Wastewater Treatment Wetlands: Potential Hazardous Wildlife Attractants for Airports

Robert A. Kennamer, I. Lehr Brisbin, Jr. and Carol S. Eldridge
Savannah River Ecology Laboratory, Aiken, South Carolina

D. Allen Saxon, Jr.
Augusta Utilities Department, Augusta, Georgia

ABSTRACT: Wetlands constructed for the treatment of urban wastewater effluent have gained worldwide popularity in recent decades. Placement of such wetlands near airports however, is strongly discouraged by the U.S. Federal Aviation Administration, other national airport authorities, and the International Bird Strike Committee because they attract birds that may increase strike risks for aircraft. Despite recognition of this and other wildlife hazards to aircraft and efforts implemented to limit such land-use activities near airports, validated methods are still urgently needed to mitigate wildlife hazards on or near airports because bird populations and bird-aircraft strikes in the U.S. and elsewhere around the world persistently trend upward. The city of Augusta, Georgia USA designed and developed 144 ha of wastewater treatment wetlands on land adjacent to its Regional Airport at Bush Field during 1997–2002. In December 2001, we began temporal and spatial monitoring of bird activities in this area, recording species, their numbers, and flight characteristics. Within 2 years of completion, the wetlands, dominated by giant cutgrass (*Zizaniopsis miliacea*) and cattails (*Typha* spp.), served as a nighttime roost for millions of migratory blackbirds (family Icteridae) that crossed the airfield in massive flocks daily at sunrise and sunset during November–March. Beginning in December 2005, we investigated the efficacy of habitat alteration techniques to displace the blackbirds, including the use of airboats to mechanically crush wetland vegetation in portions of the treatment wetlands. The results of this method were highly significant, with far fewer blackbirds landing in crushed-vegetation areas than in uncrushed areas. Beginning with the fall of 2008, this vegetation-crushing technique was implemented annually for the entire wetland system; long-term post-crush bird monitoring indicated that blackbird roosting within the wetlands was almost nonexistent and blackbird activity around the airport was reduced by about 2 orders of magnitude. The ability of the wetland vegetation to process wastewater effluent was not negatively affected by vegetation alteration. This work successfully demonstrated that with thoughtful wildlife hazard management, including the consideration of novel techniques, it may be possible to mitigate large-scale undesirable wildlife attraction associated with certain land-use activities. Importantly, this success was accomplished through non-lethal means, using a relatively simplistic habitat altering technique. Throughout the succession of these events, careful monitoring of bird-aircraft strikes, bird numbers and their movements, and an unbiased evaluation of bird mitigation efforts formed the foundation of the success that was achieved.

Key Words: airports, bird-aircraft strikes, blackbirds, Georgia, giant cutgrass, habitat management, human-wildlife conflicts, Icteridae, wastewater treatment wetlands, *Zizaniopsis miliacea*.

Proceedings of the 15th Wildlife Damage Management Conference.
(J. B. Armstrong, G. R. Gallagher, Eds). 2013. Pp. 119-131.

INTRODUCTION

The functional role of natural wetlands in maintaining or improving water quality has been known to man since the times of ancient Egyptian and Chinese cultures (Brix 1994, Price and Probert 1997). Only in the last century however, has this knowledge been extended to the construction of wetland systems specifically engineered for wastewater treatment (Brix 1994). Use of such wetland systems has increased substantially in recent decades with their recognition as a cost-effective wastewater treatment technology (US-EPA 1993). Man-made treatment wetlands are designed to take advantage of many of the same water-cleansing processes that occur among natural wetland vegetation, soils, and microbial assemblages (Kadlec et al. 1979). These wetland habitats, whether natural or man-made, frequently attract diverse wildlife assemblages and are valued as areas for human interaction with nature (Knight 1997, US-EPA 1999, Rousseau et al. 2008).

Historically, airports have been sited away from metropolitan centers because they require large expanses of land and their placement in areas that are marginal for urban development has been considered the best option by land-use planners. Wetlands are frequently a part of the natural landscape in the vicinity of airports and they not only attract a great diversity of wildlife, but numbers of some species can be quite large, particularly for birds (Frederick and McGehee 1994, Chimney and Gawlik 2007). Urban waste (both solid and liquid) management facilities also have often been relegated to undeveloped areas and are generally recognized for attracting wildlife (Burger and Gochfeld 1983, Belant et al. 1993, 1995, Gabrey 1997). When located near airports, waste management facilities increase the potential for attracting wildlife closer to airports (Caccamise et al. 1996). Although concern for aircraft safety increases dramatically when large numbers of birds are attracted to areas in close proximity to airports, land-use planners have often overlooked the hazard (Blackwell et al. 2009). Within the U.S., the Department of Transportation's Federal Aviation Administration (FAA) has federal authority to provide for safe and efficient use of the nations airspace, which includes setting standards for aircraft, pilots, and airports. The FAA has maintained a database of reported aircraft collisions with wildlife since 1990, and numbers of strikes (civil and military aircraft) reported annually has increased dramatically, from 1,804 in 1990 to >10,000 in 2011 (Dolbeer et al. 2012). Populations of large birds known to represent a strike hazard to aircraft have been increasing in recent decades as well (Dolbeer and Eschenfelder 2003). These trends illustrate the need to validate methods for mitigating wildlife hazards on or near airports.

