initiated here. A major improvement in our ability to conduct this type of analysis would be to change the CISC database structure so that prior history is not lost when stands are harvested and replanted. Information is also lost with the current database structure when stand boundaries are redrawn (for instance, when small, similar stands are combined into a single stand). At such times, stands are often renumbered, resulting in the loss of all historical information associated with the former stand numbers. We strongly urge that managers be receptive to the need for historical information on their management lands by retaining such information in their stand databases.

The final step in the process of quantifying long-term habitat change using the CISC databases was to overlay avian habitat requirements onto the projected habitat conditions for different time periods, and estimate change for specific bird species. We compared avian surveys conducted by E. Odum in the early 1950s (summarized by Meyers and Odum *this volume*) with J. B. Dunning's studies of birds of open habitats (clearcuts) and pine forest during the late 1980s and early 1990s (for methods see Dunning and Watts 1990, Dunning et al. *this volume*). With few exceptions, we found that breeding densities and species lists from Odum's "pine" and "pine scrub" habitat categories were similar to modern avifaunas in mature longleaf pine forest stands (Table 3). The active and fallow agricultural fields surveyed by Odum (Meyers and Odum *this volume*) contained an avifauna distinct from those in open habitats present on the SRS today (Kilgo et al. *this volume*; J. B. Dunning, pers. obs.). Thus a first approximation of changes in the avian communities on the SRS can be tracked by reconstructing changes in open and pine-dominated habitats in different regions of the SRS.

EXISTING SRS DATA SETS

A rich and relatively long historical set of databases on the flora and fauna is available for

TABLE 3. MOST COMMON BIRDS RECORDED ON SURVEYS IN 1950S (ODUM[a]) AND 1980–1990 (DUNNING[b]) OF THE SRS

	Census Period, Habitat Sampled, Species Richness			
Rank Abundance	1950s Agricultural Fields (S = 8)	1950s Pine & Pine Scrub (S = 18)	1990s Clearcuts (S = 27)	1990s Mature Pine –
1	Eastern Meadowlark	PINE WARBLER	**Prairie Warbler**	EASTERN TOWHEE
2	Field Sparrow	**PRAIRIE WARBLER**	**Eastern Towhee**	PINE WARBLER
3	**PRAIRIE WARBLER**	**BACHMAN'S SPARROW**	Indigo Bunting	BACHMAN'S SPARROW
4	Eastern Kingbird	**NORTHERN CARDINAL**	**Bachman's Sparrow**	Indigo Bunting
5	**MOURNING DOVE**	**EASTERN TOWHEE**	Yellow-breasted Chat	PRAIRIE WARBLER
6	RED-HEADED WOODPECKER	Brown-headed Nuthatch	Northern Bobwhite	MOURNING DOVE
7	Eastern Bluebird	Summer Tanager	**Northern Cardinal**	Carolina Wren
8	Orchard Oriole	Tufted Titmouse	**Mourning Dove**	EASTERN WOOD-PEWEE
9		EASTERN WOOD-PEWEE	Blue Grosbeak	NORTHERN CARDINAL
10		Great Crested Flycatcher	Brown-headed Cowbird	RED-HEADED WOODPECKER

Notes: Species found in either of the 1950s surveys and 1980–1990 clearcut surveys are indicated with **boldface**; species in either of the early surveys and late surveys in mature pine stands are indicated with CAPITALS. Note that 6 of the species most common in early pine/pine scrub habitat occur in both clearcuts and mature forest from later survey period, while only 3 of the species most common in agricultural fields in the 1950s appear on the 1990s lists. Scientific names are in Appendix 1.

[a] For list of sources see Meyers and Odum (*this volume*).

[b] J.B. Dunning, pers. comm.

SRS. Extensive vegetation and bird data sets (Meyers and Odum *this volume*) are among those available. Additional data on climate, physiography, topography, and soils also may be useful. For simplicity, we reconstruct land-use histories without reference to these other data sets. The approach depends upon use of the existing and past vegetation data bases to reconstruct past land-use, a bird-habitat association model to predict past bird communities, and a group of validation vegetation and bird data sets to compare estimates of past land use and bird communities to those actually measured at the time.

VEGETATION

Several vegetation coverages exist for the site, four of which are important as reconstruction tools. These are the existing USDA Forest Service (USFS) Geographic Information System coverage (GIS), the set of current and past records of the Continuous Inventory of Stand Conditions data base (CISC), current and past aerial photographs, and the Forest Inventory and Analysis (FIA) survey data.

Existing GIS coverage

This is a thorough, accurate map of the boundaries of the existing compartments and stands, digitized to high standards of accuracy. Boundaries of management compartments are expected to be stable over time, while boundaries of stands reflect the different timber staff assistants and their views of management options.

Advantages.—The high quality of existing GIS coverage for SRS means that reconstruction will be relatively easy to accomplish. Manipulation of CISC data for existing stands in the GIS is relatively direct and rapid. Use of the GIS to identify larger scale units of habitat for particular bird species is easy.

Disadvantages.—A large investment in quality control and digitizing initial information, as well as in maintenance of equipment and data, is involved in use of the GIS. GIS lacks the flexibility to change stand boundaries that is inherent in individual typing of aerial photographs because the GIS is a depiction digitized from other sources rather than the primary data source.

Current CISC data

The CISC data base includes information identifying the individual stands within compartments. Associated with each stand is a tabular data set that reflects the management information concerning the vegetation of each stand. Forest type and site index data, stand condition class, intended management type and associated site index for that management type, stand age expressed as the stand birthdate, a modest number of quantitative measurements of the vegetation, and some indication of the management actions taken during the current entry cycle form the data in CISC. CISC data are gathered by staff foresters and reflect a minimal amount of effort consistent with classification to the appropriate forest type.

Advantages.—CISC data are the inventory data on which land management decisions are based. Using them directly ties information on nontarget resources like birds to the best representation of the conditions on the ground. All members of land management and management planning teams are familiar with the data, their use, and limitations.

Disadvantages.—CISC data have uneven accuracy from place to place, period of time to period of time, and are subject to certain kinds of observer variation that can be frustrating. Some preparers of CISC data are prone to interpret the field information on stand composition with a bias toward economically important trees in the stands. Others will have relatively less bias to commercial species. Variation in typing is due to such biases. The relatively small number of actual biological descriptors in the CISC data creates difficulties for workers wishing to infer the presence or absence of other attributes of stands, such as snag densities, presence of certain volumes of downed woody material, and the like.

Current and past aerial photographs

At approximately 10-yr intervals, complete coverage of low altitude aerial photographs has been taken to permit foresters to develop type maps for managed forest lands as part of the reentry cycle. An evaluation of existing sets of aerial photographs will permit development of an independent map of forest stands from each set of photographs.

Advantages.—Each available set of aerial photographs is a document of conditions existing at a particular time. As such, these records are a most useful documentation of actual conditions. As remotely sensed data, the photographs cover areas much larger than stands, and landscape features can be measured from them. Observer variation in developing forest type maps can be examined by having several different observers produce type maps from the same set of aerial photographs.

Disadvantages.—The major disadvantage of using aerial photographs is the very time-consuming process of examination required for observers to interpret them. Because the time required is great, it may be cost prohibitive to use complete sets of past photographs to reconstruct land use history.

FIA plot data

The FIA Unit of the Southern Research Station, USFS, maintains a set of permanent plots in forest throughout the South. A number of permanent plots are on the SRS. Each of these plots has been measured at least one time, and some as many as three or four times, at approximately 7–12 year intervals. Data from these plots can be used to estimate the amount of forest on the SRS. Location information is also available for the plots, permitting limited spatial analyses. It is also possible to use the measurements on the FIA plots to estimate certain quantitative measures of vegetation composition and structure not available in CISC.

Advantages.—FIA data are gathered to very high standards of accuracy, and involve a large number of quantitative measures of vegetation structure. The relatively large number of FIA plots on the SRS makes this an ideal site to use the FIA datasets as a means to quantify measurements of vegetation structure at the larger scale of the stands on a site of reasonable extent. Current FIA data sets are a vastly underused resource for tasks such as this one.

Disadvantages.—Because FIA data are gathered at randomly located plots, the measurements made on FIA plots are representative of forest types. Consequently, they are not mappable directly as are CISC and GIS data, and the forest type boundaries made on aerial photographs. Sensitivity of location data associated with FIA plots may make certain kinds of uses difficult for others wishing to use them for purposes of historical land use reconstruction.

BIRD PREDICTION DATA SETS

Two primary data sets exist for development of estimates of bird occurrence associated with land use reconstructions, Hamel (1992) and the USFS Region 8 BIRDHAB model (U.S. Forest Service 1994). Both are derived from the matrices of species by vegetation type associations developed in Hamel et al. (1982), in which the authors developed a set of species-by-habitat matrices for bird occurrence in the Southeast. These were tested in limited way by Hamel (1984, Hamel et al. 1988) and currently are being tested extensively by USFS Southern Research Station personnel using bird census data from SRS. The BIRDHAB model has been extensively modified to provide a user-friendly method for wildlife biologists and others in Region 8 to be able to use the GIS to associate bird species to mapped habitat conditions as found in CISC. Each of these data bases is sufficient to associate a group of bird species with a mapped stand.

Advantages.—Projections of the data in Hamel (1992) or BIRDHAB is easy to accomplish because each is an automated product. Each includes capability to associate birds with each acre of the SRS or any other southern forest land. Matrices in each were designed specifically to associate birds with forest type and stand condition designations such as those in Table 2.

Disadvantages.—Because the data in Hamel (1992) and BIRDHAB are generally applicable, and designed to associate birds with relatively broad vegetation type or forest type categories, each of these works represents a set of hypotheses of occurrence. Neither is capable of associating species with particular vectors of empirical measurements of vegetation structure, particularly as that vegetation structure may vary among stands that fall within the same forest type-stand condition class combination.

TESTING THE PREDICTIONS

Two kinds of tests are desirable from the data developed in the procedures outlined here. In one kind of test, past projections are compared with each other to identify uncertainty inherent in the reconstruction, hence the planning, process. In the other kind of test, past projections are compared with measurements made in other studies on the site. Each of these sorts of comparisons provides important information for managers on the effectiveness of the planning process.

CONSISTENCY OF PAST RECONSTRUCTIONS MEASURES RELIABILITY OF PREDICTIONS

The several reconstructed land use histories, e.g., one for each interval of CISC coverage, one for each set of aerial photographs, can be compared with each other to assess whether and to what extent the records of land use agree with each other. It is unlikely that they will agree, perhaps not even closely. Differences among the projections of land use is a measure of the uncertainty inherent in projections based on the inventory information that managers must use.

Bird communities based upon the historical projections of land use can be compared among themselves. The differences among these projections are another measure of the uncertainty on which management decisions must be based. Variation observed here is an actual measure of the variation introduced by the planning process. It is variation in possible estimates of nontarget resources based on information designed to monitor target resources.

ACCURACY OF THE PROJECTIONS REFLECTS THE SUFFICIENCY OF MANAGEMENT INFORMATION

Comparison of projected land use history with specific measures of landscape, such as those derived from retyping old aerial photographs or from historical vegetation studies, provides a measure of the accuracy of the land use projections. Testing the accuracy of projections made from data 10- vs. 20- vs. 30-yr distant from the source of the projections is a valid estimate of the uncertainty inherent in the projection process as it extends farther from the current time period. Comparison of bird community projections with those actually observed in the past studies of the SRS avifauna estimates the accuracy of predictions based upon general habitat association models.

