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EFFECTS OF ALTERED HYDROLOGY ON THE BREEDING ECOLOGY OF THE FLORIDA GRASSHOPPER SPARROW AND BACHMAN'S SPARROW

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Abstract.—The hydrology of central and south Florida has been greatly altered in recent decades for agricultural and residential purposes and these changes affect birds in a variety of ways. We sought to determine if changes in hydrology affected the breeding ecology of two rare ground-nesting sparrows, the federally endangered Florida Grasshopper Sparrow (*Ammodramus savannarum floridanus*), and the regionally threatened Bachman's Sparrow (*Aimophila aestivalis*). From 1996 to 1998, we conducted standard spot-mapping surveys to determine territory densities, and made behavioral observations to develop an index of reproductive success at three sites in central Florida. We also developed a Seasonal Moisture Index from recorded water scores recorded at each survey visit. One site, was wetter than the other two sites. We detected no Florida Grasshopper Sparrow reproduction at the wetter site, while the other two sites had successful reproduction. Bachman's Sparrow territory densities and reproductive success were not affected by wet conditions. Differences in patterns of micro-site nest selection might explain the differences between these species. Our results suggest that high water levels pose a substantial threat to the federally endangered Florida Grasshopper Sparrow.

Passerines face a number of constraints to successful nesting, including predation, parasites, food limitations, and weather (Wiens 1969). Additive factors that decrease nesting success could have adverse impacts on bird populations. We sought to understand whether

ground-nesting birds might suffer additional reproductive failures due to flooding of available nesting sites.

The hydrology of central and south Florida has been greatly altered for agricultural and residential purposes. In Florida artificially inundated, unusually high water levels have resulted in reduced nesting success for ground-nesting Sandhill Cranes (*Grus canadensis*) (Dwyer and Tanner 1992). Frederick and Collopy (1989) noted ciconiiform species abandoned nests in Florida when water levels were high. They hypothesized this was due to the adults' inability to find food under these conditions. Bancroft et al. (1988) also found a direct relationship between breeding attempts and the amount of rainfall preceding the breeding season for Wood Storks (*Mycteria americana*).

While studying the breeding ecology of two ground-nesting passerines, Florida Grasshopper Sparrow (*Ammodramus savannarum floridanus*), and Bachman's Sparrow (*Aimophila aestivalis*) (Perkins et al. 2003), we recorded unusually high water levels on one of three study sites in central Florida. These high water levels resulted from the modification of an elevated road that prevented water flow, impounding previously free-flowing water onto sparrow breeding habitat. This unusual and unexpected hydrological event gave us the opportunity to study the effects of different water regimes on the breeding ecology of two rare grassland birds.

Florida Grasshopper Sparrows are restricted to highly fragmented dry prairie and are listed as an endangered species by the U.S. Fish and Wildlife Service (Federal Register 1986). The species has declined and contracted in range (Delany et al. 1985, Delany and Cox 1986, Delany and Linda 1994, Delany et al. 1995), and there are only five known breeding populations. At the time of this study, there were three populations at Avon Park Air Force Range (located at Delta/OQ Range, Bravo Range, and Echo Range), one population each at Three Lakes Wildlife Management Area (Three Lakes), National Audubon's Ordway-Whittell Kissimmee Prairie Sanctuary (Audubon), and Kissimmee Prairie State Preserve (Kissimmee Preserve).

Since this study was conducted, there have been three changes to the number of populations. The Bravo population has steadily declined, and no birds were detected at this site in 2003 (R. Bowman, pers. comm.). The Audubon site was acquired by the state of Florida as an addition to Kissimmee Preserve, and extensive burning and roller-chopping has restored a prairie corridor to Kissimmee Preserve. Audubon and Kissimmee Preserve, are now considered to be a single, interconnected sub-population. One additional population has been located on private land in Okeechobee County (D. Pierce, USFWS, pers. comm.) since this study occurred.