In 1997, the city of Augusta, Georgia USA was placed under a U.S. Federal Court order to improve the water quality of its treated wastewater discharges to the Savannah River. The mandate to Augusta officials was to develop a "Constructed Wetlands" project to provide tertiary treatment of effluents from the James B. Messerly Wastewater Treatment Plant (WWTP) before release into the river. The FAA, in its Advisory Circular 139, Section 337 (FAA 2007), recommends separation criteria for land-use practices that attract hazardous wildlife to the vicinity of airports. Because the constructed wetlands were located on land adjacent to Augusta Regional Airport at Bush Field (Figure 1) and well within all FAA-specified perimeter zones for airport protection from wildlife hazards, the FAA expressed concern early in the project's history that birds attracted to the treatment wetlands may pose an increased risk of bird-aircraft strikes. In particular, the concern was that large bodied waterfowl (family Anatidae) would be attracted to open-water areas of the constructed wetlands. As a result, Augusta officials were obligated to monitor potential wildlife hazards. Our initial objective was to provide site-specific data on bird movement patterns through the airspace over and surrounding Augusta Regional Airport, including that of the adjacent constructed wetlands. In late 2001, we initiated ground-based bird surveys to document species, numbers, altitudes and flight directions of birds in the area. Most bird species using the constructed wetlands were not considered a threat to the safety of aircraft operating at Augusta Regional Airport (Kennamer, unpublished data). However, an increasing bird-aircraft strike risk became apparent because of migratory blackbirds (family Icteridae) roosting at night within the constructed wetlands.

Figure 1. Augusta Regional Airport at Bush Field and the constructed wetlands of Augusta, Georgia, USA. On its eastern side (top of photo), the airport borders the Savannah River. Locations of count points (stars) used during the study are shown, including 3 locations on the airfield (CP#1, CP#2, CP#3) and 1 location within the constructed wetlands (CP#4).

Blackbirds and European starlings (*Sturnus vulgaris*) have drawn concern as strike hazards because of their abundant and growing numbers, and their tendency to gather in large feeding and roosting flocks (Dolbeer 1984, 1990). We therefore expanded our simple monitoring objective to include the development and assessment of efforts to mitigate strike-risk posed specifically by blackbirds, primarily through habitat alteration techniques at the constructed wetlands. We first conducted a pilot study during the fall and winter of 2005–06 in which we used an airboat to crush limited portions of the wetland vegetation and then examined bird use afterwards. Once convinced that crushing the vegetation by airboat tended to reduce/eliminate blackbird roosting and did not permanently damage the vegetation, consideration was given to crushing vegetation in the entire constructed wetlands. Beginning in 2008–09, all emergent vegetation in the 144-hectare (ha) constructed wetlands system was crushed by airboats annually in the fall to discourage roosting by flocking blackbirds. In this paper, we: 1) report results from initial monitoring that identified problematic roosting of blackbirds in the constructed wetlands, 2) use pilot study data to test the hypothesis that management of wetland vegetation (mechanical crushing by airboat) would have no effect on use of the constructed wetlands by blackbirds roosting in the vegetation, and 3) use long-term bird monitoring data to test the hypothesis that annual fall crushing of all vegetation in the constructed wetlands would have no effect on blackbird roost-flight activity around the airport.

STUDY AREA

Augusta Regional Airport at Bush Field

Bird monitoring and research took place at Augusta Regional Airport at Bush Field (Figure 1; FAA Identifier: AGS; Latitude, Longitude: 33-22.196667N , 081-57.870000W; Elevation: 43.9 m above mean sea level). The airfield was first established in 1941 as a U.S. Army Air Corps flight training school and was later (1948) transferred to city ownership (Cashin 2003). Augusta Regional Airport became a commercial carrier airport in 1950. The airport is 11 km south of the central business district of Augusta (Richmond County) Georgia, a city of almost 196,000 people as of the 2010 U.S. census (US Census Bureau 2013). Augusta Regional Airport consists of 2 runways, including the primary runway, 17/35, measuring 2439 m x 46 m, and runway 8/26 measuring 1830 m x 23 m (Figure 1). Operational statistics for 2012 included 27,860 total aircraft operations ($\bar{x}$ = 76/day), comprised of 43.1% air taxi, 38.3% transient general aviation, 7.2% military, 6.8% local general aviation, and 4.6% commercial (FAA 2013). Augusta Regional Airport experiences peak aircraft movement activity each year during the Masters Golf Tournament, held annually in Augusta during the first full week of April.

Richmond County, including Augusta Regional Airport, is part of the southeastern U.S. Upper Atlantic Coastal Plain physiographic region of the southeastern U.S. The airport itself covers an area of 5.7 km^2 and is bordered on its east side by the Savannah River (Figure 1), which separates the states of Georgia and South Carolina. The Savannah River is a major river of the southeastern U.S., at 484 km long and draining 27,390 km^2. Habitat types found on the airfield include managed grassland or herbaceous areas, water features, woody or shrubby areas, and disturbed or developed areas. An approximately 55 km^2 area to the north and east of the airport was identified as containing the primary wetland habitats in the vicinity of the airport. Based on a GIS habitat coverage developed from 1997 multispectral Landsat Thematic Mapper Data, about 40% of this area was comprised of wetland habitat.