Results of these comparisons will be instructive in showing managers the extent to which initial efforts to associate nontarget resources with categories in the management inventory and information system can be adequate for predictive purposes.

DISCUSSION

It has been said that "It is not management unless it is done on purpose." This reasonable standard for managerial activity fails to incorporate the reality that each management action affects not only the target resources, for which the activity was done "on purpose," but also may affect a wide range of nontarget resources as well. Each of these resources is affected in an unintentional way. Consequently, the effect of a management activity on a particular resource, such as a community of birds, may be beneficial, neutral, or detrimental.

Current forest management practices often appear to follow a row-crop agriculture mindset (cf. Garrett and Buck 1997), wherein the process is viewed strictly as a controlled activity leading to production of targeted amounts of specific known commodities. Only quality control measures are needed for a production activity, for which all relevant outcomes are believed to be known. With respect to nontarget resources, forest management is not such a controlled activity, nor is it short-term.

Management of forest succession or timber harvest rotation is a long-term process. Short-term monitoring records of management actions inhibit development of a collective history of that process. Without the collective history from a site, planning is not easily done and effects of management activities on nontarget resources are unavailable for improvement or even examination.

A real missing link in the land management process has been the recognition that each management activity is a manipulative experiment as well as a production activity. These experiments create an historical record of land management on a site. Far too seldom have these "experiments" been documented, so that their results could be used to adjust future management. Far too often the results of these "experiments" have been used by opponents of the manager to discredit the management. Neither of these outcomes is particularly useful to the nontarget resources in question.

Several methods for projecting the past history of the forest stands at the SRS have been described. An example of the use of one of them has been presented. Each ideally will produce a set of maps with associated tabular data. These data reflect several different projections of the actual extent, distribution, and characteristics of the forests of the SRS. The landscape structure of these projections could be estimated to characterize the spatial heterogeneity across the SRS. Comparison of techniques can identify characteristics of accuracy, precision, and efficiency in the projections of habitats. Using a single recent CISC coverage, it was possible to estimate the past extent of age class coverage on the SRS for 80–90% of the sample pine forest area.

Projected bird communities can be compared as well. Differences among them will be instructive of sources of error involved in habitat projections themselves, in associations of vegetation characteristics with habitats, in associations of birds with vegetation characteristics, and in spatial associations of habitats. Projected bird communities can be compared to actual measured communities when study sites for earlier works can be located on the maps. Differences between the actual and the several projected communities can similarly be apportioned into sources of error associated with the different techniques. The entire process can be used as a model for land use planning elsewhere as well, in locations where land use records are less extensive than those maintained at SRS.

Those working at SRI stand in a fairly enviable position of using historical records to establish predicted future conditions of the forest, and then testing the predictions against actual realizations. Differences between current and predicted current conditions are measures of the uncertainty inherent in land management planning. Knowledge of that uncertainty will be a powerful tool a manager can employ during development of a forest plan or other document indicating management intent.

CONCLUSION

Existing data sets for the managed lands of SRS can be summarized and several reconstructions of past habitat conditions made from them. While the task is not trivial, SRS is an ideal area to demonstrate the process described here. Existing data sets on past bird distributions on SRS can be used to assess relationships between birds and habitats on SRS at present and in the past. Habitat and bird community trend information potentially can be developed from these comparisons.

Data and analyses developed for this volume provide an unparalleled opportunity to elaborate and to test a process of forest reconstruction that is applicable to National Forest lands in the South. Although not universally applicable, this approach might even be called a "model" for forest reconstruction.

The process is not without difficulty, however. Lost data will be a potentially debilitating factor to conducting the projections inherent in testing these methods of land use reconstruction. But they will be an even greater debility for application at sites other than SRS. Readers must realize that management applications in actuality are not yet conducted in the same way as are controlled experiments. Managers must recognize the importance of maintaining archives of past inventory information to permit reconstruction of trends in habitats and distributions of nontarget resources.

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APPENDIX 1.

SCIENTIFIC NAMES OF BIRDS MENTIONED IN THE TEXT

Northern Bobwhite	*Colinus virginianus*
Mourning Dove	*Zenaida macroura*
Passenger Pigeon	*Ectopistes migratorius*
Carolina Parakeet	*Conuropsis carolinensis*
Spotted Owl	*Strix occidentalis*
Red-headed Woodpecker	*Melanerpes erythrocephalus*
Red-cockaded Woodpecker	*Picoides borealis*
Ivory-billed Woodpecker	*Campephilus principalis*
Eastern Wood-Pewee	*Contopus virens*
Great Crested Flycatcher	*Myiarchus crinitus*
Eastern Kingbird	*Tyrannus tyrannus*
Tufted Titmouse	*Baeolophus bicolor*
Brown-headed Nuthatch	*Sitta pusilla*
Carolina Wren	*Thryothorus ludovicianus*
Eastern Bluebird	*Sialia sialis*
Bachman's Warbler	*Vermivora bachmanii*
Pine Warbler	*Dendroica pinus*
Prairie Warbler	*Dendroica discolor*
Yellow-breasted Chat	*Icteria virens*
Summer Tanager	*Piranga rubra*
Eastern Towhee	*Pipilo erythrophthalmus*
Bachman's Sparrow	*Aimophila aestivalis*
Field Sparrow	*Spizella pusilla*
Northern Cardinal	*Cardinalis cardinalis*
Blue Grosbeak	*Guiraca caerulea*
Indigo Bunting	*Passerina cyanea*
Eastern Meadowlark	*Sturnella magna*
Brown-headed Cowbird	*Molothrus ater*
Orchard Oriole	*Icterus spurius*

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RISING IMPORTANCE OF THE LANDSCAPE PERSPECTIVE: AN AREA OF COLLABORATION BETWEEN MANAGERS AND RESEARCHERS

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Abstract. One area where basic researchers and managers have collaborated is in increasing the landscape perspective within their respective fields. Research and land management strategies have shifted towards greater consideration of landscape factors, a shift born from controversy over forest management. We learned several principles from our observations of this movement: many theoretical studies later held tremendous management value; controversy led to greater interest in science; competing demands on forested lands highlighted the need for landscape considerations; and there are great needs for new information. Controversy can be a great catalyst for researchers and managers to work together, and concerted efforts have brought advances in landscape understanding. Notable successes include a proactive model for understanding landscape processes. We are still far from effective landscape management. Most of the change has been in our thinking, not our actions. Managers and researchers at the Savannah River Site and on other managed forestlands have a great opportunity to forge a new "radical center" where collaboration is recognized as the route to greater understanding and action. The substantial history of collaboration between groups on the Savannah River Site to meet commodity production goals, conservation objectives, and research needs across diverse landscapes suggests that such a "radical center" is attainable.

Key Words: avian research, controversy, landscape, natural resource management, Savannah River Site.

One actively changing arena where Savannah River Site (SRS) management and researchers have worked closely together is landscape ecology. The SRS has been the site of several innovative landscape studies (Liu et al. 1995, Dunning et al. 1995, Haddad 1997), and research administrators in the Savannah River Natural Resource Management and Research Institute (SRI) have explicitly encouraged researchers to adopt landscape perspectives in their work. The Biodiversity Program of the SRI has funded landscape-level avian study since the late 1980s, including both computer simulation (Liu 1993, Liu et al. 1994) and field studies (Dunning et al. 1995, Kilgo et al. 1997). The Biodiversity Program also has encouraged a strong experimental program in landscape ecology with other organisms (e.g., butterflies [Haddad 1997] and small mammals [Anderson and Danielson 1997]). Because the successful implementation of such programs requires involvement of both researchers and managers, it is worth considering the landscape perspective from management and research points of view to provide several frames of reference for sponsoring a successful collaboration. In this paper, we examine the importance of the landscape perspective in management and research, and how attitudes towards this perspective have changed. We review the general differences in the perspectives of managers and researchers that have influenced our approaches to the landscape, giving examples of successes, lessons learned, and formulas for success.

THE IMPORTANCE OF A LANDSCAPE PERSPECTIVE

Why is it even necessary to discuss the importance of the landscape? In many regards, the importance of the landscape has become a cliche in management and research policy. Usually, however, few data exist on which to base landscape-level management. As much as we like to think that land management has taken on a landscape approach, impacts of many private timber sales and at least some public sales are analyzed without long-term projections of future landscapes that could be anticipated under the landowners' harvest programs, not to mention the ignoring of the neighboring landowners' programs. This is extremely significant because 80% of the timber harvest comes from private land, and private land constitutes 72% of the U.S. commercial timber acreage (American Forest Council 1991). Fifty-seven percent of all commercial forest acreage is non-industrial private forest lands (American Forest Council 1991). There are landscape plans for some industrial, state, and federal lands, but lands under active timber management without landscape plans are a major portion of the forest land base. Even where adjacent land managers are attempting to implement landscape plans, there can be serious impediments to coordination caused by different policies and management goals (Cortner et al. 1996). Researchers are designing investigations and analyzing completed studies without knowledge of the broader area in which their study sites are located. In spite of the apparent importance given to landscape issues, very little experimental research is designed to test landscape problems (Marzluff and Salabanks 1998). So even with the increase in time and paper that have been devoted to promoting landscape perspectives, most actions in the real world still consider a relatively small area. Thus the spatial scales of landscape analysis and planning still need to be increased. Mostly it is just our thinking that has changed.

The landscape approach is important because it is needed to research conservation problems appropriately, monitor environmental health, and manage the land. It is necessary for assessments of biological diversity (Probst and Crow 1991) and for natural resource analysis (Crow 1991). The distribution of habitats across complex landscapes needs to be considered when studying and managing animals that use a variety of habitats during migration (elk, neotropical migrant birds, and amphibians), seasonal or daily movements (Hunter 1997), or dispersal among parts of a metapopulation (Hunter 1997). Marcot (1997) suggested that not only the distribution of old stands may be important in landscape management, but that old forest elements between forest reserves are important for hidden species playing key ecological roles. Fragmentation is a landscape problem that increases edge, decreases interior conditions, and reduces viability of habitat for some species by isolating patches (Whitcomb et al. 1981). This isolation may slow or prevent dispersal of young (Hunter 1997).

Not only are the physical attributes of the landscape important, there are also ecological processes that operate at the larger scale (Dunning et al. 1992). Many processes are linked across landscapes, including effects from keystone species that travel between patches, nutrient cycling, and natural disturbance patterns like flood and fire (Carroll and Meffe 1994). There can be hierarchical linkage of processes through different scales (Allen and Starr 1982, May 1994), and different properties can emerge at different scales (Crow and Gustafsen 1997). Population-level processes such as predation are affected by the arrangement of organisms and habitats (Roff 1974). Natural disturbance regimes must be preserved at the appropriate scale to preserve the associated dynamics (Swanson et al. 1997). In summary, an increasing number of studies have shown associations between the landscape and birds (Marzluff and Sallabanks 1998).

Mistakes have been made when long-term landscape perspectives were not employed. A major conservation initiative of the 1960s and 1970s was the limiting of clearcut sizes and the scattering of harvest units across the landscape. Now, in our presumably more enlightened state, we find that perhaps it was dangerous to have asked for the small clearcuts, because we got them. The dispersed patch system (or "cookie cutter" approach) in forest harvesting led to increased fragmentation and a larger, perpetually drivable road system that was necessary to enable the creation and maintenance of these small harvest units. As we investigate the negative impacts of fragmentation, we can now realize that the larger-scale, landscape impacts of dispersed harvest systems were not given the same level of consideration as the small-scale, local habitat impacts when the cookie cutter approach was first designed.