Bachman's Sparrows are also residents of the dry prairie of central Florida, and are restricted in distribution to the southeastern United

States. Although commonly associated with mature long-leaf pine (*Pinus palustris*) forests with grassy open understories (Brooks 1938, Stoddard 1978), Bachman's Sparrows are widespread on treeless dry prairie. This species' northern range has recently contracted (Dunning and Watts 1990), and populations in the south have declined (Jackson 1985).

Abrupt, abnormal changes in hydrology may impact the reproductive success of ground-nesting birds that have already adapted to the natural hydrological regime of a particular area. In central Florida, the rainy season occurs from June to August. Because the topography is flat and soil layers below the surface are impervious, rainwater does not drain readily but moves slowly downslope towards the Everglades (Abrahamson and Hartnett 1990). These two species of sparrows may be impacted by impoundment of water at their breeding locations, especially in the late spring and summer. We wanted to determine if the unusual artificially high water levels at Audubon present during the period from 1996 to 1998 affected territory densities and reproductive success of these two rare locally distributed ground-nesting species.

METHODS

STUDY SITES

Native dry prairie is characterized as flat, unforested, fire-dependent grassland with scattered shrubs. Dominant graminoids include wiregrass (*Aristida beyrichiana*), toothache grass (*Ctenium aromaticum*), bluestem (*Andropogon* spp.), and beak rush (*Rhynchospora* spp.); dominant shrubs include saw palmetto (*Serenoa repens*), dwarf oak (*Quercus minima*), fetterbush (*Lyonia lucida*), and gallberry (*Ilex glabra*); dominant forbs include bachelor's button (*Polygala* spp.), yellow-eyed grass (*Xyris* spp.), hat pin (*Eriocaulon decangulare*), meadow beauty (*Rhexia* spp.) and a variety of milkweeds, orchids and asters (Shriver 1996).

In this study we focused on three breeding populations of Florida Grasshopper Sparrows at sites that were <50 km apart (Fig. 1). Avon Park has approximately 4,200 ha of native prairie and three populations of Florida Grasshopper Sparrows. It is owned and managed by the Department of Defense and is located in Highlands and Polk counties. We studied the population at the 700 ha Delta/OQ Range area (27°37'N 81°19'S). Three Lakes has approximately 4,000 ha of dry prairie in Osceola County (27°47'N 81°06'W) and is owned and managed by the Florida Fish and Wildlife Conservation Commission. Audubon has approximately1,000 ha of dry prairie in Okeechobee County (27°34'N 80°58'W) and was owned and managed by the National Audubon Society during the period of this study. A primitive dirt road that abuts the southern border of Audubon crossed the entire width of the southward drainage basin. Alterations were made to the road in 1995 such that southward water flow was impeded. This substantially raised water levels throughout the dry prairie at this site.

CENSUS METHODS

From 1996 to 1998, we censused approximately 360 ha of dry prairie in 30 permanent plots (12 at Delta/OQ, 10 at Three Lakes, 8 at Kissimmee Prairie), ranging from 7 to 22 ha in size. We marked and gridded permanent plots at 50-m intervals to determine sparrow breeding densities and reproductive success. Territories of Florida Grasshopper and Bachman's sparrows were delineated using standard spot-mapping and flushing