Augusta Wastewater Treatment Facilities

The James B. Messerly WWTP is located immediately north of the airport and is the primary wastewater treatment facility for the city of Augusta. The plant is a conventional activated-sludge plant which processes approximately 28–30 million gallons of raw sewage daily from the city's collection system. The Messerly WWTP was operated by the Augusta Utilities Department prior to 1999, but Augusta has since privatized the plant's operations. During periods of operational control by Operations Management International (OMI) Inc. (1999–2009) and ESG Operations Inc. (2010–present), numerous operational changes were made, effecting improvements in the secondary wastewater treatment effluents discharged from the WWTP.

Phase 1 of Augusta's constructed wetlands project, including 2 wetland cells totaling 24 ha, was completed and placed into experimental operation by late 1997. Phase 2 expansion of the artificial wetlands was completed in early 2001, adding 7 more wetland cells. With the Phase 3 expansion in 2002, the completed Augusta constructed wetlands grew to its present size of about 144 ha (12 cells; Figure 1), now being among the largest U.S. surface-flow systems constructed for tertiary wastewater treatment (Eidson and Flite 2005). Establishment of vegetation in wetland cells progressed rapidly. By 2003, planted areas of the artificial wetlands were densely vegetated with emergent giant cutgrass (*Zizaniopsis miliacea*) and cattails (*Typha* spp.). Additional details regarding Augusta's constructed wetlands design and function are provided by Eidson and Flite (2005). In 2005, vegetated parts of some wetland cells experienced dieback (thinning) attributed to invasive muskrats (*Ondatra zibethicus*). Muskrats have previously been identified as a threat to vegetation in such constructed wetland systems (Rousseau et al. 2008). Trapping and removal efforts directed at the muskrats eliminated several hundred animals and by 2008, the progressive dieback appeared to have been halted and a period of vegetation recovery began.

METHODS

Point Location Bird Monitoring

From December, 2001 through September 2012, bird movements were routinely monitored from 4 specific locations (count points) established at Augusta Regional Airport (CP#1, CP#2, CP#3; Figure 1) and the constructed wetlands (CP#4; Figure 1). We selected locations of count points to ensure adequate visual coverage of the airfield and wetlands while limiting observational area overlap among locations. We divided daylight hours into 4 approximately equal time blocks: (1) 15 minutes before sunrise until 0900 hours, (2) 0901 hours until 1200 hours, (3) 1201 hours until 1500 hours, and (4) 1501 hours until 15 minutes after sunset (Eastern Standard Time). Observations were generally made at 2 different count points within 2 different time blocks daily, for 2 days each week, for 4 weeks each month. This approach allowed for all possible combinations of the 4 count points and the 4 time blocks to be sampled monthly in a predefined and randomized study design. We made observations over an approximate 2.5-hour period, consisting of 3-to-4 30-minute observation sessions with a 10-minute lapse between each session. Observations were generally initiated at the beginning of a time block with the exception of the last (evening) time block, which was timed so that the final 30-minute session ended 15 minutes after sunset. During sessions, an experienced observer scanned the 360-degree horizon with binoculars (10x magnification, 40-mm diameter objective lens) and attempted to collect data on as many flying birds as possible with no upper limit on distance from the observer (though for practical purposes generally no more than 2,000 m). Short movements by birds (< 100 m) or movements by small- and medium-sized birds (e.g., small passerines) in flocks of < 20 birds generally were not recorded. Emphasis was placed on the in-flight movements of waterfowl, double-crested cormorants (*Phalacrocorax auritus*), anhingas (*Anhinga anhinga*), wading birds (families Ardeidae, and Threskiornithidae; wood stork [*Mycteria Americana*]), diurnal raptors (families Accipitridae, Cathartidae, and

Falconidae), crows (genus *Corvus*), and other large or flocking birds (e.g., gulls and terns [family Laridae], blackbirds, and European starlings). During times of intense movements, observers gave priority to larger birds and larger flocks. We conducted observations regardless of weather conditions; inclement weather, including for example fog or rain, sometimes reduced observer detection of bird movements to distances < 200 m. In addition to meteorological data noted at the beginning of each 30-minute session, for each individual observation we also recorded: time, species, actual or estimated number of individuals (i.e., flock size), approximate distance from the observer, approximate direction from observer (using the 8 primary compass points), estimated altitude above land or water (categorized as < 35 m, 35–150 m, 150–330 m, 330–600 m and > 600 m), approximate direction of bird movement (using the 8 primary compass points), and bird behavior (i.e., level flight, landing, taking-off, soaring, circling, hovering, perched, ground forage).

Pilot Study Vegetation-Crushing

In the fall and winter of 2005–06, we conducted a pilot study of the potential effectiveness of using airboats to crush the wetland cell vegetation as a habitat modification to displace or reduce numbers of blackbirds roosting in the constructed wetlands. On 7 December 2005, an airboat was used to begin crushing emergent vegetation (i.e., wetland mitigation treatment) in one-half of cell 7 and all of cell 11 (total of 18 ha) in an attempt to reduce the amount of standing vegetation available for use as a roosting substrate by blackbirds. Crushing this amount of vegetation required about 15 hours (over 4 days) of actively operating the airboat, or about 50 min/ha.

