This book is dedicated to the memory of Richard "Butch" Olendorff (1943–1994) whose neverending optimism and amazing foresight allowed him to conceive the theme of this book over twenty years ago when he wrote these words in his now classic work on raptors, *Golden Eagle Country*:

"... birds of prey are exploiting the potential of living in concert with men. Given half a chance, they will even breed in spite of us."

Raptors in Human Landscapes

Adaptations to built and cultivated environments

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Use of Reservoirs and other Artificial Impoundments by Bald Eagles in South Carolina

A. Lawrence Bryan, Jr., Thomas M. Murphy, Keith L. Bildstein, I. Lehr Brisbin, Jr. and John J. Mayer

Abstract – Active bald eagle nest territories in South Carolina increased from 12 in 1977 to 84 in 1993. Nest territories associated with reservoirs increased from one in 1982 to 29 in 1993. This was a significantly faster rate of increase than was the rate for territories not associated with reservoirs. Reservoir territories also produced significantly more fledglings per nest than a sample of non-reservoir territories in the ACE basin. Eagle sightings on a newly constructed reservoir (L-Lake) increased steadily throughout the study, while sightings on the 33-yr old Par Pond reservoir were minimal until a partial drawdown of that site created more favorable foraging conditions. Bald eagles appear to be able to rapidly find and use both new reservoirs or newly conducive conditions at older reservoirs. Eagle use of these reservoirs did not appear to be linked to densities of waterfowl and marsh birds (as potential prey) or other fish-eating birds (as indicators of abundant fish).

Key words: bald eagle; breeding territory; foraging habitat; impoundments; reservoirs.

Historically, nesting bald eagles were common throughout the coastal plain of the southeastern United States (US), as well as along major river drainages and the few large lakes found in the region (US Fish and Wildlife Service (USFWS) 1984, Wood *et al.* 1990). Southeastern eagle populations were greatly reduced in the 1970s by the same factors (shooting, habitat alteration, and most recently organochlorine pesticides) that depleted other populations of this species (USFWS 1984). The increased protection later afforded to eagles and their habitats has resulted in a recovery of bald eagle populations, and several southeastern states have reached or exceeded recovery goals as laid out in the Bald Eagle Recovery Plan (USFWS 1984, Wood *et al.* 1990).

At the same time that population expansions were taking place, large amounts of new aquatic habitat were being created in the southeastern US in the form of man-made impoundments of many sizes, and many of these are now receiving significant use by both breeding and non-breeding eagles. Three major

reservoirs (comprising lakes Marion, Moultrie and Wateree) in South Carolina's coastal plain were completed in the 1940s and were colonized by eagles as the reservoirs matured and waterbird use intensified. Some use of these reservoirs by nesting eagles was documented, but this was all but eliminated as eagle populations declined in the 1970s. Since that period, as the South Carolina bald eagle population has recovered, eagle use of reservoirs has also expanded.

South Carolina supports a bald eagle population which has been growing steadily since the late 1970s and contains the third largest population in the southeastern states (USFWS 1984, Wood *et al.* 1990). Population growth has occurred in the absence of a reintroduction program in the state, although such programs exist in adjacent North Carolina, Tennessee and Georgia.

Bald eagles have been observed at reservoirs on the US Department of Energy's Savannah River Site, in southwestern South Carolina, since the late 1950s (Norris 1963, Mayer *et al.* 1985). An eagle nest was discovered adjacent to Par Pond in 1986 (Mayer *et al.* 1988) and a second nest was discovered near L-Lake in 1990 (Wike *et al.* 1993).

Using South Carolina as an example, our goal is to describe the use of reservoirs and other freshwater, man-made impoundments >40 ha in size by breeding bald eagles. We will also compare the reproductive successes of nests associated with reservoirs to those of nests from the Ashepoo-Cumbahee-Edisto River (ACE) Basin in South Carolina, where eagles feed in coastal and riverine habitats. In order to more thoroughly describe the actual patterns of impoundment use by eagles in this region, the reservoir system on the Savannah River Site was selected for detailed surveys designed to examine the spatial and temporal patterns of eagle use of such aquatic systems.

METHODS

Study Area

South Carolina has >1600 man-made freshwater impoundments >4.05 ha in size, covering >210 000 ha (SCWRC 1991). Nineteen impoundments are >405 ha. The function of most of these impoundments is recreational, but 15 of the 19 larger impoundments are used primarily to produce electric power.