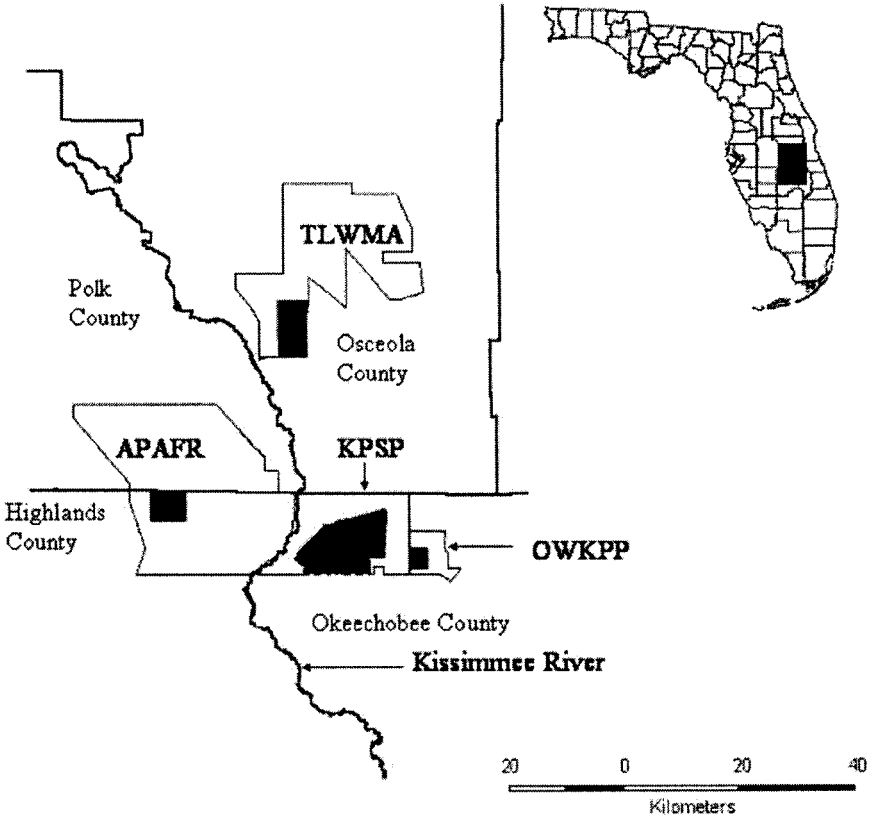

Figure 1. Location of dry prairie study sites (in black) in central Florida, USA, 1996-1998. Our 3 sites were located within Delta/OQ, Avon Park Air Force Range (APAFR); Three Lakes Wildlife Management Area (TLWMA); Ordway-Whittall Kissimmee Prairie Preserve (OWKPP); and Kissimmee Prairie State Preserve (KPSP) is also shown.

techniques (International Bird Census Committee 1970, Wiens 1969). Censusing began in early March and concluded at the end of the breeding season in late August or early September. Sparrow densities were calculated as the number of territories per 10 ha. Territories with more than 50% of their area within a plot were counted.

We censused each territory at least 12 times to determine habitat quality. This allowed us to develop an index of reproductive success for each territory. We used a slight modification of the reproductive index developed by Vickery et al. (1992). Reproductive success for each territory was ranked from 1 to 4, as follows: rank 1 = unpaired male present 4+ weeks; rank 2 = paired male and female present 4+ weeks, rank 3 = nest-building stage; sparrow carrying nesting material, adult chipping persistently in our presence, or giving distraction display; rank 4 = nestling stage; sparrow carrying food to presumed nestlings, or adults observed with nestlings. We then classified territories as successful if they were ranked 4, or unsuccessful if they were ranked 1, 2 or 3. We also determined a territory density in each year at each site.

WATER LEVELS

Water levels were monitored from 1996 to 1998. For each spot-mapping visit to a plot we generated a water score from 1 to 5. A plot was scored as follows: (1) if it was completely dry throughout the plot, (2) if it was dry and moist (defined as damp, but no standing water) in different portions of the plot, (3) if it was completely moist throughout the plot, (4) if it was a combination of moist in some areas of the plot, and had >25%, but less than <75% standing water (defined as >2 cm) and (5) if there was standing water on >75% of the plot.