Following the wetland mitigation treatment, we observed the responses of blackbirds attempting to roost in the study cells on 8 evenings during 16 December 2005–22 March 2006. To evaluate the effectiveness of the treatment, crushed vegetation areas were paired with adjacent uncrushed areas of the same size, to serve as "controls" in the study. Roost flights were observed while we were positioned between 2 adjacent wetland cells (or halves of a single cell), one with vegetation that was crushed (treatment) and another with unaltered vegetation (control). The wetland pairings included crushed cell 11 versus uncrushed cell 10 and the crushed half of cell 7 versus the uncrushed half of cell 7. Elevated (1 m above ground) observation platforms were used to ensure adequate visual coverage of the wetland cells of interest. Since blackbirds roosting in the constructed wetlands arrived in the evenings and departed at dawn, our observations were conducted during evening arrival periods, from 45 minutes before sunset until 15 minutes after sunset (60 minutes per count series). During the counts, observers scanned selected wetland cells with binoculars for 1-minute intervals, attempting to record as many birds landing within each study cell as possible. One-minute observations alternated between the paired wetlands, creating paired counts for direct comparison. To control for potentially confounding issues associated with variable weather conditions, we conducted these observations only during evenings when there was no precipitation and there was less than 50% cloud cover.

Data Analysis

For the pilot study of vegetation crushing by airboats, we excluded from analyses any paired observations when the recorded number of landing blackbirds for both counts of a pair was < 10 individuals. We excluded such paired observations because the evening roost flights generally did not begin at the onset of a count series at 45 minutes before sunset; typically, it was 10–30 minutes into a 60-minute count series before substantial numbers of blackbirds began arriving at the constructed wetlands. Thus, we used 259 pairs of 1-minute counts that were conducted during December 2005–March 2006. The sample of 259 paired count differences (uncrushed minus crushed counts) did not reflect a normal distribution (i.e., there was positive skewing; Shapiro-Wilk test: $W = 0.5884$, $P < 0.0001$). To evaluate significance of the vegetation-crushing treatment, we used a Wilcoxon signed-rank test (Sokal and Rohlf 1995) to test the null hypothesis that the median difference between paired observations was zero. We accepted significance of this test at a $P \leq 0.05$ level.

To evaluate the ultimate success of the complete crushing of the constructed wetlands vegetation as a mitigation treatment to reduce blackbird numbers around the airport, we selected point-location bird monitoring data from all 4 count points (Figure 1); we included only data from November through March (Julian days 1–90 and 304–366) annually, the period when migratory blackbird populations were present in the area (Figure 2).

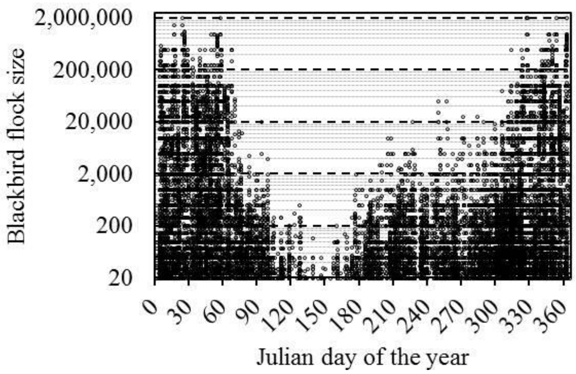

Figure 2. Frequency distribution of blackbird flock sizes (logarithmic scaled) observed at Augusta Regional Airport at Bush Field and the constructed wetlands of Augusta, Georgia, USA (full years, 2002–11) by Julian day of the year.

The monitoring data were further filtered to include only members of the Icteridae family (primarily red-winged blackbirds [*Agelaius phoeniceus*], brown-headed cowbirds [*Molothrus ater*], common grackles [*Quiscalus quiscula*], and rusty blackbirds [*Euphagus carolinus*]) and only sunrise or sunset counts (i.e., only 30-minute sessions centered on either sunrise or sunset) when the blackbirds made daily movements between roosting and foraging sites (Figure 3). As a result of this data filtering, we included 8,792 flock observations from 392, 30-minute sessions during January 2002–March 2012; individual blackbird flock observations within 30-minute sessions were summed. The sample of summed 30-minute counts of generic blackbirds deviated from a normal distribution (log-normal, positive skewing; Shapiro-Wilk test: W = 0.4615, P < 0.0001), but a log-transformation improved the likelihood of a normal distribution (Shapiro-Wilk test: W = 0.9657, P < 0.0001); log-transformed counts were subsequently used as the dependent variable in analyses described below.

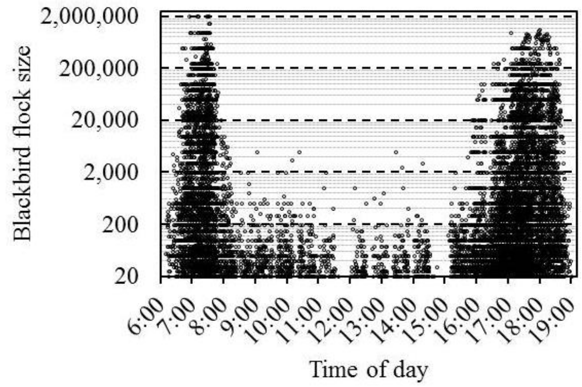

Figure 3. Frequency distribution of blackbird flock sizes (logarithmic scaled) observed at Augusta Regional Airport at Bush Field and the constructed wetlands of Augusta, Georgia, USA (2002–12) by time of day (Eastern Standard Time).