South Carolina also has >200 000 ha of coastal marshes, including approximately 28 500 ha of shallow, man-made coastal impoundments (Tiner 1977). Most of these coastal impoundments were built in the eighteenth and nineteenth centuries for the purpose of growing rice (Rogers 1970). The majority are currently managed to attract waterfowl for hunting (Tiner 1977).

The ACE Basin occupies approximately 142 000 ha of largely undeveloped land and water areas, including coastal impoundments, within the boundaries of Beaufort, Charleston, and Colleton counties of South Carolina (NOAA

1991). The basin is bounded by the Atlantic Ocean (southeast), the North Edisto River (northeast), the Coosaw River (southwest), and extends inland to include most of the Ashepoo and Combahee River drainages.

The 77 701 ha Savannah River Site (SRS), which is located along the north shore of the Savannah River in southwestern South Carolina, has been used for the production of plutonium and tritium for nuclear weapons since its closure to the public in 1952 (Fig. 1). L-Lake (405 ha), Par Pond (1100 ha), and Pond B (87 ha) are three man-made impoundments (Fig. 2) on the SRS that were constructed to serve as cooling reservoirs for thermal effluent from nuclear reactors. Par Pond was formed in 1960 and maintained a constant water level until mid-July of 1991, when the discovery of structural anomalies in its dam required the lowering of its water level by 6 m, reducing its volume and surface area by 65% and 50%, respectively. Pond B was formed in 1961 and L-Lake was formed in late 1985, and both have maintained constant water levels since the time of their construction.

Productivity

Active breeding territories of South Carolina eagles were classified as either reservoir (man-made) or non-reservoir (riverine-coastal systems), depending on the primary feeding areas used by the breeding birds. Eagles using shallow coastal impoundments (rice fields) were classified as non-reservoir. Occupation of nest sites and reproductive success of eagles were monitored by annual aerial surveys and ground observations. Numbers of active breeding territories and numbers of young fledged were recorded and related to primary feeding areas from 1977 through 1993. Rates of population increase (numbers of breeding territories) from 1982 to 1993 for reservoir and non-reservoir (statewide) eagle populations were compared by the application of a homogeneity-of-slopes model (Proc GLM, SAS 1988) to log-transformed data. The reproductive success (number of young fledged per breeding territory) of eagle populations associated with reservoirs from 1982–93 was compared with the reproductive success of ACE basin nests during the same period.

Use of SRS Impoundments

Reservoir surveys were conducted on the SRS from the fall of 1987 through the summer of 1993. They were continued on a seasonal basis four times per year (except for the winter of 1989) and from the fall of 1989 through the spring of 1991. All birds, including eagles, were counted from a small boat cruising the reservoir shoreline on three consecutive days (one day at each of the three reservoirs) at two-week intervals, three times each season (for details, see Bildstein *et al.* 1994). All birds sighted on or flying over the water, as well as those flying over land ≤20 m from the shoreline, were counted from a stationary boat at approximately 50-m intervals. Numbers of eagles, other members of the