We were primarily concerned with how water levels might affect sparrow reproduction. Standing water on a plot causes nest failure by flooding and sparrows need to renest, and therefore represents a disruption in the nesting cycle for ground-nesting sparrows. If water remained on a plot for more than 20 consecutive days, the inundation would not only destroy nests, but it would remove a whole nesting cycle based on 21- and 22-day nesting cycles for Florida Grasshopper Sparrows (Vickery 1996) and Bachman's Sparrows (Dunning and Watts 1990), respectively. We did not think that using the mean of the water scores to measure the effects of water levels on reproductive success would be appropriate because a higher average water score over the course of the breeding season would not necessarily indicate decreased breeding habitat. For example, we think that a plot rated a 3 each time during each of ten visits throughout the summer ($(10 \times 3)/10 = 3.0$) would provide better habitat than a plot rated a 2 for eight visits and a 5 for two visits ($((2 \times 8) + (5 \times 2))/10 = 2.6$), because the latter scenario would have resulted in two disruptions to the nesting cycle.

To develop a more meaningful measure of the effects of hydrological interruptions to the entire breeding cycle, we used our water scores to develop a Seasonal Moisture Index for each plot. The Seasonal Moisture Index ranged from *1* to *4* and was determined for the peak part of the breeding season, 1 April to 31 July. An index of *1* was assigned to plots that never had a water score of 5 during this period. An index of *2* was assigned to plots that had a water score of 5 on only one visit. An index of *3* was assigned to plots that had two separate non-consecutive water scores of 5 during the breeding season, or ≥20, but <30 consecutive days where the plot was scored a 5. An index of *4* was assigned to plots that had three separate non-consecutive water scores of 5, or ≥30 consecutive days of the plot being scored as a 5. We did not survey plots daily, so we assumed that if a plot had standing water on two subsequent visits then it was saturated during the intervening time period.

STATISTICAL ANALYSIS

This study was a result of unexpected artificial inundation of one site, therefore we could not randomly assign plots at different sites to a particular Seasonal Moisture Index with a balanced design. Some plots had the same Seasonal Moisture Index over all three years, whereas other plots had two or three different Seasonal Moisture Index ranks over the three-year period. The wettest plots all occurred at Audubon. This unbalanced design prevented us from using statistical measures to determine how reproductive success and territory density was affected by different water levels. Instead, we used an analysis of variance to determine if there were differences in Seasonal Moisture Indices between sites in each year from 1996 to 1998. When we detected a difference, we used a Duncan multiple range test to determine where these differences were. For territory density and reproductive estimates we combined the plots at each site into one estimate for each site because the water levels likely affected all plots within a site in a similar fashion.

RESULTS

Seasonal moisture indices were significantly wetter at Audubon than Three Lakes and Delta/OQ in 1996 ($F = 9.42$, $df = 2$, $P = 0.001$),

1997 ($F = 15.03$, $df = 2$, $P < 0.001$), and 1998 ($F = 11.36$, $df = 2$, $P < 0.001$) (Table 1).

Audubon had 0% success rate in all three years, compared to 9-31% at Delta/OQ, and 32-41% at Three Lakes (Table 2). Territory density at Audubon declined from 1.10 territories/10 ha in 1996 to 0.66 in 1997 and 0.11 in 1998. Territory densities ranged from 1.57 to 1.97 territories/10 ha at Delta/OQ, and 2.00 to 3.86 territories/10 ha at Three Lakes over the same time period (Table 2).

Bachman's Sparrows did not show as strong a pattern as Florida Grasshopper Sparrows. Bachman's Sparrow reproductive success was lowest at Audubon in all three years, but ranged from 13-25%. Three Lakes had the highest territory density, while Audubon and Delta/OQ had similar densities.

Increased water levels at Audubon may have been responsible for Florida Grasshopper Sparrow declines at this site; densities ranged between 1.09 and 1.75 territories/10 ha from 1993-1996 (Shriver 1996), but declined to 0.65 and 0.11 territories/10 ha in 1997 and 1998, respectively (Fig. 2). Surveys of this site in 1999-2001 failed to locate any Florida Grasshopper Sparrows (P. Gray, pers. comm.). Because the water levels were raised during the winter of 1995-96, territory density declines were not observed until 1997, the first year high water levels could have affected reproduction during the 1996 breeding season.