We created a "habitat condition" categorical effect to include with the collected blackbird count data to specifically test effectiveness of the vegetation crushing at the constructed wetlands. Data from appropriate years were consolidated into categories representing the prevailing habitat conditions at the constructed wetlands (Figure 4), including: 1) the falls and winters of 2001–02 through 2002–03 when wetland vegetation stands were still maturing, 2) the falls and winters of 2003–04 through 2004–05 when maximal vegetation density prevailed, 3) the falls and winters of 2005–06 through 2008–09 when the wetland vegetation was impacted by muskrat activity (i.e., less than full density because of dieback), and 4) the falls and winters of 2009–10 through 2011–12 when airboat crushing of all the vegetation was routinely performed between mid-October and mid-November annually. Although all vegetation was first crushed by airboat

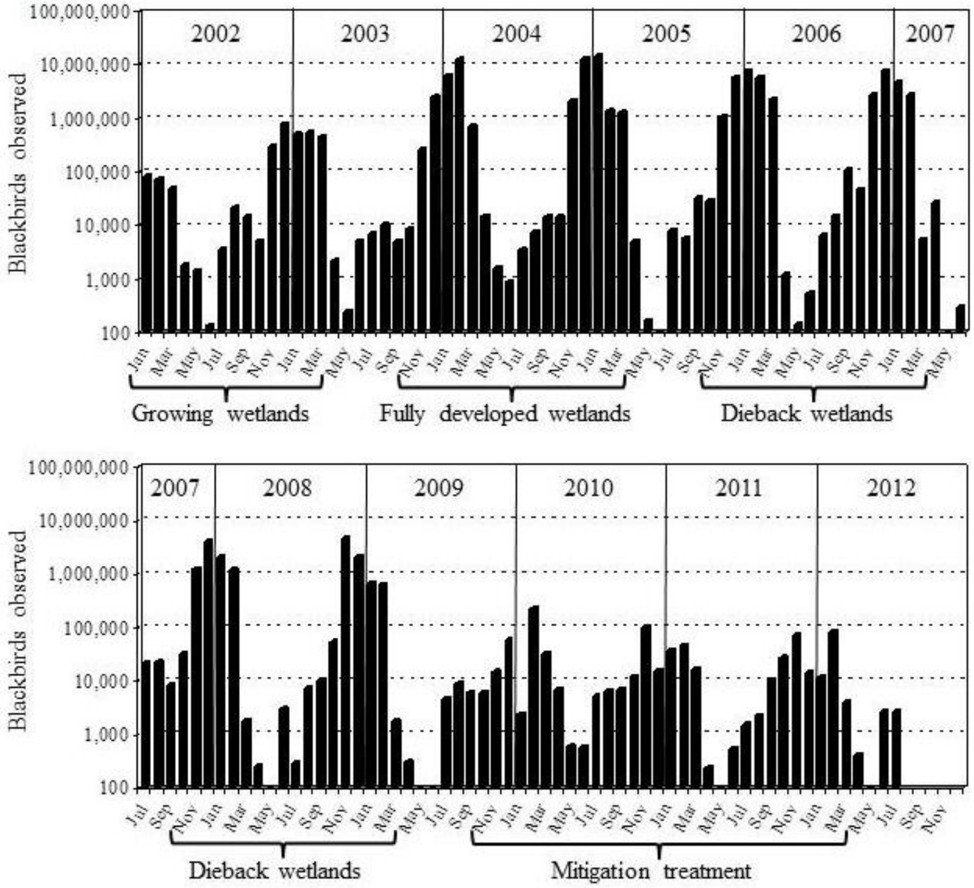

Figure 4. Monthly maximum number of blackbirds observed during any single time block–count point combination (30-minute count) at Augusta Regional Airport at Bush Field or the constructed wetlands of Augusta, Georgia, USA (2002–12). Bracketed periods represent differing habitat conditions prevailing at the constructed wetlands during fall and winter months of peak blackbird roosting (see text for full details).

beginning in the fall and winter 2008–09, the period of crushing for that initial season was 17 November–10 December 2008, a month later than in subsequent years. Moreover, this first year of vegetation crushing represented a transitional period and so data for this season were assigned to the category with vegetation dieback due to muskrats.

We tested the additive effects of month (MON; November–March), time block (TB; Sunrise, Sunset), and wetland condition or treatment (TRT; Growing Wetlands, Fully Developed Wetlands, Dieback Wetlands, and Mitigation Treatment), plus 2-way interactions of these three main effects, on log-transformed 30-minute counts of blackbirds. We constructed various models containing all combinations of the effects of interest, and each model was subjected to an analysis of variance using a standard least-squares fit (JMP Pro Version 9.0.3, SAS Institute, Inc., Cary, NC). Model selection was based on Akaike's information criterion with bias adjustment for small sample sizes (AIC_c; Burnham and Anderson 2002). For tested models we present AIC_c differences among ordered models and the top model (ΔAIC_c), and an index to plausibility (weight) for model comparisons (w_i). For the best model selected, we provide results from analysis of variance, including post-hoc Tukey HSD tests and specific orthogonal contrast tests of interest for least-squares means separations. Least-squares means of log-transformed counts of blackbirds were back-transformed for presentation along with 95% confidence intervals (CIs). We accepted significance of all tests at a $P \leq 0.05$ level.