PROGRESS MADE

To illustrate how much the perspective on landscape/local scales has changed, consider the transformation of research and land management paradigms in recent decades. The descriptive approach of the early naturalists evolved into the early experimental (or pseudo-experimental) approach of the ecologist and wildlife researcher. This experimental approach often focused on the density of animals in different forest stands and presumably examined habitat selection and habitat quality (Van Horne 1983). Now the avian researcher often designs studies investigating natural history information such as productivity, survivorship, and foraging habitat, but (in ideal situations) gathers this data in an experimental approach involving longer time and larger areas than used by the early naturalists that focused on these same topics.

The land manager (forest manager) of an earlier era was primarily concerned with sustained yield of timber and boosting forest productivity for wood products. Within this management framework, questions of habitat availability for wildlife were answered by providing a range of stand ages up to the maximum sustained yield rotation age. Next, the federal manager was concerned with multiple use, and though charged with maintenance of all species, commodity outputs still seemed to receive the focus. Most recently, the manager needed scientifically defensible management plans that provided for not only multiple use, but biodiversity, recovery of species, and ecological restoration. Ecosystem management at the landscape level is increasingly recognized by managers as a key to developing these plans (Risser 1988).

By the late 1980's and early 1990's, we were starting to think about landscape problems like never before. The researchers' input took on new value. An urgency for more information stimulated more support for research from U.S. Forest Service (USFS), for example, leading to requests for significantly greater funding. With support from the White House and Congress, the research budget increased between 1990 and 1995 while the USFS was moving toward ecosystem management (J. Toliver, Research Budget Coordinator, U.S. Forest Service, pers. comm.). While Congress has decreased the overall research budget (in real terms) since 1995, the USFS has held money constant in threatened and endangered species and ecosystem research programs by shifting funds from other research programs (J. Toliver, pers. comm.). This need for unbiased information was also one of the primary impetuses for the creation of the National Biological Survey (now the Biological Research Division of the U.S. Geological Survey).

Our progress includes several land management success stories. The multi-species habitat conservation plan developed for the California Coastal Sage Scrub was a landmark because it was the first comprehensive, ecosystem-based conservation plan drafted under the U.S. Endangered Species Act (O'Connell and Johnson 1997). The plan covers 15,240 km^2 in five counties, and integrates the efforts of numerous political jurisdictions. More than 120,000 ha of large blocks of habitat are expected to be preserved in conservation reserves (O'Connell and Johnson 1997).

The Coastal Sage Scrub plan evolved from the inadequacy of focusing management on single species and small-scale habitat planning. In 1995, Riverside County, California, completed an arduous, seven-year effort to create a habitat conservation plan for the endangered Stephens' kangaroo rat (*Dipodomys stephensi*). In the interim, however, three other species (a shrimp, a frog, and a bird) found in the same region were listed under the Endangered Species Act. Rather than start all over with plans for each of these additional species, planning officials in the affected southern California counties developed a comprehensive plan (called a Natural Communities Conservation Plan, NCCP) to protect the endangered ecosystem (O'Connell and Johnson 1997). An integral part of the NCCP is the development of a GIS database of land attributes that crosses political and ownership boundaries. With this database, planners can assess the landscape context of specific blocks of remaining habitat, identify important linkages between blocks, and determine proximity to core areas of conservation value (Stine 1996). Together with comprehensive population viability analyses of two of the endangered species (Price and Kelly 1994, Akçakaya and Atwood 1997), the California Coastal Sage Scrub NCCP is a benchmark for interagency, cross-boundary conservation planning.

Another success story resulted from controversy over an endangered species listing. In the 1980s, the U.S. Forest Service was charged with failure to comply with its own regulations under the National Forest Management Act (Gordon and Lyons 1997) in its management for the Northern Spotted Owl (*Strix occidentalis occidentalis*). The conservation strategy and recovery plan that was developed for the Northern Spotted Owl (Thomas et al. 1990, U.S. Department of Interior 1992) synthesized existing knowledge to lay the groundwork for a vast regional landscape management approach, later broadened to a multi-species plan (FEMAT 1993). Acceptance of this plan was not immediate, in part because it was developed by scientists, and thus managers felt little ownership in the final plan (Johnson 1997). The initial Spotted Owl effort did succeed in bring landscape science more effectively into management planning, but it was not a fully collaborative effort.

Finally, the Savannah River Site (SRS) is a current example of collaboration in both landscape management and basic research. How this landscape perspective developed is worth considering. The land that became the SRS was originally an agricultural landscape, converted to a largely forested condition by an aggressive tree-planting program in the 1950s and 1960s (White and Gaines *this volume*). This transformation was largely complete by the 1970s, before the interest in landscape ecology formed. Thus, there was little research done to monitor population or ecosystem response to the widespread changes. By the early 1980s, however, the Department of Energy (DOE, which funds virtually all research and management on the SRS) and the USFS (which implements the management) required information on how land use across the SRS impacted wildlife populations, endangered species, ecosystem functions, and other phenomena covered by DOE's mission.

Through the Savannah River Ecology Laboratory (SREL) and the Savannah River Institute (SRI), DOE had funded enormous amounts of high-quality, basic ecological research. But land managers sometimes complained that too much of the research was not focused directly to their urgent questions (J. Dunning, pers. obs.). The development of the landscape perspective in the 1980s provided a meeting ground for these potential antagonists.

To understand fully the impacts of timber operations on wildlife species of management interest, the managers within SRI needed to know how their land use affected species such as the

Red-cockaded Woodpecker (*Picoides borealis*) and Bachman's Sparrow (*Aimophila aestivalis*). Timber management changed the distribution of forest age classes across the SRS annually, and since both of these species were relatively poor dispersers, landscape-level impacts of these changes in habitat distribution were possible, indeed likely.

At the same time, ecologists at SREL and the University of Georgia were searching for an appropriate study system for testing landscape ecology theory. SRI agreed to fund a research program in which field studies to identify landscape influences were initiated, and a simulation model of timber management across the landscape scale was developed (Liu et al. 1995, Dunning et al. *this volume*). The modeling provided advice to the timber managers regarding potential impacts of their program on wildlife. The models themselves were an innovative application of a new ecological tool, spatially explicit modeling (Pulliam et al. 1992).

Both university ecologists and management-related biologists contributed to this collaboration. Timber management databases proved to be an invaluable resource for constructing current and past landscape distributions of habitats. The current 5-year and 50-year management plans gave the modeling project long-range forecasts of landscape change that could be built into the simulations. The ecologists contributed basic natural-history studies of habitat selection, demography, and dispersal for parameterizing the model. In conducting basic landscape research, the ecologists produced results that suggested the potential impacts of long-range management strategies. These results yielded practical gains to the development of management planning (Liu et al. 1995). Based in part on the success of this collaboration, additional studies of landscape effects on other birds, mammals, lizards, and butterflies were funded by SRI's Biodiversity Program, and conducted by ecologists from the University of Georgia, SREL, SRI and other universities (for example, Anderson and Danielson 1997, Haddad 1997, Kilgo et al. 1997).

We are finding, however, that even where there has been a great deal of research and landscape collaboration, there are still outstanding issues. With its large size (approximately 77,000 ha), the SRS would appear to be large enough to be independent of surrounding influences. We know from ongoing landscape analyses, however, that the SRS differs from adjacent land in characteristics such as human land-use practices, forest cover and type, urbanization, habitat fragmentation, and influences of exotic or feral organisms. Kilgo et al. (*this volume*) demonstrate that these differences translate to identifiable differences in bird populations. We have found that bird species associated with human land-use practices outside the SRS are present in greater numbers on the periphery within the SRS than they are in the interior (J. Dunning, unpubl. data), for instance. Thus, even large management units need to consider the impacts of landscape factors both within and external to the management unit itself. Data for such consideration are rarely available.

LESSONS FROM THE PAST

The greatest movement towards landscape considerations was born from controversies over forest management impacts on several species. These controversies influenced a redirection of resources and thinking toward the landscape approach. Ecosystem management, therefore, emerged in response to legal and societal demands, not science (Gordon and Lyons 1997). Red-cockaded Woodpecker issues in the East and grizzly bear (*Ursus arctos horribilis*) and elk (*Cervus elaphus*) issues in the West, followed by the Northern Spotted Owl issue, focused attention on large-scale questions. These questions involved population viability, the influence of adjacent habitats, dispersal, temporal scales, area sensitivity, metapopulation considerations, and the role of natural and manmade disturbances. The result of this focus was the movement toward ecosystem management, with its explicit emphasis on large spatial and temporal scales (Grumbine 1994).

There are several lessons here. One is that the basic scientific work of MacArthur and Wilson (1967), Levins (1969), and others that seemed so theoretical to some, eventually held tremendous management value. Another lesson is that it took third party catalysts to move the fringe ideas to the center through actions such as petitions to list species, and appeals and lawsuits on management decisions such as recovery plans and forest plans. These catalytic efforts brought science into the spotlight as societal and legal pressures have caused environmental advocates and land managers alike to reach out to science for answers (Gordon and Lyons 1997).

This emphasis on science, in turn, leads to the next lesson: that there is probably never enough information available to develop a land management plan thoroughly. It rapidly became apparent how little information was available. Land managers, especially with the USFS, needed the ability to manage the land to meet legal mandates for biodiversity and threatened and endangered species and to answer the charges of their critics. They became almost eager for long-term landscape analyses as these were seen as tools to help avoid appeals and to keep the timber program going. Habitat-specific density, basic productivity, juvenile and adult mortality, need for multiple habitats in close proximity, natural population fluctuations, source and sink habitats, and use of corridors were all issues or parameters that were critical to landscape analyses, but for which there was a lack of field knowledge (Conroy et al. 1995, Dunning et al. 1995).

Another lesson from observing this influence of controversy is that when a concerted effort was focused on a problem, great progress was made in our understanding of landscape influences. In three of the four catalytic species mentioned, application of the Endangered Species Act and the resulting "threat" to timber outputs motivated the effort. The coordinated effort that went into some of the elk research and management, however, holds a special model for bird researchers because it did not evolve from the level of crisis that the other three did. Because we could find no comparable avian model, we present some details of an elk research program.

The Montana Cooperative Elk-Logging Study (Lyon et al. 1985) was formed in 1970 by Montana Department of Fish, Wildlife, and Parks, the University of Montana, and the USFS. The program was later joined by the Bureau of Land Management and Plum Creek Timber Co., Inc. The effort evolved from discussions about a proposed timber sale and its potential effects on elk. Managers and biologists became acutely aware that predictions of the effects were highly speculative. Given the public interest in elk, predictions on how management would impact elk would be needed again and again.

Two oversight committees were organized to guide a widespread, long-term study of landscape management for elk. A steering committee of agency administrators was led by a chair position rotating annually between the agencies. This committee met at least annually to review progress, determine direction, and provide support. A research committee of scientists, also with representation from each agency, was led by a permanent chair. This committee standardized terminology and methodology to maintain credibility and acceptance. It developed the research program, selected study areas, prepared study plans for each project, conducted the research, and prepared annual reports on accomplishments, plans, and budgets for proposed work. Plans and budgets were submitted to the steering committee for approval. Funds were primarily redirected within existing programs and no agency gave up control of its funds, except through separate cooperative agreements between agencies or outside contracting. Once project plans and budgets were approved, each agency funded and managed the research projects it had committed to perform on its lands.