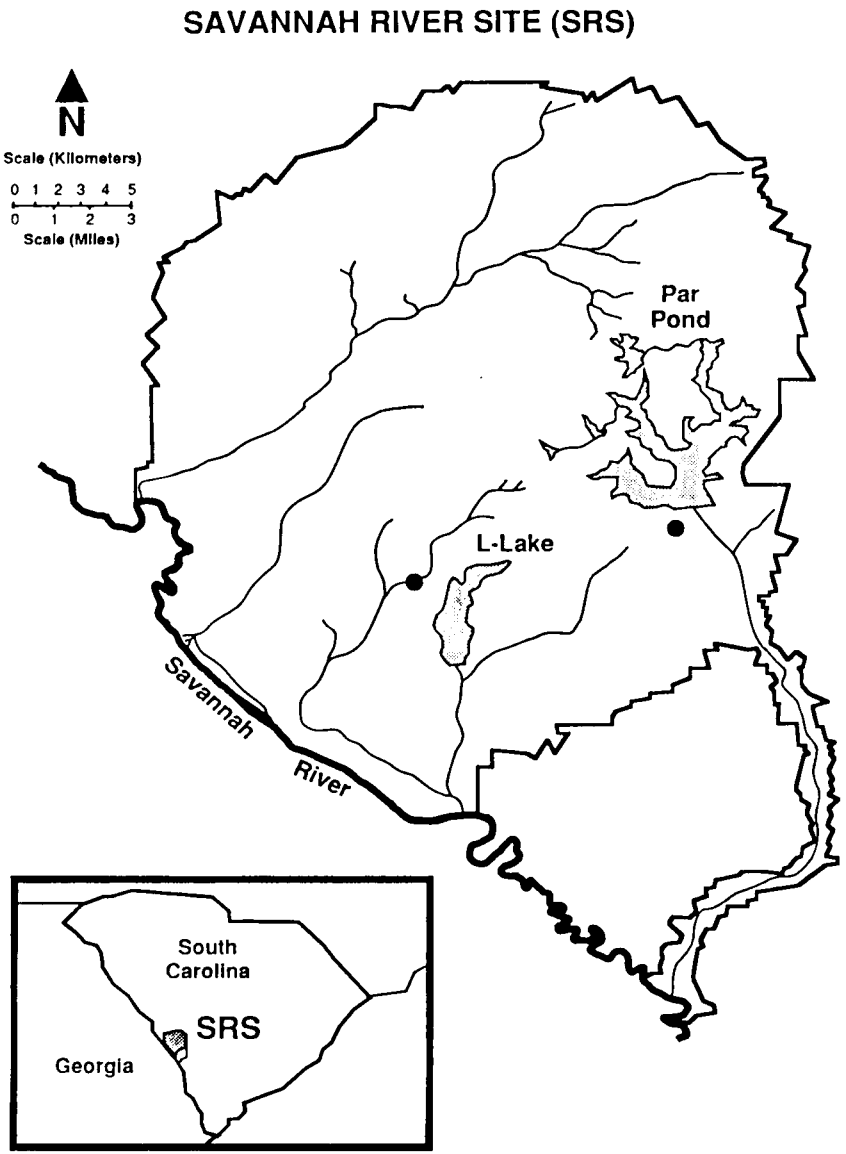

Figure 1. US Department of Energy's Savannah River Site, showing locations of the L-Lake and Par Pond reservoir systems. Solid circles indicate locations of bald eagle nests.

open-water fish-eating guild, marsh birds, primarily American coots and common moorhens, and waterfowl were censused to determine whether eagle densities were related to densities of other fish-eating birds or potential prey species (marsh birds and waterfowl; see Appendix 1 for avian species observed during censuses). Densities were quantified as birds per km of shoreline for each