RESULTS

Initial Recognition of the Bird-Strike Risk

Migratory blackbirds quickly located Augusta's constructed wetlands and made increasing use of the local area as emergent vegetation stands increased in density. Maximum numbers of almost 15 million blackbirds were observed just 4 years following the 2001 vegetation planting in the expanded wastewater treatment wetlands (Figure 4). These enormous numbers of densely flocking blackbirds made daily movements at sunrise and sunset (Figure 3) during November through mid-March (Figure 2). The sunrise movements were typically from the constructed wetlands heading directly toward Augusta Regional Airport, crossing over the airfield and continuing to the south and southwest. Then, each evening, a reversal of the sunrise movement pattern was evident as blackbirds moved from the south and southwest directly over the airfield, heading northeast and back into the constructed wetlands vicinity to roost for the night. Considering the extremely high numbers of flocking blackbirds that were making these movements twice daily over the airfield, bird strikes reported for the airfield were only modestly increased to 7–8 strikes over a 2-yr period (2004–05 and 2005–06) around the time of sunrise or sunset during November through March. Despite this relatively low number of reported bird strikes, we frequently observed dense flocks of blackbirds avoiding aircraft that were landing or departing at the airfield.

Pilot Study Vegetation-Crushing

Following the December 2005 crushing of about 12–13% of the constructed wetlands vegetation during the pilot study, we found evidence in clear support of the ability of this habitat-altering technique to mitigate the problematic roosting of blackbirds. Among 259, 1-minute counts in crushed-vegetation areas, the average number of landing blackbirds was only 1.2 (median = 0; maximum = 50); 75% (194) were counts of no landing blackbirds. In contrast, among 259, 1-minute counts in uncrushed-vegetation areas, the average number of landing blackbirds was 325 (median = 180, maximum = 3,500). A Wilcoxon signed-rank test of the 259 paired, 1-minute observations of landing blackbirds in crushed versus uncrushed vegetation areas was significant (S = 16835.0, P < 0.0001).

Long-term Success of Vegetation-Crushing

Using point count bird monitoring data we evaluated the long-term efficacy of using airboats to crush vegetation in the fall as a deterrence measure against roosting blackbirds in the fall and winter. The most parsimonious model of log-transformed blackbird numbers during 30-minute counts included MON, TB, TRT, and the MONxTRT interaction (Table 1). This model was 5.65 AIC$_c$ units better than the second-best model, which included all effects in the best model except TB. In the top-performing model, the MON effect was significant ($F_{4,\ 371}$ = 29.12; P < 0.0001); a post-hoc Tukey HSD test of least-squares means differences among months indicated that both November and March blackbird counts differed from counts in all other months (all Ps < 0.05), while counts from December through February did not differ among each other (all Ps > 0.05; Figure 5).

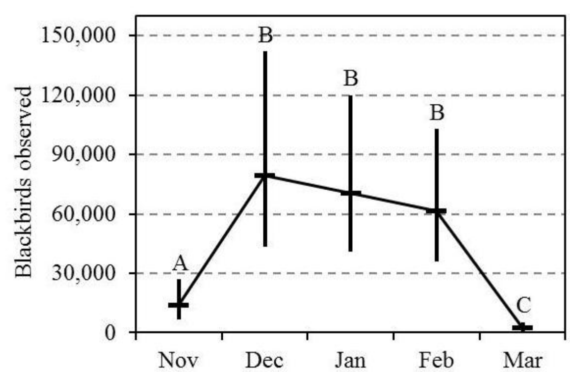

Figure 5. Geometric mean (back-transformations of log-counts; horizontal bars) and 95% CIs (vertical bars) of blackbird numbers observed during 30-minute counts (sunrise or sunset) at Augusta Regional Airport at Bush Field and the constructed wetlands of Augusta, Georgia, USA, during November–March (2002–12). Least-squares means from months with the same letter were not significantly different from one another in comparisons using a Tukey HSD test (P > 0.05).

Table 1. Summary of model selection results (for the top 9 models) obtained by Akaike's information criterion, adjusted for small sample sizes (AIC_c); models were constructed to explain variation in log-transformed blackbird counts/30 min (n = 392). K is the number of parameters in a model; ΔAIC_c is the difference in AIC_c between any model and the top model; w_i is an index to plausibility (weight) for model comparisons; R^2 is the coefficient of determination; F is the whole-model F-test ratio; and, P is the probability level. Data were collected from Augusta Regional Airport at Bush Field and the nearby Augusta constructed wetlands, Georgia, USA (2002–12).

Model[1]	K	ΔAIC_c	w_i	R^2	F	P
MON+TB+TRT+(MON*TRT) [2]	6	0.00	0.931	0.579	25.5	<0.0001
MON+TRT+(MON*TRT)	5	5.65	0.055	0.570	26.0	<0.0001
MON+TB+TRT+(MON*TB)+(MON*TRT)+ (TB*TRT)	8	8.38	0.014	0.587	19.2	<0.0001
MON+TB+TRT	5	57.83	0.000	0.478	43.8	<0.0001
MON+TB+TRT+(TB*TRT)	6	59.99	0.000	0.484	32.4	<0.0001
MON+TRT	4	63.12	0.000	0.468	48.3	<0.0001
MON+TB+TRT+(MON*TB)	6	63.88	0.000	0.481	29.3	<0.0001
TB+TRT	4	171.79	0.000	0.287	38.9	<0.0001
TB+TRT+(TB*TRT)	5	175.68	0.000	0.291	22.5	<0.0001

[1]MON = Month (November–March); TB = Time Block (Sunrise, Sunset); TRT = Treatment (Growing Wetlands, Fully Developed Wetlands, Dieback Wetlands, and Mitigation Treatment).
[2]AIC_c = 1783.23 for the most parsimonious model.