The Elk-Logging Cooperative developed research in seven different geographic areas, with research at a site lasting as long as 12 years. The original agreement was for ten years of research, but was extended to 15 years (Lyon et al. 1985). Anthropogenic and landscape-scale factors were analyzed to determine their relationship with elk habitat selection. Factors included the amount of traffic on roads, the density of roads, amount and quality of cover, topographic factors, and logging activity (intensity, duration, extent). This research led to a very good basic understanding of landscape patterns and regional landscape differences that influenced elk distribution, movement, and how elk were displaced by human activity throughout the year and from year-to-year (Lyon et al. 1985). The number of vested cooperators leant credibility to the results.

The research committee was also charged with technical transfer in three areas: public awareness, land-management application, and scientific documentation. It was required that management recommendations be included in the annual report beginning in the third year, and that recommendations be phrased in a positive manner and be based on research from within each state. It is interesting to note that the research committee was initially reluctant to present its findings, because to the scientists, it seemed premature. The steering committee insisted, however, and annually thereafter, the participating management biologists formed the cumulative results into operating guidelines for regions of the state. Specific situations such as long migration routes were addressed with specific recommendations. The management recommendations then went through a workshop to test their readability with interagency personnel working in timber, range, wildlife, and engineering.

This coordinated effort laid the foundation for other landscape studies, such as elk vulnerability to hunting and grizzly bear displacement. Perhaps more importantly, it led directly and indirectly to the development of a variety of elk habitat effectiveness models to aid land management decisions (Lyon 1983, Leege 1984, Wisdom et al. 1986, Ager et al. 1991). These models can quantitatively assess impacts of cover removal and of miles of road open to public traffic, enabling a comparison of alternative management plans in a landscape setting. Thus, like the SRS research program, the collaboration of western managers and elk researchers led to great improvement in our understanding of organismal response to landscape change.

LOOKING AHEAD

As previously mentioned, controversy can be a catalytic force. On the other hand, Hank Fischer (pers. comm.) of Defenders of Wildlife, who was intimately involved with two extremely contentious issues (grizzly bear recovery and reintroduction of wolves into Yellowstone National Park), has begun talking recently of the "radical center". He coined the term because so many natural resource issues have become so polarized that it now seems radical to think in terms of the middle ground. It is in this middle ground that manager and scientist can come together as a team to forge a collaboration that can be recognized as the route to greater understanding and action. It is here that we also find a contrast in the way researchers and managers approach their work. There are a few inhibitions to overcome before we are fully functional in the radical center, however, and we will elaborate on these.

We mentioned earlier that science is in the spotlight. Actually, it might best be characterized as scientists having been dragged out of seclusion into public debate (Noon and Murphy 1994). It is especially true that the debate over the spotted owl brought scientists into the fray (Gordon and Lyons 1997). While most scientists hail this spotlight on science as a positive thing in general, many scientists are not comfortable with the spotlight when it involves them personally and directly as an expert (Viederman et al. 1994, Hagan 1995). The expert is called upon to give endorsements or direction where information is limited and expert opinion is needed (D. Arrington, U.S. Air Force, pers. comm.). It can be horrifying to the research ecologist to see the work of many scientists over many years in many different areas boiled down to one simple linear relationship. The scientist works in the realm of 95% or 99% probabilities from experiments, not 70% or 80% probabilities from some Delphi approach. Some scientists are more comfortable pursuing some eccentric interest and complaining about the obscurity and loneliness of research pursuits.

Managers ask hard questions, some of which have never been answered directly by science. The managers must make important decisions based on whatever science can be brought to bear. Making decisions and politicking are certainly not the realm of the average scientist. The scientist often falls into the school of thought where uncertainty is the rule and therefore conservative management provides the only prudent course, whereas there are questions that can only be answered by the "hard experience" of adaptive management (Bunnell 1989). Biologists may fail to appreciate that their ideas and values must compete with others (Kochert and Collopy 1998) and that many proposals will fail if the plans are not skillfully defended.

The manager, on the other hand, is sometimes uncomfortable with researchers and is under pressure from the public. There is often a difference in educational background between managers and researchers (Hejl and Granillo 1998) and scientists are sometimes considered condescending towards managers (Hejl and Granillo 1998). The manager often suffers from stereotyping wherein he is viewed as more of a bureaucrat than a proponent of applied science (Hejl and Granillo 1998). The manager has production goals and deadlines to meet. But in sharp contrast to the researcher, the manager also has to satisfy a large, diverse, impatient public at the same time. Managers are, therefore, more interested in an immediate model of management options generated by a consensus of "experts" than in a proposal for a 10-year project to look at productivity of juvenile birds in different habitat types. What the manager may not appreciate is that models are fed with basic information from basic research. The obscure, glamourless work of the naturalist fuels these data-hungry endeavors. By now, many managers do realize that the sum of competing demands on the land requires a landscape perspective, especially where these demands exceed the land's capacity to produce, forcing compromise and optimization. The manager, hampered by the lack of integrating techniques for wildlife and forestry (Bunnell 1989), is looking for scientific, defensible methods to guide a balanced approach. So managers are increasingly turning to the scientist for answers and defense as never before. It is probably safe to say that "science-on-demand" will be sought heavily in the future (Gordon and Lyons 1997). What more could the researcher ask for?

There is strong potential for a team effort in which researchers can become indispensable to managers because their work can be seen as integral to the operation of the management area. Research is not a luxury that cannot be afforded, it is part of the adaptive management concept (Walters 1986). Managers, in turn, can be seen as indispensable sources of resources, local knowledge and expertise (not just funding) to researchers. Because the researchers on a team are often held more accountable for producing "useful" information and models, at least a substantial part of a broad research program is likely to be in tune with management needs. With the right mix, this mutualism becomes synergistic and more is achievable than ever imagined by the under-appreciated researcher and the besieged manager.

PRESCRIPTION FOR SUCCESS

Considering the lessons, the elk model, and benefits of team collaboration that we have presented, what is a reasonable prescription for successfully implementing a landscape approach for avian research and management that is synergistic? We believe that we must organize regionally, communicate effectively, participate in each other's jobs, and provide incentives to work together.

We must organize on a regional basis (not to be confused with agency regional areas) with steering and research committees, as did the elk-logging studies and as Partners-in-Flight has done to identify research needs and collaboration possibilities (Arnett and Sallabanks 1998). We need to outline specific research/management needs at all management levels (Arnett and Sallabanks 1998) with questionnaires and workshops. Arnett and Sallabanks (1998) have suggested, for example, that in general terms, our research needs to identify causes of avian population change, metapopulation processes, species at risk and the causes of their risk, natural variation, and species-specific habitat requirements. Research should be designed around adaptive management principles (Walters 1986) at a variety of spatial scales and longer time frames to better identify causal, rather than correlative, relationships (Marzluff and Sallabanks 1998). Research programs should preserve autonomous budgets and ownership in local projects, yet mutually decide upon common methodologies. We also need to focus on development of monitoring methods patterned after Hutto's (1998) suggestions so we may track our successes and failures and flag species in decline.

Researchers have not communicated their findings in an effective or timely manner outside of academic journals, leading to very poor accessibility of information (Hejl and Granillo1998). Often information is only published in journals that managers never see. We strongly suggest publishing in U.S. government agency technical publications because they are relied upon fairly heavily by a broad spectrum of managers and scientists. When possible, these publications need to be responsive to the managers' preference for information in a "cookbook" format rather than in-depth reports (Arnett and Sallabanks 1998). For the format of information to be most useful, researchers should give managers implementable tools (models, management scenarios, and species and habitat priorities for management; Hejl and Granillo 1998, Kochert and Collopy 1998) that can be used both in planning and cited as "products" for management support. While providing management scenarios, the researcher should show both the advantages and disadvantages for the management alternatives (Faaborg et al. 1998). All of these reports should undergo intensive peer review to maintain credibility and readability (Johnson 1997), and we should ensure that authors are given credit for peer-reviewed publication. Academic tenure and promotion policies must be modified to make these publications worthwhile efforts for non-government scientists.

Information needs to be timely. We should encourage publication of annual briefs and management recommendations beginning after two or three years of data collection. In addition to publications, workshops for managers and press releases for the public should be widespread as soon as results are suggestive of management action.

Researchers and managers should participate in each other's jobs. Managers should help formulate research goals and design research. Specifically, managers have skills in planning manpower and logistical support, and can provide suggestions for adaptive management strategies. Researchers should participate with managers by developing project alternatives (Hejl and Granillo 1998), by participating in background landscape analyses for decision documents, and by being involved in public hearings and briefings of congressional and state officials (Kochert and Collopy 1998). This involvement would allow scientists to witness information and modeling needs. Researchers need to understand the social, political, and economic factors involved in land management (Hejl and Granillo 1998). Scientists also need to understand that the best hope for avoiding land management driven by special interest groups is through the participation of knowledgeable individuals (Ganey and Dargan 1998). Mutual involvement by managers and researchers should close the large management/research gap identified by Finch and Patton-Mallory (1993).

Finally, we should provide incentives to work together, such as awards for collaborative efforts and information transfer (Hejl and Granillo 1998). Universities have initiated annual awards for research teamwork as a way of encouraging interdisciplinary work. We should consider awards for research/management teamwork, to be presented at the annual meetings of professional societies (both ornithological and management). Perhaps these awards can be jointly sponsored by research societies, management agencies, and professional societies. Award recipients should receive either a personal cash award or an extra budgetary award, such as expense money for extra travel and publication costs for dissemination of results to help encourage collaboration.

CONCLUSION

We are making progress. We have some relatively new-found principles that we can apply to help us meet wildlife management goals for the landscape. For example, we have simulation models that project impacts of timber harvest patterns on population viability (Franklin and Forman 1987, Li et al. 1993; Liu et al. 1994, 1995) that help us understand how we might improve on the cookie cutter pattern by approaching timber management differently. However, we need to expand our knowledge of how these theoretical ideas hold up in real-world situations. The October 1997 issue of the journal *Ecology* includes a special feature on positive interactions in ecological communities (Kareiva and Bertness 1997). These seven papers detail a new appreciation of the role that facilitation and mutualism play in structuring natural communities. This facilitation is a good role model for conducting ecological research. Facilitation between managers and researchers can yield a more organized approach to topics such as landscape influences than is possible by independent (and potentially competitive) approaches.

Landscape research and management on the SRS is a good example of the potential of facilitation. A basic research program on landscape influences has been supported by both research-oriented laboratories (SREL) and management agencies (SRI). Landscape considerations have been incorporated into management plans (e.g., U.S. Forest Service 1992) that have major impacts on commodity production, while basic ecologists have been called upon to help managers design conservation reserves across the SRS (e.g., set-asides; White and Gaines *this volume*). The degree to which the landscape perspective has been incorporated to date shows the potential for collaboration between researchers and managers and between groups at different ends of the "applied" versus "basic" science gradient.