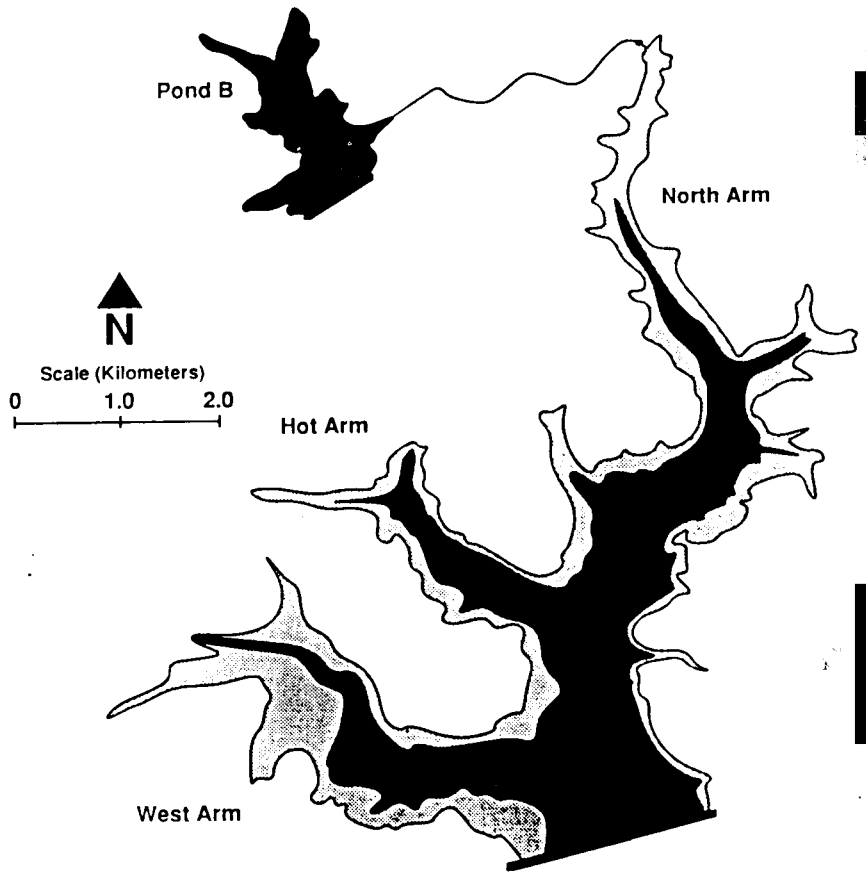

Figure 2. The Par Pond reservoir on the US Department of Energy's Savannah River Site. Blackened areas represent open water, and stippled areas indicate mud flats exposed following partial drawdown of the reservoir in 1991. Boat surveys routes were confined to the reservoir's Hot Arm.

reservoir: L-Lake 20.2 km; Par Pond 7.9 km; and Pond B 9 km. Only the 7.9 km of shoreline comprising Par Pond's Hot Arm was surveyed.

RESULTS

Numbers of Nests

The number of known active bald eagle nest territories in South Carolina grew rapidly from 1977 ($N = 12$) to 1993 ($N = 86$). This included exponential increases in both reservoir and non-reservoir territories (Fig. 3). Comparative

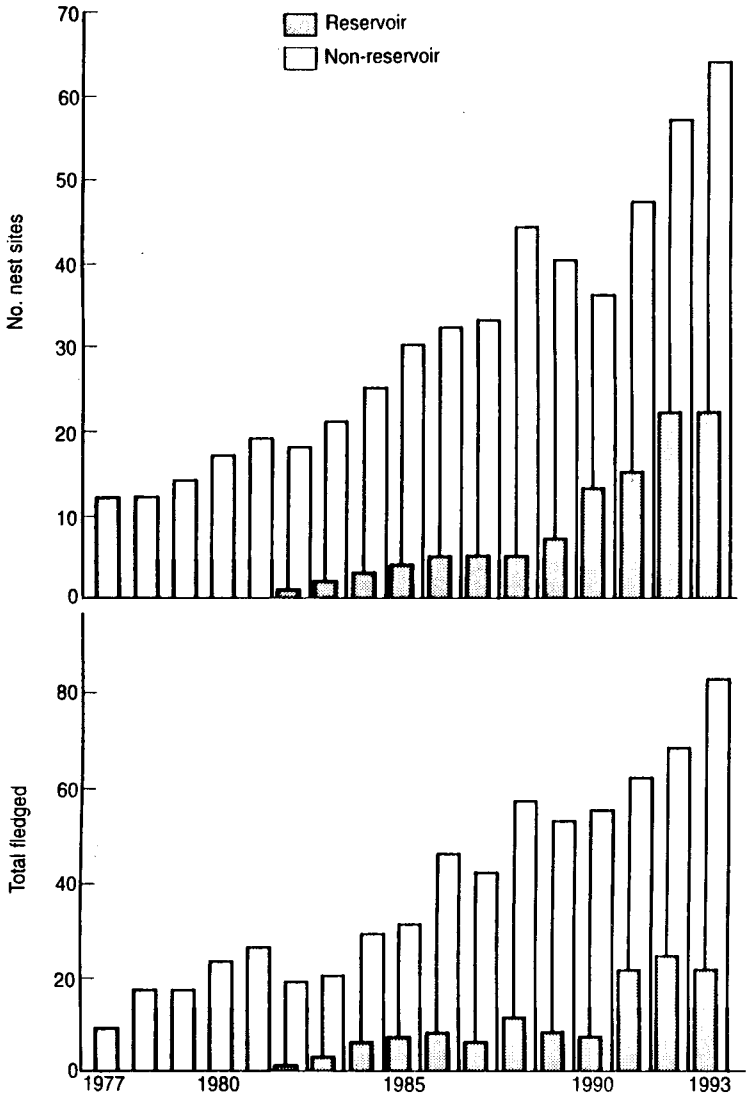

Figure 3. Number of active bald eagle nesting territories and fledglings produced on reservoir and non-reservoir sites in South Carolina: 1977–93.

analysis of the increase in numbers (*log-transformed*) of both types of territories indicated that the population of eagles associated with reservoirs increased at a faster rate (slope = 0.11) than the population not associated with reservoirs (slope = 0.04; Student's $t = -8.0$, Prob $>|t| = 0.0001$). The first South Carolina eagle nest associated with a reservoir since the 1970s was reported in 1982, when a nest was found on the Lake Marion reservoir. By 1993, 26% of the state's total of 88 nests was associated with reservoirs.