Blackbird counts made during the sunrise TB ($\bar{x}$ = 35,775; 95% CI = 25,463 – 50,312) were greater than those made during the sunset TB ($\bar{x}$ = 18,996; 95% CI = 13,630 – 26,476; $F_{1, 371}$ = 7.55; P = 0.006). Distributions of individual blackbird observations within the 30-minute sessions by TB indicated that morning movements from the roost area were well-centered on the time of sunrise (Figure 6A), resulting in more complete counts of total bird movements in mornings than during evening 30-minute sessions (Figure 6B). The TRT effect was also significant in the top-performing model ($F_{3, 371}$ = 81.57; P < 0.0001); in a specified orthogonal contrast analysis testing the TRT effect of greatest interest, fall and winter roost movements of blackbirds in years when vegetation-crushing occurred from mid-October to mid-November were less than in all other years of the Augusta constructed wetland's 11-yr history (t = −13.44; P < 0.0001; Figure 7). Although the MONxTRT interaction was significant ($F_{12, 371}$ = 7.39; P < 0.0001) in the top performing model, indicating that TRT effects differed by MON in some cases, for the specified orthogonal contrasts of greatest interest, numbers of blackbirds observed

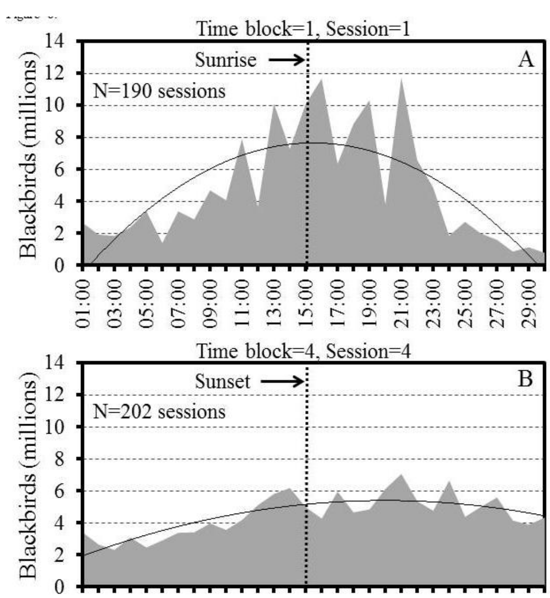

Figure 6. Distributions of blackbird numbers observed over the course of 392 30-minute counts at Augusta Regional Airport at Bush Field and the constructed wetlands of Augusta, Georgia, USA, during sunrise (A) and sunset (B) time blocks (2002–12). Curves fit to the distributions illustrate the relative completeness of roost-flight counts within the 30-minute count periods that were used.

when vegetation crushing was in effect were less than blackbird numbers observed when the constructed wetlands vegetation was at its maximum density, for every month (range of *t*s: −8.38 – −2.45; *P*s < 0.015; Figure 8).

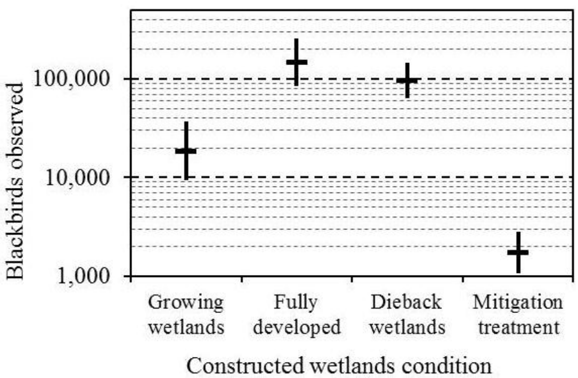

Figure 7. Geometric mean (back-transformations of log-counts; horizontal bars) and 95% CIs (vertical bars) of blackbird numbers observed during 30-minute counts (sunrise or sunset) at Augusta Regional Airport at Bush Field and the constructed wetlands of Augusta, Georgia, USA, during November–March (2002–12).

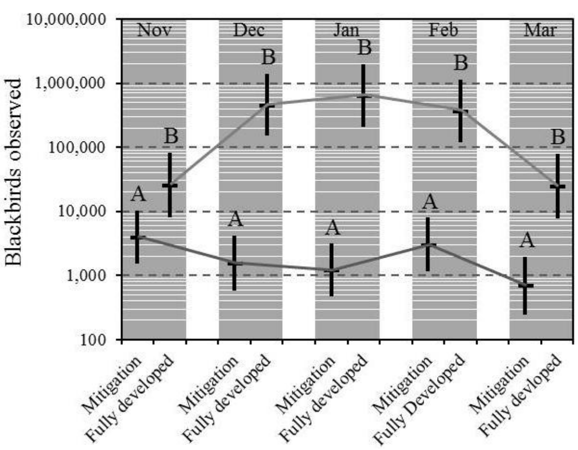

Figure 8. Geometric mean (back-transformations of log-counts; horizontal bars) and 95% CIs (vertical bars) of blackbird numbers observed during 30-minute counts (sunrise or sunset) at Augusta Regional Airport at Bush Field and the constructed wetlands of Augusta, Georgia, USA, during November–March (2002–12). Constructed wetlands habitat conditions (Mitigation Treatment vs. Fully Developed Wetlands) within months (individual shaded areas) with the same letter are not significantly different from one another (*P* > 0.05).