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THE MESOPREDATOR RELEASE HYPOTHESIS: INTEGRATING LANDBIRD MANAGEMENT WITH ECOLOGICAL THEORY

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Abstract. The mesopredator release hypothesis explains long-term population declines of ground- and shrub-nesting North American landbirds by suggesting that the extirpation of top predators from North America has released populations of medium-sized, mammalian nest predators. A perspective from theoretical ecology concerned with food web regulation suggests that mesopredator release following top predator removal (an example of a top-down trophic cascade) is most likely in food webs characterized by (1) efficient predation with prey held well below resource limitation, (2) lack of extensive omnivory, and (3) either low diversity of top predators, or all top predators removed together. These conditions are generally met by the landbird-mesopredator-top predator system. Empirical studies of these phenomena suggest that terrestrial mesopredator populations can in fact be released by loss of a top predator, and that addition of a top predator can significantly increase nest success of ground-nesting birds through a reduction of mesopredator populations. However intriguing these findings may be, experimental confirmation of mesopredator release and its effects on landbirds are still lacking. Because of its large size, relatively well-known predator history, and long-term data base on avian populations, the Savannah River Site would be an ideal location for conducting top predator removal and/or exclosure experiments. Results will be informative for land managers concerned with maintaining viable landbird populations.

Key words: ecological theory, management, mesopredator release, Song Sparrow, top predator.

Land managers concerned with maintaining wildlife species diversity typically rely on input from task-oriented wildlife biologists that provide data on selected game and/or nongame species. Only rarely do land managers receive input from theoretical ecologists, who typically are concerned with elucidating general principles of how individuals, populations and ecosystems function. In this paper we describe a profitable union of management science and theoretical ecology. The approach focuses on empirical and theoretical studies of food web regulation and the significance of that regulation for managing viable landbird communities.

Nest predation is the most important source of nest mortality among North American landbirds (Ricklefs 1969), and may be a main cause of population declines suggested for many landbird species (Böhning-Gaese et al. 1993, Robinson et al. 1995). Although for some Neotropical migrants declines may not be due to high nest predation, ground- and low shrub-nesting nesting species as a whole (representing a variety of migratory strategies) have shown widespread, long-term population declines (1966–1994) in eastern North America (Böhning-Gaese et al. 1993; see Peterjohn et al. 1995 for an alternative view). Arboreal-nesting species have not shown consistent declines in the same region and time interval (Böhning-Gaese et al. 1993). These facts suggest an important role for terrestrial mammals in driving declines of ground- and low shrub-nesting species. The mesopredator release hypothesis (hereafter, MRH) suggests that the historical reduction of top predators in North America (e.g., the cougar, *Felis concolor,* bobcat, *Lynx rufus,* gray wolf, *Canis lupus,* and in some areas the coyote, *C. latrans*) has resulted in "mesopredator release," a population explosion of medium-sized omnivores that are frequent nest predators (e.g., the raccoon, *Procyon lotor,* Virginia opossum, *Didelphis virginiana,* and striped skunk, *Mephitis mephitis*). According to the MRH, the historical increase in nest predation by mesopredators has caused declines in ground-nesting landbirds.

Testing the MRH has major implications for managing viable populations of landbirds. For example, would introducing a top predator into a large nature reserve (with unacceptably high mesopredator population density) necessarily increase landbird population density and/or species diversity? We assess the MRH and prospects for its application in management from two perspectives. First we consider theoretical ecology concerned with food web structure and regulation, with special reference to why or why not top terrestrial carnivores might successfully regulate mesopredator abundance and landbird nest success. Second, we examine studies of landbird-mesopredator-top predator relationships, to learn directly whether such interactions might be occurring in nature. The major conclusion is that top predators can, and probably do, influence mesopredators and songbirds as predicted by the hypothesis, but definitive experiments in terrestrial ecosystems are still lacking. Therefore, we close with a brief discussion of why the Savannah River Site (SRS) in South

Carolina offers a good opportunity to fill this gap in our knowledge.

TOP-DOWN EFFECTS IN ECOLOGICAL SYSTEMS

The MRH is a specific case of a more general hypothesis of top-down control in ecological communities. By "top-down control," we mean that the effects of predators on their prey directly or indirectly play a major role in structuring ecological communities. The notion of strong top-down effects in natural communities dates back to Darwin (1859), who noted that preventing mowing or browsing of turf increased biomass but lowered diversity. Early laboratory experiments (Gause 1934, Huffaker and Kennett 1956) showed that predators could control prey densities in the simplest systems, but the importance of predation in structuring natural communities remains controversial.

In an influential paper, Hairston et al. (1960) argued that most natural communities were structured by top-down effects. Predators, being limited only by competition for their herbivore prey, reduce herbivores to low densities; herbivores as a result have little impact on plants, which are limited by competition instead. The Hairston et al. model was constructed for a 3-trophic level community, but Fretwell (1977) and Oksanen et al. (1981) generalized it for any number of trophic levels: of n trophic levels, production at level n (the top) should be limited by competition, level n-1 by predation from level n, level n-2 by competition, and so on alternately down the food chain. When a top predator is removed, the pattern of regulation at each trophic level should shift accordingly (e.g., Peacock 1982). The MRH assumes top-down regulation such that top predators (n) limit the abundance of mesopredators (n-1) and prevent mesopredators from limiting landbirds (n-2). When top predators are removed mesopredators (which are now the top level n') increase sufficiently to depress landbird densities (now n'-1).

While the Hairston et al. model assumes both that top predators limit prey at level n-1 and that prey production at n-1 limits top predators, only the first assumption is necessary for top-down effects to be strong on a particular species. In fact, the top-down effects of a predator on one species of prey are likely to be strongest when the predator has abundant alternative prey (e.g., Caughley et al. 1980, Terborgh 1992).

The idea of strong top-down structuring in natural communities has been controversial (Hunter and Price 1992, Power 1992, Strong 1992). In some communities predators control prey densities (e.g., Estes et al. 1978, Caughley et al. 1980, Schoener and Spiller 1987, Dial and Roughgarden 1995), but in others they do not (Jackson and Kaufmann 1987). In many cases predator effects are felt only in some microhabitats (Hacker and Bertness 1995, Robson 1996) or by only some prey species (Morin 1984, Sinclair 1995, Johnson et al. 1996; review in Pimm 1980). Frequently, predator activity will remove one prey species, but another, less vulnerable species will replace it and total productivity may be unchanged (Paine 1980, Black and Hairston 1988, Crowder et al. 1988, Strong 1992). Even strong predator effects do not guarantee that top-down effects will propagate further down the food chain (McQueen et al. 1989). Removal of the top predator may release its prey, but an effect on the next trophic level requires that the released prey can be an effective regulator of its prey in turn.

Clear cases are known where effects of predator manipulation extend down through three or more trophic levels ("trophic cascades;" e.g., Edson 1985, Spiller and Schoener 1990, Dial and Roughgarden 1995, Morin 1995, Robson 1996; citations in Brett and Goldman 1997), but this result is not universal and may even be unusual (Strong 1992). Some theoretical models predict temporal variation in top-down vs. bottom-up regulation (Bartell et al. 1988), and careful experimental approaches often find simultaneous influences of both predators (top-down) and resources (bottom-up) at a given trophic level. Bottom-up control may be more important near the base of a food chain, with top-down effects more important at higher trophic levels (McQueen et al. 1986, 1989; Brett and Goldman 1997).

TOP-DOWN EFFECTS AND MESOPREDATOR RELEASE

Because top-down effects are not universally strong, recent treatments have taken a pluralistic approach (McQueen et al. 1986, Hunter and Price 1992), asking in which ecological circumstances top-down effects on a particular trophic level might be more or less intense. In assessing the mesopredator release hypothesis, then, we can look to ecological theory for insight into whether strong top-down effects might be expected for the top predator/mesopredator/landbird system. Little integration of the MRH and trophic cascade literatures has occurred as yet. While a few MRH papers mention examples of top-down control from other systems (Terborgh and Winter 1980, Soulé et al. 1988), none to our knowledge cite any theoretical background. Similarly, none among 25 papers examined on top-down effects in theory or in other systems refers to the mesopredator release-landbird decline idea. It is possible that data on the MRH can illuminate trophic cascades, and general consideration of trophic cascades can illuminate the MRH.

A number of ecological factors have been suggested to influence the likelihood of strong top-down effects in a particular system (Hunter and Price 1992, Power 1992). Here we consider how some of these factors weigh for or against the plausibility of landbird decline via mesopredator release, and ask what is needed to learn in order to support or reject the MRH. The general message is that careful consideration of theoretical context can help guide research programs.

PREDATOR EFFICIENCY

Inefficient predators are unlikely to regulate their prey (Power 1992; an efficient predator is one that can, when common, exploit its prey at a very high rate and drive it to very low densities). Predators may be inefficient if aggressive behavior causes strong interference among predator individuals (Hassell 1978, Loyn et al. 1983); if prey have effective chemical, physical, or behavioral defenses or if such defenses are inducible (Farrell et al. 1991, Dini et al. 1993, Polis and Strong 1996, Zangerl and Rutledge 1996); or if predators are limited by scarce resources other than the prey in question (Connell 1961) or have a life stage limited by such a resource (Mittelbach et al. 1988, Polis and Strong 1996). In contrast, predators are likely to be particularly efficient if their densities are kept high by an abundance of alternative prey (e.g., Caughley et al. 1980).

The MRH assumes that both the top predator-mesopredator link and, following mesopredator release, the mesopredator-landbird link are characterized by efficient predation. This certainly appears true for mesopredator-landbird interactions. Most mesopredators eat eggs and nestlings opportunistically, and are limited by more abundant prey (Leach and Frazier 1953, Terborgh and Winter 1980, Sieving 1992, Vickery et al. 1992). While birds do show some behavioral defenses against nest predation (e.g., Berg 1996), measured nest predation rates are generally high (Ricklefs 1969) and can exceed 90% (range 11–99% [mean 48%] for 125 temperate landbird estimates reported or reviewed by Brawn and Robinson 1996 and Martin 1993). We doubt that defense against mesopredators or interference among mesopredators have strong effects on mesopredator-landbird interactions, especially because the main mesopredators in eastern North America (raccoon, striped skunk, and opossum) are not strongly territorial (McManus 1974, Lotze and Anderson 1979, Wade-Smith and Verts 1982). Top predators are generally very efficient predators on mesopredators, because they will take many alternative prey and possibly can drive mesopredator densities quite low without becoming food-limited (Soulé et al. 1988, Terborgh 1992).

SCOPE FOR EXPANSION AFTER PREDATOR RELEASE

The trophic cascade concept predicts that removal of a predator (at trophic level *n*) results in prey (*n*-1) expanding from a density set by predation to a new, higher density set by resources (Peacock 1982). However, the latter density may not be much higher than the former. If it is not, we should not expect strong top-down effects on level *n*-2 (Soranno et al. 1993). In the mesopredator-landbird example, however, mesopredator increases after top predator extirpation have been substantial (Terborgh 1992, Sovada et al. 1995), although we do not know whether this will be universally true. Similarly, suppression of nest predators may decrease nest predation rates, but if other sources of mortality compensate, the decrease in predation may have little effect on bird densities.