Table 1. Comparison of the number of fledglings produced by South Carolina bald eagle nests associated with man-made reservoirs and non-reservoir habitats between 1982 and 1993.

	Eagle territory type	
Number of fledglings	Reservoir *N* (%)	Non-reservoir *N* (%)
0	29 (28.4)	65 (29.5)
1	22 (21.6)	87 (39.6)
2	50 (49.0)	65 (29.5)
3	1 (1.0)	3 (1.4)
Total	102	220

Reproductive Success

The average annual productivity of statewide eagle territories ranged from 0.69 fledglings per territory in 1977 to 1.39 in 1986. Total production of fledglings statewide increased to a high of 103 in 1993.

Approximately 72% of both reservoir and ACE basin territories fledged young from 1982 through 1993. Eagle territories associated with reservoirs ($N = 102$) produced an average of 1.23 ± 0.88 (SD) fledglings per nest during this period, while ACE Basin territories ($N = 220$) produced 1.03 ± 0.80 (SD) fledglings. Reservoir nests produced significantly more fledglings per nest than ACE Basin nests ($\chi^2 = 14.07$, df = 3, $P = 0.003$), with a higher percentage of nests fledging a second nestling (Table 1).

Avian Use of SRS Impoundments

Avian use of the SRS reservoirs was dominated by migratory waterfowl, primarily ring-necked ducks and lesser scaup and marsh birds (primarily American coots) during winter and spring seasons (Fig. 4). Fish-eating birds, primarily double-crested cormorants, were abundant in spring, and long-legged waders were most common in summer and fall (Fig. 4).

Bald eagles were observed on L-Lake throughout the study and their use of that area appeared to increase during the study period (Fig. 5). Eagles were not observed on Par Pond during the surveys until the winter of 1992 (Fig. 6). Observations of eagles on Pond B, the smallest of the three reservoirs on the SRS, were infrequent. Numbers of bald eagles observed during surveys of the L-Lake and Par Pond reservoirs did not appear to be directly associated with seasonal variations in the densities of any of the other guilds observed (Figs. 5 and 6). However, the densities of both eagles and other fish-eating birds increased on Par Pond after the drawdown of the reservoir during summer of 1991.