Discussion

High water levels, either natural or artificial, can have profound effects on ground-nesting birds. Florida dry prairie has a flat topography and a hardpan soil layer (Abrahamson and Hartnett 1990) which makes large portions of the prairie susceptible to flooding after heavy

Table 1. Seasonal Moisture Indices (SMI) and standard deviations from plots at Delta/OQ Range (n = 12), Three Lakes Wildlife Management Area (n = 13), and Ordway-Whittell Kissimmee Prairie Sanctuary (n = 8) from 1996-1998. Results of a Duncan multiple range test show that Audubon was significantly wetter than Delta/OQ Range and Three Lakes in all three years.

Year	Site	SMI	Standard Deviation	Duncan
1996	Delta/OQ	1.75	0.62	A
1996	Three Lakes	1.92	1.19	A
1996	Audubon	3.38	0.52	B
1997	Delta/OQ	1.17	0.39	A
1997	Three Lakes	1.69	0.95	A
1997	Audubon	3.00	0.76	B
1998	Delta/OQ	1.00	0.00	A
1998	Three Lakes	1.00	0.00	A
1998	Audubon	1.50	0.53	B

Table 2. Number of territories, hectares surveyed, density (#/10 hectares) and reproductive success of Florida Grasshopper and Bachman's sparrows from plots at Delta/OQ Range (n = 12), Three Lakes Wildlife Management Area (n = 13), and Ordway-Whittell Kissimmee Prairie Sanctuary (n = 8) from 1996-1998.

Year	Site	Territories	Hectares	Density	Success
Florida Grasshopper Sparrow					
1996	Delta/OQ	29	152.5	1.90	31.0
1996	Three Lakes	33	112.5	2.93	33.3
1996	Audubon	10	91.5	1.10	0.0
1997	Delta/OQ	30	152.5	1.97	20.0
1997	Three Lakes	44	114.0	3.86	40.9
1997	Audubon	6	91.5	0.66	0.0
1998	Delta/OQ	23	146.5	1.57	8.7
1998	Three Lakes	22	110.0	2.00	31.8
1998	Audubon	1	91.5	0.11	0.0
Bachman's Sparrow					
1996	Delta/OQ	14	152.5	0.92	35.7
1996	Three Lakes	23	112.5	1.77	21.7
1996	Audubon	14	91.5	1.53	14.3
1997	Delta/OQ	20	152.5	1.31	40.0
1997	Three Lakes	30	114.0	2.33	36.7
1997	Audubon	8	91.5	0.88	25.0
1998	Delta/OQ	14	146.5	0.95	35.7
1998	Three Lakes	27	110.0	2.11	37.0
1998	Audubon	8	91.5	0.88	12.5

rains. However, after inundation these prairie fragments drain quickly (D. Perkins, pers. obs.), and the flora and fauna appear to be adapted to these temporary changes in water levels. However, from 1996-1998, Audubon was artificially inundated and was wetter than either of the other two sites. We think these abnormally high water levels contributed to decreased Florida Grasshopper Sparrow productivity, leading to an acute population decline (Fig. 2).

Bachman's Sparrows were not as strongly affected by variable water levels; there was still evidence of reproductive success, and densities at Audubon were similar to Delta/OQ. This is probably due to different nest site selection. Shriver (1996) found that Bachman's Sparrow territories were consistently closer to shrub cover than random points in unoccupied habitat. Shrubby patches are usually situated on drier micro-sites. Bachman's Sparrow nests are often located in saw palmetto areas and are sometimes slightly above the ground (D. Perkins, pers. obs.), while Florida Grasshopper Sparrow nests are often located in shallow excavations (<3.2 cm) in the ground and by dwarf live oak (*Quercus minima*) and clumps of native grasses (Delany and Linda 1998). It seems likely that these adaptations enable Bach-