INTERACTION AMONG NONADJACENT TROPHIC LEVELS

The prediction that the removal of trophic level *n* should depress species at *n*-2 (via release of level *n*-1) depends on a view of food chains where all interactions are between species at adjacent trophic levels. Nonadjacent levels may interact through nutrient release by predation (Vanni and Layne 1997), or through modification of shared habitat (Power 1992). However, the most common kind of interaction between nonadjacent trophic levels is doubtless omnivory (we use this term in its food-web sense: consumption of prey from more than one trophic level; Pimm 1982). Clear trophic cascades are expected only when consumers can be easily assigned to distinct trophic levels, and this may be uncommon (Power 1992, Strong 1992, Polis and Strong 1996; but see Hairston and Hairston 1997). With strong omnivory, predicting responses to predator removal becomes more complex. For instance, if species A eats B eats C, but A also eats substantial numbers of C, it is unclear whether removing A should cause an increase or decrease in C, for which the easing of predation by A may be outweighed by increased predation by a released population of B. Spiller and Schoener (1990) removed lizards in a lizard-spider-herbivorous insect-sea grape food chain, and found that damage to plants by midges decreased (in a typical trophic cascade) but homopteran damage actually increased. They attributed this result to omnivory by lizards, which consume both spiders and homopterans but not midges. In the mesopredator-landbird system, top predators such as coyotes and wolves take nest contents (Leach and Frazier 1953, Sovada et al. 1995 for prairie ducks) as well as larger prey, but it seems likely that they have their strongest effect via mesopredator densities rather than direct predation. The same is true for peregrine falcons in a peregrine-crow-seabird food chain (Paine et al. 1990).

BUFFERING BY DIVERSITY

Strong (1992) argued that trophic cascades should be confined to low-diversity systems or systems where a few species can have disproportionate effects on community structure. In more diverse systems, Strong suggested that top-down control will be buffered and weak because in complex food webs consumption effects are spread over many predators for each prey, and many prey for each predator. At any trophic level, then, removing one species only will allow another to increase and substitute in function: predator for predator, prey for prey, or producer for producer. Many clear trophic cascades indeed are found in low-diversity systems or in highly specialized food chains (Strong 1992, Gómez and Zamora 1994). Furthermore, replacement of one species by another (among either predators or prey) is an extremely common response to predator manipulation (Paine 1980, Loyn et al. 1983, Black and Hairston 1988, Crowder et al. 1988, Strong 1992).

The diversity issue raises two major questions for the MRH. First, can different top predators substitute for one another? Historically, in most regions of North America all mammalian top predators were probably extirpated more or less together, and so substitution of one top predator for another is unlikely to have buffered effects on mesopredators. However, some areas have recently reacquired top predators as coyotes have undergone a major range expansion. The effect on landbirds of wolf or large cat reintroductions may depend on the presence or absence of coyotes and on how these alternative top predators interact. Second, does increased predation from released mesopredators simply replace consumption by other species? For instance, raccoon abundance may have increased because of top predator extirpation, but there might be no net effect on landbirds if predation by raccoons simply removes eggs that would have been taken by snakes anyway.

EQUILIBRIUM OR NON-EQUILIBRIUM COMMUNITIES

Trophic cascade theory is an equilibrium theory, and it envisages communities where species abundances are relatively stable and locally regulated by density-dependent predation or competition. When populations are perturbed away from equilibria, strong top-down effects will not be expected. Landbird densities are certainly perturbed by disturbances (Rogers et al. 1991), and many landbird populations are probably decoupled from local regulation by source-sink relationships (e.g. Rogers 1994, Brawn and Robinson 1996, Smith et al. 1996, Rogers et al. 1997). If these effects are strong, then testing the MRH may mean analyzing population trend data on broad spatial scales (to remove source-sink effects), while removing disturbance effects statistically.

EVIDENCE FOR TROPHIC CASCADES IN TERRESTRIAL ECOSYSTEMS: LANDBIRDS, MESOPREDATORS, AND TOP PREDATORS

The above perspective from theoretical ecology suggests that top-down trophic cascades are possible for the landbird-mesopredator system. We next review the sparse evidence from empirical studies for their existence. The two main concepts underlying the MRH have their historical roots in John Terborgh's original discussion of extinction-prone species in the Neotropics (Terborgh 1974). Terborgh noted that after the Chagres River was dammed to form part of the Panama Canal around 1914, forming Barro Colorado Island (BCI) in Lake Gatun, a number of ground-dwelling landbirds subsequently became extinct, ostensibly because large carnivores themselves died out. Extinction of top predators may have in turn led to high "released" mesopredator populations, and subsequent low avian nest success. A recommendation was made for maintaining complete ecosystems (all trophic levels, including top predators) in order to preserve maximum biodiversity. Terborgh and Winter (1980) more explicitly discussed these trophic relationships for BCI, suggesting that its high population densities of nest-destroying mesopredators (coatimundi, *Nasua narica,* collared peccary, *Tayassu tajacu,* nine-banded armadillo, *Dasypus novemcinctus*), released from regulation by the extinction of top predators (Harpy Eagle, *Harpia harpyja,* cougar, and jaguar, *Felis onca*), in large part caused extinction of 15–18 species of ground-nesting landbirds. Further partial support for this neotropical trophic cascade came from comparing coatimundi density between Cocha Cashu, Peru, a forest site where large felids are common, and BCI. Coatimundi density was at least 20 times greater at BCI than Cocha Cashu (Terborgh 1992). Sieving (1992) consistently found higher predation rates on ground- and shrub-borne artificial nests at BCI than in nearby mainland forest.

Two additional studies supporting the MRH bear mention. Soulé et al. (1988) found higher landbird species diversity in California chaparral

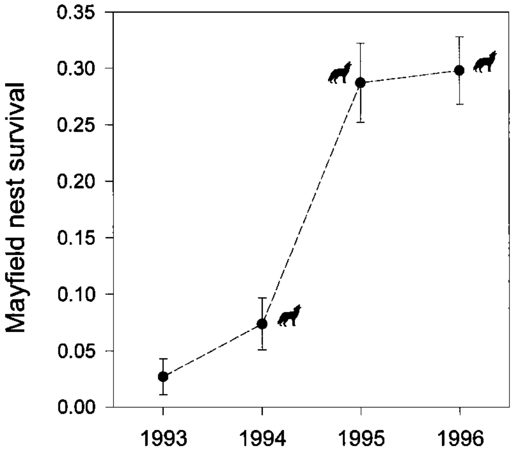

FIGURE 1. Annual increases in the Mayfield estimator of nest survival (mean ± SE, after Mayfield 1975 and Hensler and Nichols 1981) at Lux Arbor, southwest Michigan, 1993–96. Years when coyotes were detected (by sightings of adults, dens found, and scat counts) at Lux Arbor are indicated by the stylized coyote symbol. Sample sizes were 20, 25, 26, and 35 nests per year for 1993–1996, respectively. Using the program CONTRAST and the Bonferroni adjustment of the critical P-value for a posteriori contrasts, 1993 differed significantly from 1994–1996 pooled, but 1993 and 1994 were not significantly different. Thus nest survival did not increase beyond pre-coyote levels until coyotes had been present about 1 year at Lux Arbor.

fragments with coyotes than in otherwise similar fragments without coyotes. In an entirely different ecosystem, Sovada et al. (1995) demonstrated higher nest success of prairie ducks in areas where coyotes are the main canid than in areas where the red fox (*Vulpes fulva*), a major predator of duck nests, is the main canid. Coyotes, which rarely prey on duck nests, were assumed to depress the abundance of red foxes (Sovada et al. 1995).

Finally, results from a four-year "natural experiment" with Song Sparrows (*Melospiza melodia,* a ground-nesting landbird) in the agricultural landscape of southwestern Michigan support the MRH (Rogers and Caro 1998). Coyotes were absent from the Lux Arbor Reserve (650 ha of fields, woodlots, and lake borders) in 1993 and present in 1994, 1995 and 1996. Over this interval, Mayfield nest survival increased, and the relative frequency of nest predation decreased (Fig. 1). Coyotes may have reduced nest predation in 1994–1996 by depressing the abundance of raccoons, apparently the main nest predator in the study area. Coyotes are well-known to prey upon raccoons (Andrews and Boggess 1978, Clark et al. 1989, Hasbrouck et al. 1992), and an inverse relationship between coyote population density and raccoon population density has been observed (Sargeant et al. 1993). In an experiment with artificial nests in the same Michigan landscape, mesopredator abundance and predation rate on ground nests were positively related, as predicted by the MRH (Rogers and Caro 1998).

ADVANTAGES OF TESTING THE MESOPREDATOR RELEASE HYPOTHESIS AT THE SAVANNAH RIVER SITE: INTEGRATING LANDBIRD MANAGEMENT WITH ECOLOGICAL THEORY

This final section considers how the SRS would be useful as an experimental and observational site to further our understanding of the trophic role of top mammalian predators and how that role influences landbird population viability. A land manager seeking that understanding might ask four different questions concerned with the possible outcomes of maintaining populations of top predators in a given nature reserve. This final section attempts to answer these anticipated questions, integrating the present main theoretical findings with the utility of using SRS as a model ecosystem.

WILL A TOP PREDATOR REDUCE MESOPREDATOR POPULATIONS IN A GIVEN RESERVE TO THE POINT WHERE GROUND-NESTING LANDBIRDS WOULD BENEFIT?

One of the main theoretical findings of the present report was that increasing landbird nest success (and possibly, but not necessarily, population density) is likely if a top predator is efficient, i.e., if predation reduces a prey population below its level of resource limitation. In the eastern North American top predator-landbird-mesopredator system, the top predator most likely to be maintained as a viable population is the coyote. Studies supporting coyote predation upon raccoons, a frequently common mesopredator, were cited above. In addition, in central Iowa, remains of radio-collared adult male raccoons have been found following coyote predation (W. Clark, personal communication). Efficient predation on mesopredators by coyotes is likely if coyote density is maintained by abundant alternative prey, such as voles and winter- and auto-killed deer. This is a plausible scenario for many nature reserves, given the frequently high abundance of these prey types in many regions of North America. A local reduction in mesopredator density of only 1–2 raccoons per 30 pairs of breeding landbirds would seem a priori to be sufficient to increase landbird nest density significantly, but this estimate needs empirical testing.

How might the SRS function in tests for efficient predation on mesopredators? The above considerations do not take into account the role of non-mammalian nest predators, such as snakes, which are major nest predators in many parts of North America, including SRS. Data are urgently needed on the effects of top predators on landbirds in terrestrial ecosystems with and without snakes. A particularly useful study would test for such effects in the SRS and a comparably-sized reserve lacking snakes.

An important related point is that "efficient predation" on mesopredators by a top carnivore need not involve a trophic relationship sensu stricto. Adult female raccoons travelling with young of the year during the nesting season of many North American landbirds (April–July) should avoid areas of high coyote density to reduce predation risk to their young, a significant investment in fitness. Indeed, raccoons avoid food-rich areas experimentally marked with coyote urine in Iowa (C. M. Rogers, unpubl. data), and tame raccoons show strong avoidance of areas with coyotes present (without having seen coyotes), also in Iowa (W. J. Fitzgerald, pers. comm.).

WILL TOP PREDATORS CONSUME LANDBIRD NEST CONTENTS AS WELL AS REDUCE MESOPREDATOR ABUNDANCE?

A second main theoretical finding was that landbird density might not be increased if an introduced top predator is omnivorous, i.e., a top predator feeds at multiple trophic levels and reduces landbird density as well as mesopredator density. Continuing to reason about using coyotes as top predators in a given nature reserve, this canid is known to prey upon ground-nesting landbird nest contents, including the incubating female, but such predation is rare (Rogers et al. 1997). Thus some omnivory is likely, but would probably be insignificant (the main prey items of North American coyotes were discussed above; see also Andrews and Boggess 1978, Parker 1995).

IS A GIVEN RESERVE LARGE ENOUGH TO SUPPORT A VIABLE POPULATION OF TOP PREDATORS?