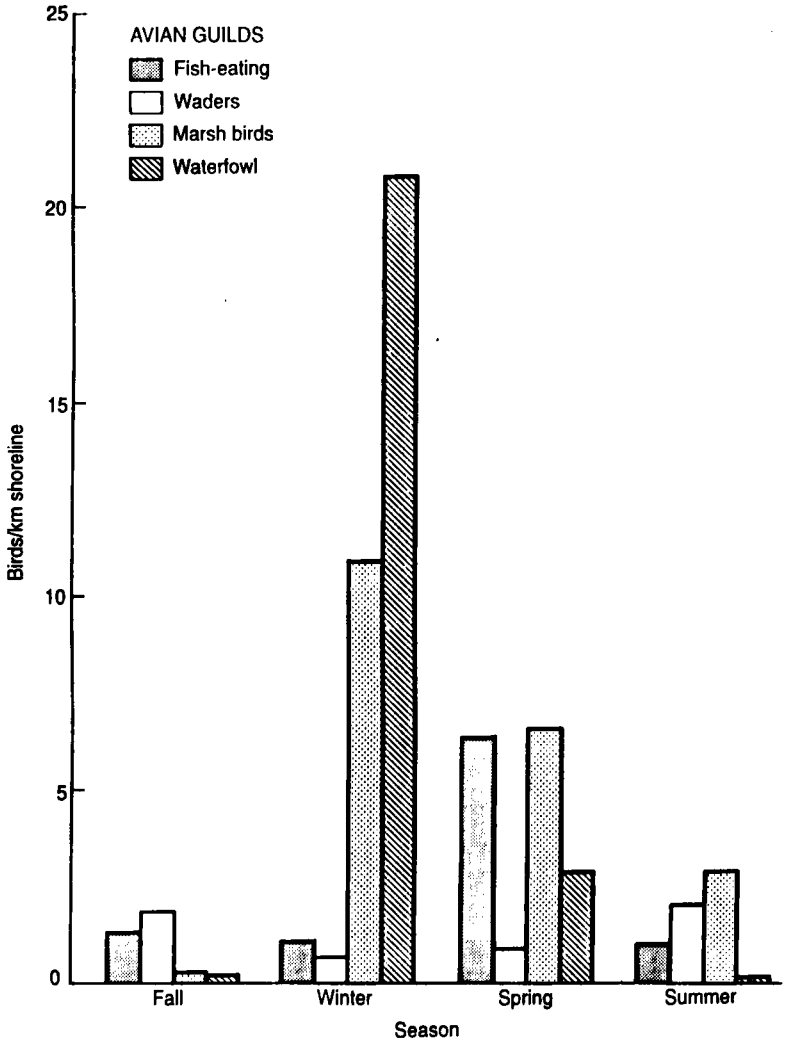

Figure 4. Seasonal use of the L-Lake Reservoir by avian guilds.

DISCUSSION

As of 1993, the South Carolina population of breeding bald eagles had surpassed its recovery goal of 40 occupied breeding territories (USFWS 1984) by 120%. Many breeding areas have been and still are associated with reservoirs. The percentage of eagle breeding territories associated with reservoirs has increased steadily into the 1990s and linear models (this study) suggest that the rate of increase in territories is greater in reservoir habitats than in non-reservoir

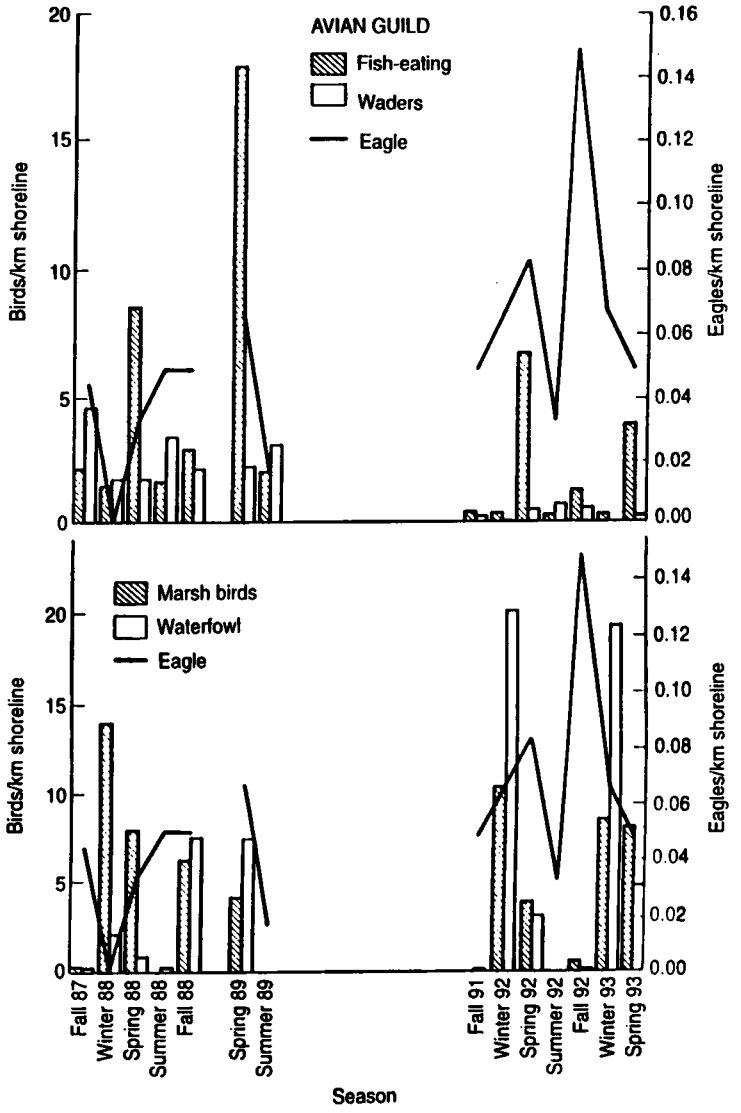

Figure 5. Avian use of the L-Lake Reservoir: 1987–93.

habitats. Continued study of these populations and their habitats is needed to accurately estimate population growth and possible carrying capacities.