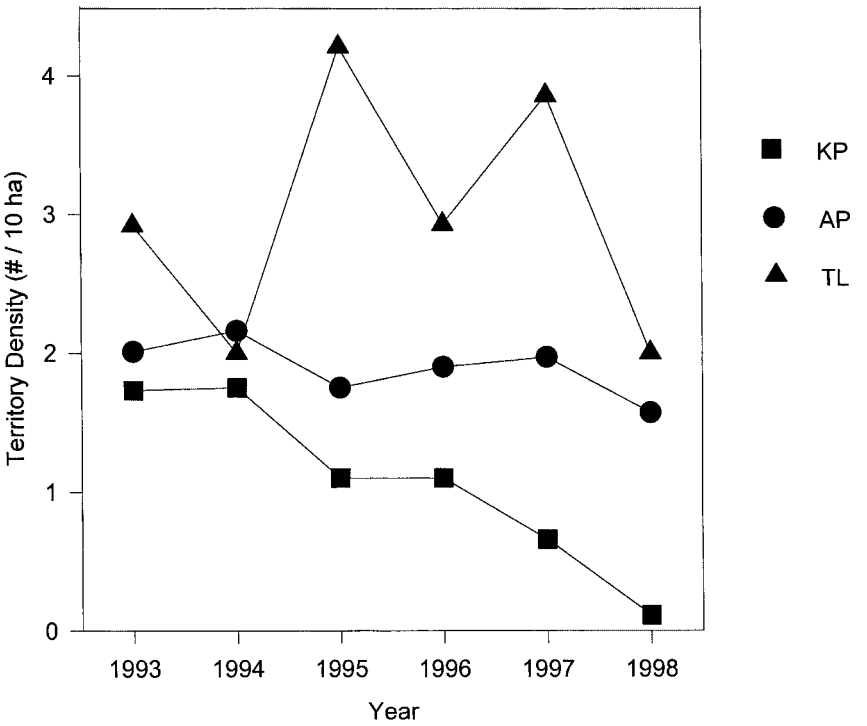

Figure 2. Florida Grasshopper Sparrow densities at Delta/OQ (AP), Three Lakes Wildlife Management Area (TL), and Ordway-Whittell Kissimmee Prairie (KP), Florida, from 1993 to 1998. Figure shows decline of sparrows at KP after impoundment was installed in the winter 1995-96.

man's Sparrow nests to survive higher water levels than Florida Grasshopper Sparrow nests.

Artificially high water levels appeared to have profound detrimental effects on Florida Grasshopper Sparrows. In addition to the effects altered hydrology had on breeding ecology, high water levels may also affect the available food supply by altering invertebrate populations, and decreasing the persistence of seeds. High water levels appear to be the primary reason for the population's sharp decline and extirpation at Audubon.

We do not have hydrology data that precedes 1996, and therefore we cannot rule out other causes for the low reproductive rates and subsequent decline of Florida Grasshopper Sparrows at Audubon. Shriver (1996) used the same methodology and most of the same study plots at all three sites from 1993 to 1995. Shriver (1996) reported reproductive success rates of 18% and 13% from Audubon in 1993 and 1994, respectively, compared to 16% and 30% at Delta/OQ, and 16% and 29% at

Three Lakes in those same two years (Table 3). However, in 1995 when the flooding began, Shriver (1996) noted 0% success rate at Audubon compare to 63% and 31% at Delta/OQ and Three Lakes, respectively. There have been no major changes in land management at any of the three sites from 1993 to 1998, and we are unaware of other agents, besides high water levels, that may have contributed to the lower reproductive rates, and dramatic decline at Audubon.