The large size of SRS can permit evaluation of the role of top predators in "reserves" of differing size. This might be achieved by subdivision of available space into geographically separated research areas (large, medium, and small). Such information would be of interest to land managers concerned with maximizing wildlife species diversity in nature reserves of different areas. A likely size effect is that small areas with low habitat diversity support lower population density of top predators than larger areas, which can be expected to have higher habitat diversity. Additional factors potentially related to reserve size also can be addressed, such as the effect of proximity to developed areas.

WHAT EFFECT WILL A TOP PREDATOR HAVE ON AVIAN SPECIES DIVERSITY?

Significant numbers of top predators are long gone from SRS, and there is a historical data base including censuses of landbird abundance and species diversity from the 1950s to the present (gathered by Eugene Odum and colleagues; see Meyers and Odum *this volume*), providing an effective "top predators absent" data base. A more recent background data set on nesting success of landbirds at SRS is also available (Sargent et al. 1997). Coyotes are just now reaching South Carolina as they continue their eastward range expansion from the Great Plains (Parker 1995). They are present at SRS now, and might build up high densities there in the near future (as they have done since 1993 in southwestern Michigan). Sidney Gauthreaux and his colleagues (pers. comm.) are conducting standardized landbird censuses at SRS, and, when continued, this research can provide "top predators present" population and community data. Thus, an informative natural experiment could be completed in the foreseeable future.

Note that the dependent variable of ultimate interest to wildlife biologists and managers is bird species diversity, not nesting success; however, the two probably are closely related. To illustrate, bird communities typically show a log-normal distribution of species, which includes rare and uncommon species in addition to common and abundant species. Rare and possibly also uncommon species might be preserved in a small- to medium-sized nature reserve by the presence of a top predator that facilitates success of a small number of nests through a depression of mesopredators. Such an effect was suggested by the data of Soulé et al (1988), who found higher bird species diversity in chaparral fragments with coyotes than without them.

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COORDINATING SHORT-TERM PROJECTS INTO AN EFFECTIVE RESEARCH PROGRAM: EFFECTS OF SITE PREPARATION METHODS ON BIRD COMMUNITIES IN PINE PLANTATIONS

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Abstract. Several short-term projects conducted at the Savannah River Site have focused on the effects on avian populations of different techniques of preparing a site for tree planting in young pine plantations. The purpose of this paper is to provide an overview of these studies, to summarize the information they provide regarding the effects of pine management on avian communities, and to demonstrate how multiple short-term projects can be used to address pressing management issues. O'Connell (1993), Sparling (1996), and Branch (1998) examined breeding and wintering bird use of areas treated with several mechanical and chemical site preparation methods. Overall, there were few treatment-related effects on bird populations. Both O'Connell and Sparling believed that the few differences in bird use of treatment plots were associated with minor differences in the structural diversity of the vegetation. Each of these short-term studies provided timely information on an issue of management importance and, taken together, they provide a more comprehensive picture of the effects of site preparation methods on bird communities in pine plantations than a single long-term study.

Key Words: abundance, evenness, diversity, herbicides, richness, short-term research, Savannah River Site, site preparation, South Carolina.

Demand for softwood products from the southern United States has resulted in conversion of many natural pine and pine-hardwood forests to even-aged pine plantations. Pine plantations in the Southeast annually produce about 17% of the country's total softwood supply. Because of increased demand, pine plantations may furnish almost half of the nation's softwood by the year 2000, and possibly two-thirds by 2030 (U.S. Forest Service 1988).

Early stages of pine plantations provide excellent habitat for a number of early successional species of birds (Noble and Hamilton 1975, Meyers and Johnson 1978). However, within these early stages we know little about the influences of vegetative composition and structure on avian communities, which may vary considerably. For example, before seedling trees are planted, the plantation site must be prepared such that seedling survival will be maximized. Site preparation often involves elimination or reduction of vegetative competition, either through chemical (i.e., herbicide) or mechanical (e.g., shearing of residual plant material from the previous stand, raking and piling roots, etc.) means. Different site preparation techniques provide variable plant communities and vegetative structures (presence or absence of snags, hardwood sprouts, coarse woody debris, etc).

Production and environmental concerns over the loss of site productivity, soil erosion, increased costs, and variable efficacy has resulted in shifts from mechanical site preparation methods to use of forest herbicides over the past two to three decades. Although herbicides are not toxic to wildlife when used at labeled rates, they may affect wildlife indirectly by altering vegetative composition and structure (McComb and Hurst 1987). The herbicides currently used by forest industries have different selectivities and therefore redeveloping plant communities often vary among herbicide treatments. Additionally, the development of new, more selective herbicides, along with changes in the timing of applications, negate the establishment of long-term studies to document the influence of a particular site-preparation treatment on avian communities.

The ephemeral nature of these early successional communities and the rapid changes in forest regeneration technologies necessitate application of a series of short-term research projects. During the past seven years, three graduate research projects conducted at the Savannah River Site (SRS) under the direction of K. V. Miller have examined the effects of chemical and mechanical site preparation on songbird populations. O'Connell (1993) and O'Connell and Miller (1994) examined breeding bird abundances at two, three, and five years post-treatment on areas treated with mechanical versus hexazinone site preparation. Sparling (1996) studied breeding and wintering bird populations at one to two years post-treatment on areas receiving various site preparation treatments: mechanical, hexazinone, imazapyr, and picloram + triclopyr. Branch (1998) studied post-treatment years three and four on Sparling's plots. The purpose of this paper is to provide an overview of these studies and summarize the information they provide on the effects of pine plantation site preparation on avian populations. In so doing, we hope to demonstrate how multiple short-term projects can be used, indeed sometimes must be used, to address pressing management issues.

STUDY DESIGNS

The study design of O'Connell (1993) consisted of three replications of two treatments in age classes two, three, and five years post-treatment on areas ranging from 11–24 ha. Areas were chosen from historically planted loblolly pine (*Pinus taeda*) plantations on similar soil types. The chemical treatment included a broadcast of Pronone 10G® (hexazinone) at rates from 1.4 to 2.3 kg active ingredient/ha. Mechanical treatment consisted of shearing residual standing vegetation with a V-blade and windrowing residual plant material with a root rake. Comparisons between treatments were made for the following bird community parameters: Shannon diversity, Shannon evenness, Margalef richness, total abundance, and species-specific abundance.

In addition to comparing the effects of mechanical and chemical treatments, Sparling (1996) and Branch (1998) examined the effects of 3 different herbicides on redeveloping plant and animal communities. The study design of Sparling (1996) and Branch (1998) included three replications of each of the following: Arsenal® (imazapyr), Velpar® ULW (hexazinone), Tordon K®+Garlon 3A® (picloram+triclopyr), and a mechanical treatment (root-raking and windrowing). Hexazinone was applied using a backpack sprayer in April 1992, while imazapyr and picloram+triclopyr were applied with a boom sprayer mounted on a tractor in May 1992. Mechanically prepared areas were treated in October 1992. Longleaf pine (*Pinus palustris*) was planted on a 1.3 × 3.1 m spacing in February 1993. Comparisons among treatments were made for the following bird community parameters: Shannon diversity, Shannon evenness, species richness, and total abundance.

All three studies used 25-m fixed-radius point counts to census birds from April–June. O'Connell (1993) sampled at five point count stations on each of his 18 treatment plots and visited each station twice during the breeding season. Sparling (1996) and Branch (1998) sampled at six stations on each of 12 treatment plots and visited each station three times during the breeding season and three times during winter (December). Counts were conducted within three hours of sunrise and were not conducted on rainy or excessively windy days. Each station was sampled for five minutes, and all birds seen or heard within the plot, but not flying overhead, were recorded. See O'Connell (1993) and Sparling (1996) for detailed descriptions of vegetation sampling techniques.

TABLE 1. Avian Species Diversity and Abundance (Mean number per treatment area ± SE) Two, Three, and Five Years Post-treatment on Chemically and Mechanically Prepared Sites in Barnwell County, S.C., 1991–1992 (adapted from O'Connell 1993)

Bird community parameter[a]	Hexazinone	Mechanical
2 years post-treatment		
H'	2.47 (0.08)A[b]	2.15 (0.05)B
J'	0.95 (0.01)	0.92 (0.02)
R	3.92 (0.38)	3.24 (0.20)
Abundance	31.70 (13.4)	24.70 (6.7)
Brown-headed Cowbird	3.66 (0.33)A	1.66 (0.33)B
Eastern Bluebird	1.67 (0.33)A	0.00 (0.00)B
Mourning Dove	3.00 (0.00)A	1.00 (1.00)B
Yellow-breasted Chat	1.33 (0.67)B	3.33 (0.33)A
3 years post-treatment		
H'	2.39 (0.07)A	2.10 (0.03)B
J'	0.92 (0.01)	0.92 (0.03)
R	3.80 (0.21)	3.03 (0.41)
Abundance	25.30 (10.3)	22.00 (9.0)
Carolina Wren	0.00 (0.00)B	1.33 (0.33)A
Chipping Sparrow	2.00 (0.00)A	0.00 (0.00)B
Yellow-breasted Chat	0.67 (0.33)B	2.67 (0.67)A
5 years post-treatment		
H'	2.04 (0.08)	1.91 (0.05)
J'	0.91 (0.02)	0.92 (0.01)
R	3.07 (0.22)	2.70 (0.17)
Abundance	12.03 (6.6)	11.70 (5.9)

[a] H' = Shannon diversity; J' = Shannon evenness; R = Margalef richness.

[b] Within a row, means followed by different letters are significantly different at $P \leq 0.10$.

FINDINGS

O'CONNELL (1993)

Totals of 29, 26, and 21 avian species were recorded at two, three, and five years post-treatment, respectively. Total bird abundances did not differ between treatments in any age class (Table 1). Indigo Buntings (*Passerina cyanea*) were the most commonly observed species on all sites. At two years post-treatment, Brown-headed Cowbirds (*Molothrus ater*) and Mourning Doves (*Zenaida macroura*) also were recorded commonly. Mourning Doves and Eastern Bluebirds (*Sialia sialis*) were more abundant on hexazinone sites, whereas Yellow-breasted Chats (*Icteria virens*) were more abundant on mechanical treatments. At three years post-treatment, common species were Indigo Buntings, Brown-headed Cowbirds, and Prairie Warblers (*Dendroica discolor*). Chipping Sparrows (*Spizella passerina*) were more abundant on hexazinone treatments, whereas Yellow-breasted Chats and Carolina Wrens (*Thryothorus ludovicianus*) were more abundant on the mechanically treated areas. Bird species diversity was greater on the hexazinone plots at two and three years post-treatment. At five years post-treatment, commonly recorded species included Prairie Warblers, Indigo Buntings, and Carolina Wrens, but no differences in diversity, evenness, richness, or the abundance of any species were detected between treatments. Total bird abundance was correlated with herbaceous species diversi-

TABLE 2. Avian Species Diversity and Abundance (mean number per census plot ± SE) on Chemically and Mechanically Prepared Sites at One, Two, and Three years Post-Treatment in Barnwell County, S.C., 1993–1996 (Adapted from Sparling 1996 and Branch 1998)