The dispersal of eagles inland from historic (coastal) areas could be a response to the availability of food resources at these reservoir sites. However, the continued growth of ACE Basin and other non-reservoir eagle populations during the last 17 yr suggests that eagles moving to reservoirs were not compelled to do so due to a lack of available habitat in this region. Dead and injured fish associated with hydro-electric dams have been documented as

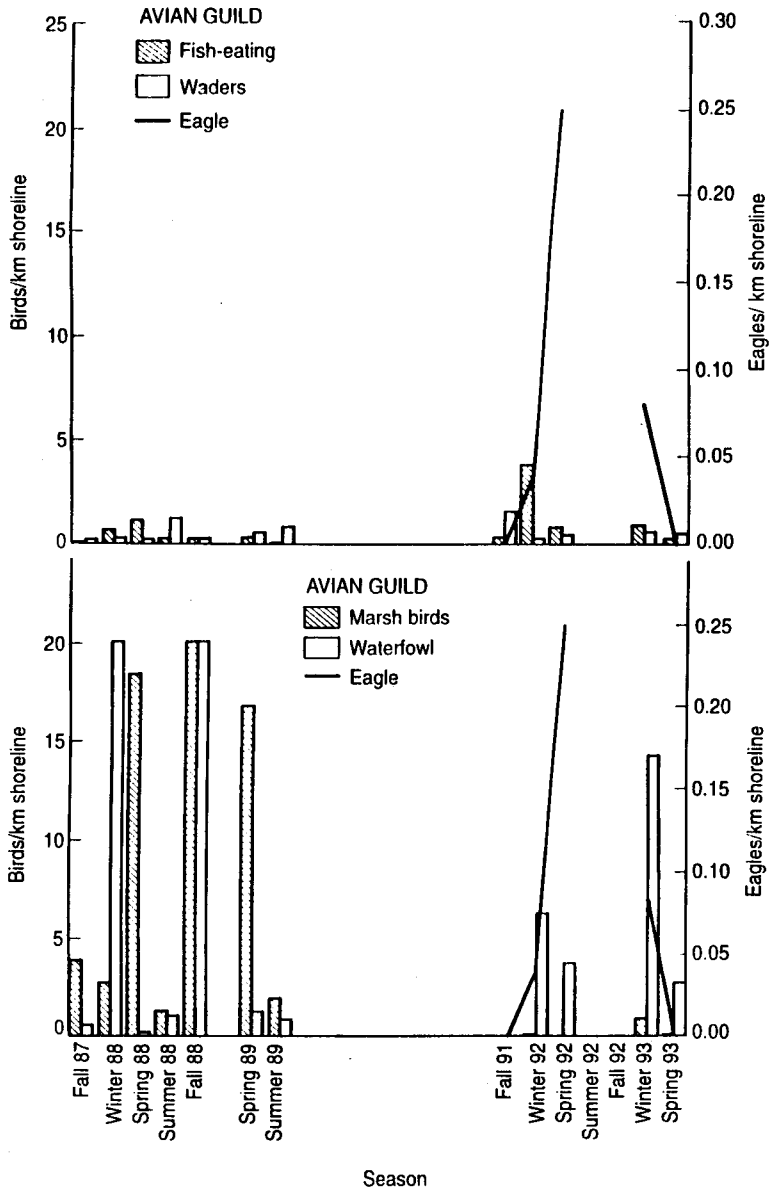

Figure 6. Avian use of the Par Pond Reservoir: 1987–93.

attracting foraging bald eagles (Stalmaster 1987). Fish may be more abundant in recently constructed reservoirs because of the "trophic upsurge" associated with internal and external nutrient loading (see Kimmel and Groeger 1986) and more available because of reduced littoral vegetation at these sites (Bildstein *et al.* 1994). Reservoir drawdowns, such as the Par Bond reservoir in 1991, can make

prey more available by concentrating fish in a reduced area, as well as by reducing protective cover for fish if water levels drop below the level of littoral vegetation. These factors may have been responsible for the increase in numbers of eagles and other piscivorous birds at Par Pond in the winter of 1992 (Fig. 6).