Fortunately, the hydrology at Audubon was restored in 1998. The U.S. Fish and Wildlife Service and the landowners bordering Audubon reached an agreement to restore the natural hydrology of this prairie. In addition, new dry prairie habitat, Kissimmee Preserve, was purchased immediately west of Audubon by the state of Florida in 2001. Kissimmee Preserve has the largest known population (P. Small, pers. comm.) of Florida Grasshopper Sparrows. Personnel at Kissimmee Preserve implemented four years of intensive burning and habitat management in an effort to restore the habitat between Kissimmee Preserve and Audubon. In the 2002 breeding season, three singing male Florida Grasshopper Sparrows were heard at Audubon. In addition 28 singing males

Table 3. Number of territories, hectares surveyed, density (#/10 hectares) and reproductive success of Florida Grasshopper and Bachman's sparrows from plots at Delta/OQ Range (n = 12), Three Lakes Wildlife Management Area (n = 14), and Ordway-Whittell Kissimmee Prairie Sanctuary (n = 8) from 1993-1995, from Shriver (1996).

Year	Site	Territories	Hectares	Density	Success
Florida Grasshopper Sparrow					
1993	Delta/OQ	31	154.25	2.01	16.2
1993	Three Lakes	32	109.75	2.92	15.6
1993	Audubon	11	63.75	1.73	18.2
1994	Delta/OQ	33	152.75	2.16	30.3
1994	Three Lakes	41	143.25	2.86	29.3
1994	Audubon	16	91.25	1.75	12.5
1995	Delta/OQ	35	152.75	2.29	62.9
1995	Three Lakes	57	135.50	4.21	30.3
1995	Audubon	10	91.25	1.10	0.0
Bachman's Sparrow					
1993	Delta/OQ	16	154.25	1.04	6.3
1993	Three Lakes	21	109.75	1.91	9.5
1993	Audubon	7	91.25	1.10	0.0
1994	Delta/OQ	22	152.75	1.44	45.5
1994	Three Lakes	39	143.25	2.72	30.8
1994	Audubon	14	91.25	1.53	35.7
1995	Delta/OQ	23	152.75	1.51	69.6
1995	Three Lakes	41	135.50	3.03	46.0
1995	Audubon	8	91.25	0.88	12.5

were detected on the restored prairie that used to separate these two populations (P. Small, pers. comm.). These two formerly disjunct populations now appear to be functioning as one larger population.

The extent of the dry prairie ecosystem has declined 81% in the past 30 years (Shriver and Vickery 1999). Further loss or degradation of remaining tracts of prairie could seriously damage the long-term viability of species that exist in this ecosystem. Habitat fragmentation has been documented to have detrimental effects on North American passerines (Donovan et al 1995, Robinson et al. 1995), including these two grassland birds (Perkins et al. 2003).

We hope results from this study will emphasize the need to prevent further hydrologic alterations that inundate remaining dry prairie in Florida and other hydrologically similar grassland sites. The extirpation of Florida Grasshopper Sparrows at Audubon provides a clear example regarding this species' limited tolerance for unnaturally prolonged flooding. The Comprehensive Everglades Restoration Plan is currently underway in Florida by the Army Corps of Engineers, the South Florida Water Management District and the U.S. Fish and Wildlife Service. This plan includes restoring the currently channeled Kissimmee River to its historic channel and flood plain. All of the known Florida Grasshopper Sparrow populations occur within a few miles of the Kissimmee River. The Florida Grasshopper Sparrow's small fragmented populations could be susceptible to flooding from the restoration process. The loss of even one of these populations could substantially reduce the viability of this taxon (Perkins and Vickery, unpubl. data). We recommend further consideration and monitoring of Florida Grasshopper Sparrows during this restoration process.

This study has documented the effects of increased water levels on the reproductive ecology of two ground-nesting passerines. As habitat fragmentation continues throughout North America, it is likely that many avian species will experience increased predation and parasitism rates. We propose that an additional threat, such as artificially altered hydrology, is likely to result in decreased reproductive success of ground-nesting species with adverse consequences to long term viability of rare species with small populations.

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