Season	Bird community parameter[a]	Treatment			
		Hexazinone	Imazapyr	Picloram+ triclopyr	Mechanical
1993					
June	H′	1.79 (0.35)	2.30 (0.20)	1.96 (0.40)	2.10 (0.05)
	J′	0.93 (0.01)	0.92 (0.02)	0.87 (0.02)	0.94 (0.01)
	N	7.67 (2.73)	12.67 (2.67)	11.00 (3.51)	9.33 (0.33)
	Abundance	2.22 (0.48)	4.33 (0.70)	5.56 (1.08)	3.00 (0.52)
December	H′	1.32 (0.39)	1.68 (0.38)	1.62 (0.18)	1.35 (0.20)
	J′	0.63 (0.15)	0.80 (0.06)	0.85 (0.06)	0.77 (0.10)
	N	7.67 (1.33)	9.33 (3.84)	8.00 (2.65)	5.67 (0.33)
	Abundance	7.39 (2.39)	10.67 (2.05)	6.17 (2.54)	4.39 (1.26)
1994					
June	H′	2.05 (0.20)	2.22 (0.16)	2.08 (0.31)	1.47 (0.25)
	J′	0.88 (0.03)	0.89 (0.03)	0.93 (0.01)	0.76 (0.09)
	N	10.67 (2.03)	13.33 (3.84)	10.33 (2.91)	7.00 (1.15)
	Abundance	4.44 (0.93)	7.44 (1.51)	4.39 (0.81)	3.06 (0.49)
December	H′	1.25 (0.07)B[b]	1.38 (0.05)AB	1.63 (0.13)A	1.65 (0.08)A
	J′	0.82 (0.01)	0.80 (0.03)	0.82 (0.05)	0.77 (0.08)
	N	4.67 (0.33)B	5.67 (0.67)B	7.33 (0.33)A	9.00 (1.15)A
	Abundance	5.61 (1.77)	8.11 (1.88)	11.89 (2.27)	11.17 (2.51)
1995					
June	H′	2.27 (0.06)	2.45 (0.16)	2.46 (0.16)	2.14 (0.13)
	J′	0.86 (0.02)	0.89 (0.02)	0.89 (0.02)	0.84 (0.05)
	N	14.00 (1.53)	16.67 (3.53)	16.67 (3.38)	13.00 (1.53)
	Abundance	7.83 (1.17)	10.22 (1.47)	9.33 (1.32)	7.39 (0.91)
December	H′	1.56 (0.13)	1.83 (0.25)	1.86 (0.15)	1.84 (0.15)
	J′	0.71 (0.11)	0.77 (0.03)	0.78 (0.02)	0.77 (0.05)
	N	9.33 (1.53)	10.67 (2.51)	11.00 (1.73)	11.00 (1.00)
	Abundance	11.17 (2.17)	10.94 (0.67)	9.50 (0.88)	10.94 (4.79)
1996					
June	H′	2.47 (0.33)	2.69 (0.04)	275 (0.28)	2.66 (0.34)
	J′	0.87 (0.07)	0.87 (0.04)	0.91 (0.78)	0.93 (0.02)
	N	17.33 (2.89)	22.33 (2.31)	12.00 (3.61)	17.33 (0.58)
	Abundance	6.56 (1.02)	9.50 (3.56)	7.78 (2.22)	6.39 (2.02)
December	H′	1.80 (0.26)	1.80 (0.04)	1.90 (0.09)	1.86 (0.20)
	J′	0.84 (0.01)	0.82 (0.02)	0.82 (0.07)	0.87 (0.05)
	N	8.67 (2.31)	9.00 (0.00)	10.33 (1.15)	8.67 (1.15)
	Abundance	6.39 (1.84)	7.14 (1.19)	7.72 (1.92)	5.56 (0.25)

[a] H′ = Shannon diversity; J′ = Shannon evenness; N = mean number of species per plot.

[b] Within a row, means followed by different letters are significantly different at $P \leq 0.05$.

ty, herbaceous species richness, and woody species diversity.

SPARLING (1996)

Forty-seven breeding and 27 wintering bird species were recorded. Bird abundance did not differ among the treatments during any sample period (Table 2). In winter of 1994 (i.e., 2 years post-treatment), diversity was greater on picloram + triclopyr and mechanical plots than on hexazinone-treated plots. Also, species richness was lower on hexazinone and imazapyr plots than on mechanically treated plots. No other treatment-related differences in avian community measures were detected.

Winter bird abundance was correlated with vine abundance at one year post-treatment. Woody vegetation was correlated with summer and winter bird abundance at two years post-treatment. Breeding bird abundance was positively correlated with vegetation volume at lower heights (0.5–1.0 m).

BRANCH (1998)

During the third and fourth years post-treatment on Sparling's (1996) plots, Branch (1998) detected no differences in either breeding or wintering bird community variables. Analyses relating bird community variables to vegetation structural variables were unavailable. Apparently, by three to four years post-treatment, the few effects that the various herbicides had produced in the bird communities one to two years post-treatment had disappeared.

CONCLUSIONS

Both O'Connell (1993) and Sparling (1996) reported greater vertical structure on chemically treated sites than mechanically treated sites. O'Connell (1993) attributed the greater bird abundance and diversity of chemically treated sites at two and three years post-treatment to differences in vegetation components, particularly vertical structure associated with residual snags. He also noted that the greater numbers of snags present on the hexazinone treatments likely accounted for the greater numbers of cavity-nesting species such as Eastern Bluebird and species that utilize perches such as Brown-headed Cowbird and Mourning Dove. The positive relationship between bird communities and vertical vegetation structure long has been recognized (MacArthur and MacArthur 1961, James 1971, Willson 1974). Johnson and Landers (1982) attributed higher bird diversity in two year-old plantations compared to 6–15 year-old plantations to the presence of residual snags, and winter bird numbers in Texas were higher on areas with snags than on snagless areas (Dickson and Conner 1982). Similarly, in Mississippi, bird species diversity in pine stands is related directly to the number of residual snags and cavities (Darden et al. 1990). Because most forms of intensive mechanical site preparation remove the majority of standing stems from a site whereas chemical site preparation techniques leave residual snags, chemical site preparation likely is more beneficial to bird species that utilize snags, either for nesting, roosting, or as song perches.

Some species were more abundant on mechanically treated sites (O'Connell 1993). Mechanical site preparation involves collection of woody debris into windrows. These windrows and the vegetation associated with them apparently resulted in superior habitat conditions on mechanically treated sites, as compared to chemically treated sites, for shrub-scrub birds such as Carolina Wren and Yellow-breasted Chat.

The herbicides tested by Sparling (1996) and Branch (1998) differ in the suites of plants species that they control, and therefore in the redeveloping plant communities. However, these differences in the vegetative communities do not result in significant effects on avian habitat. Sparling (1996) reported few differences in vertical structure among the different herbicides one to two years post-treatment, and Branch (1998) detected no differences three to four years post-treatment. Similarly, study areas in Georgia treated with hexazinone, imazapyr, and picloram+triclopyr had similar amounts of snags and residual hardwoods at four and five years post-treatment (Moore 1996) and, consequently, the associated bird communities did not differ.

Overall, few treatment-related differences in avian abundance and diversity were detected in any of the studies, suggesting that changes in silvicultural prescriptions from mechanical to chemical site preparation may have few impacts on avian communities. The only apparent exceptions to this pattern are species that utilize the windrows associated with mechanical site preparation (i.e., Carolina Wren, Yellow-breasted Chat). Similarly, since Sparling (1996) and Branch (1998) found no differences in avian abundance and species richness among various site preparation herbicides, choice of herbicide may not be important to avian communities either. Different results may occur with other herbicides, application rates, or application timing. Additionally, the use of herbicide tank mixtures (i.e., simultaneous application of two or more of the herbicides tested in the reported studies) likely will result in greater vegetation control and could impact songbird communities, at least in the initial years post-treatment. Therefore, further research is needed to establish the generality of the results reported herein. Yet, because of their spatial and temporal similarities, these three studies provide a foundation for continued studies on the effects of various site preparation methods on breeding and wintering songbird populations.

The burgeoning use of herbicides in forestry is resulting in rapidly changing technologies. Herbicides are being employed with increasing frequency for site preparation, crop tree release, and mid-rotation stand management. Developing technologies such as more selective herbicides, changes in the timing and method of applications, and use of herbicide mixtures preclude the establishment of long-term studies to document the influence of one particular site-preparation treatment on avian communities. Additionally, early successional communities in re-establishing pine plantations are ephemeral in nature and thus necessitate application of a series of short-term research projects.

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CONCLUDING REMARKS: AVIAN STUDIES AT THE SAVANNAH RIVER SITE

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Ornithological research at the Savannah River Site during the past five decades has involved three phases: (1) During the first decade or so (1951–1965) the focus was on inventories to provide baseline data for future changes expected to result from atomic plant operations and major land-use changes (Meyers and Odum *this volume*). (2) During the 1970s and 1980s bird studies mostly involved specific species or groups of species, especially waterfowl, game birds, and endangered species such as the Wood Stork (*Mycteria americana*) and Red-cockaded Woodpecker (*Picoides borealis*) (Bryan et al. *this volume,* Franzreb et al. *this volume*). (3) In the 1990s a renewed interest in distribution and abundance of birds emerged as a result of increased interest and funding by the U.S. Forest Service, other government agencies, and regional university forestry schools. These studies emphasized research in biodiversity and management of forests to include values other than the production of wood products (e.g., Kilgo et al. *this volume*).

As outlined in Meyers and Odum (*this volume*), biological and environmental inventories were a major part of the first contracts for field research at SRS. Beginning in 1951, research contracts were drawn between the Atomic Energy Commission and the University of Georgia (UGA), the University of South Carolina (USC), and the Philadelphia Academy of Sciences. UGA contracted to inventory warm-blooded vertebrates and arthropods, and to study old-field succession. USC contracted to inventory cold-blooded vertebrates and higher plants. Inventories of the aquatic life in the Savannah River were carried out by a Philadelphia Academy task force under the direction of Ruth Patrick.

During this early period, about a quarter of the papers published by the UGA group involved birds, culminating in Robert Norris' book, "The Birds of the AEC Savannah River Plant Area" (1964, Contributions from the Charleston Museum, No. 14).

With the establishment of the permanent Savannah River Ecology Laboratory (SREL) in 1962 by UGA, there was no longer a segregation of interests (White and Gaines *this volume*). The SRS was designated as the first National Environmental Research Park (NERP) in 1972, and researchers and students from all over the United States began to conduct field studies at SRS, mostly funded and coordinated by SREL.

During the middle period of species-oriented bird studies, less than 10% of SREL papers dealt with birds. Attention spread to other taxa, especially herps, and to experimental studies in radiation ecology (some of which involved birds), thermal pollution, wetland ecology, ecotoxicology, and population genetics. As detailed by Bryan et al. (*this volume*) and Dunning et al. (*this volume*), a series of papers on Wood Storks and on the relationship between Bachman's Sparrows (*Aimophila aestivalis*) and the economics of timber harvest were noteworthy contributions during this period.

Finally, in recent years there has been a dramatic increase in interest (and funding!) throughout the forestry and wildlife professions in nongame and non-timber producing species, biodiversity, and conservation ecology. This interest has developed into essentially a landscape ecology approach to management, with emphasis on long-term research and research-management relationships, and is very apparent at SRS. I am pleased that many of the early bird censuses are being repeated, and that studies of the status of neotropical migrants and range changes associated with the "reversed latitude gradient" phenomenon (Odum et al. 1993) are underway. The SRS NERP is perhaps the best place in the United States for field experiments and models bringing together market and non-market values of forested landscapes.

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