Recent eagle colonization and increased numbers of other species in the fish-eating guild at the recently constructed SRS reservoirs suggest that these sites are capable of providing sufficient food resources. Bald eagles appear to be able rapidly to find and use both new reservoirs (L-Lake) or newly conducive conditions at older reservoirs (Par Pond drawdown). The timing of the breeding chronology of southeastern bald eagles is such that they are incubating and hatching eggs when peak numbers of overwintering waterfowl and marsh birds (potential prey) are present on southeastern reservoirs. The dispersal of eagles inland (see Mayer *et al.* 1988) from their coastal natal areas may have resulted from the availability of food at reservoirs, combined, perhaps more importantly, with the lack of competition from other eagles for resources and space.

Breeding success of eagle pairs associated with reservoirs was slightly higher than that of ACE basin eagles, although other non-reservoir breeding territories in South Carolina were as successful as reservoir territories (T.M. Murphy unpubl. data). Regardless, reservoir eagles are producing at least as well as eagles using more natural habitats and do not appear to be paying a cost in reproductive output as a result of occupying these more recent man-made habitats.

An early concern for bald eagle recovery was that populations in the southeast were largely disjunct, with isolated remnant populations in Florida, South Carolina, and the Chesapeake Bay region (USFWS 1984). If the eagles' association with reservoirs continues, the fact that impoundments and reservoirs are fairly widespread geographically in the state will reduce the likelihood of a single catastrophic event destroying either the state's eagle population or eagle production, i.e. nestlings, for a year. A prime example of the potential for such an event is the impact of Hurricane Hugo in 1989, which resulted in the loss of nest trees from 25 of South Carolina's 54 breeding areas (Murphy 1991).

Potential costs to breeding eagles using impoundments include higher rates of disturbance, notably from development of reservoir shorelines and recreational activities (Buehler *et al.* 1991, Smith 1988). Habitat alteration, including disturbance at nest sites, has been suggested as the single most important factor inhibiting eagle recovery in the southeastern region (USFWS 1984). Recreational boating was reported by Wood *et al.* (1990) to reduce the numbers of eagles utilizing particular areas of reservoirs in Florida and North Carolina, though whether this affected foraging behavior or productivity was unknown.

Contaminants often found in reservoirs, such as mercury, may also be of concern in certain situations. In general, mercury levels are higher in fish from younger oligotrophic reservoirs and lower in fish from older eutrophic reservoirs (Eisler 1987). Eagle prey species, i.e. American coot and largemouth bass (see Mayer *et al.* 1988) collected from reservoirs on the SRS for example, were found to contain levels of mercury >0.05 ppm (Clay *et al.* 1979, Pinder and Giesy 1981). This level has been associated with adverse effects in sensitive avian

species (Eisler 1987). While productivity of SRS eagle nests has been reasonably high, no data are available on the mercury levels in these birds. Furthermore, the survivorship of the fledglings produced at this site is unknown. Grier (1980) maintained that survival rates may be a more important limiting factor to bald eagles than productivity.

The recovery of eagles and their association with reservoirs in South Carolina may be a model for how other states with low initial numbers of breeding eagles might eventually effect recovery, i.e. partial build-up in historic areas, followed by expansion into newly available habitats: reservoirs. States that hack eagles on reservoirs (Odum 1980, Wood *et al.* 1990) may experience a fast rate of recovery as this species rapidly adapts to new foraging opportunities in reservoir habitats.

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APPENDIX 1

Avian guild components on Savannah River Site Reservoirs.

Guild

Open-water fish-eating:
Common loon
Horned grebe
Double-crested cormorant
Anhinga
Osprey
Bald eagle
Bonaparte's gull
Ring-billed gull
Herring gull
Caspian tern
Forster's tern
Least tern
Belted kingfisher

Long-legged Wading Birds:
Great blue heron
Great egret
Snowy egret
Wood stork
Little blue heron
Tricolored heron
Green-backed heron
Black-crowned night heron
American bittern
Least bittern

Guild

Marsh Birds:
Pied-billed grebe
American coot
Common moorhen
Purple gallinule
Lesser yellowlegs
Killdeer
Spotted sandpiper

Waterfowl:
Mallard
American black duck
Blue-winged teal
Ruddy duck
Bufflehead
Wood duck
Ring-necked duck
Lesser scaup
Northern pintail
Gadwall
American widgeon
Red-breasted merganser
Hooded merganser