DISCUSSION

Worldwide, from 1960 through 2004, more than 455 aircraft have been destroyed and over 405 human lives lost due to strikes with wildlife (Cleary and Dolbeer 2005). Among birds, the blackbirds and European starlings have drawn concern as a strike hazard because of their abundant and growing numbers, and their tendency to gather in large feeding and roosting flocks (Dolbeer 1984, 1990). Barras et al. (2003) reported that more than 1,700 strikes involving blackbirds and starlings were found in the FAA's National Wildlife Strike Database for the period 1990–2001, with a trend of increasing numbers of strikes over time. These same authors also noted more than $1.6 million in aircraft damage reported from these particular strikes and recommended the reduction or removal of suitable roosting areas in airport environments (Barras et al. 2003). Despite efforts to limit land-use practices around airports that attract birds, surprisingly few methods designed specifically to control such hazards on or near airports have been experimentally validated.

Numerous methods have been suggested for blackbird control in agricultural settings, including exclusion, alteration of farming practices, or even direct management of problem population segments through the use of deterrents and lethal removal (Dolbeer 1994, Cummings and Avery 2003). Many of these same techniques have simply been adopted in efforts to mitigate bird strike hazards on or near airfields without adequate evaluations of the effectiveness of the techniques in the airport environment.

Despite the international popularity in recent decades of wastewater treatment wetlands, siting such wetlands near airports is strongly discouraged by air travel authorities worldwide because they tend to attract birds that may increase strike risks for aircraft. Indeed, within 2 years of completion, Augusta's constructed wetlands served as a nighttime roost for millions of migratory blackbirds that crossed the nearby Augusta Regional Airport daily at sunrise and sunset in the fall and winter.

As an initial test of a potentially useful mitigation technique, we used an airboat to mechanically crush the vegetation in a limited portion of the wetland system in 2005, intending to displace roosting blackbirds. Analysis of counts of blackbirds observed landing in the constructed wetlands during the 4 months immediately following this vegetation crushing trial produced highly significant results, with far fewer blackbirds landing in crushed-vegetation areas than in uncrushed-vegetation areas. An analysis of counts of landing blackbirds made in the next migratory season determined that the effect was no longer significant. As anticipated, the wetland vegetation regenerated during the spring and summer months following the fall crushing and thus the vegetation alteration would have to be repeated annually to assure continued displacement of blackbirds. Functionality of the treatment wetlands to effectively process wastewater was not adversely affected by vegetation crushing (Saxon, unpublished data). Other techniques were attempted to reduce or eliminate blackbird roosting in the constructed wetlands, including the use of controlled vegetation burning in the fall/winter of 2007–2008, but none of these alternate methods successfully manipulated the vegetation to an extent that changed the roosting behavior of the blackbirds.

We next expanded the vegetation-crushing technique in the fall of 2008 to include the entire wetland system. Bird monitoring conducted throughout the constructed wetlands 11-yr history indicated that blackbird numbers observed during roost flights in the 3 years when vegetation-crushing occurred from mid-October to mid-November were less than in all other years. Blackbird roosting within the constructed wetlands became almost non-existent (< a few thousand), and maximum blackbird numbers observed following initiation of annual vegetation crushing dropped by > 2 orders of magnitude (Figure 4). However, blackbirds numbering into the tens of thousands still traveled along the Savannah River corridor at sunrise and sunset, which still constituted a remnant risk for strikes with aircraft using Augusta Regional Airport. Undoubtedly, other smaller blackbird roosts existed in the vicinity of the airfield.

The practice of manipulating wetland habitats to influence their use by birds is not a new concept. In areas of the northern plains where sunflower production was subjected to damage by blackbirds roosting in nearby marshes, efforts were undertaken to thin dense stands of cattails (Dolbeer 1994). These efforts included the reduction of cattail stands by herbicide application. Such an application of herbicide in the case of wetlands used for processing wastewater would not be well-advised however, since damaged vegetation likely would not effectively process effluents (Thullen et al. 2005).

Although the cattail thinning successfully decreased blackbird roosting in the marshes studied by Dolbeer (1994), it also resulted in increased use by waterfowl for nesting and other activities. This was a concern we had in the case of Augusta's constructed wetlands. When the constructed wetlands experienced vegetation thinning due to muskrat activities beginning in 2005, blackbird numbers declined (Figure 4), while wading bird and waterfowl numbers increased (Kennamer, unpublished data).We were mindful that crushing the vegetation down to the waterline might unintentionally increase use of the wetlands by these bird species, potentially creating yet another strike hazard for aircraft. Great egret (*Ardea alba*) numbers did tend to increase slightly (never more than 100–200 individuals) for brief periods during the vegetation crushing and for 1–2 weeks thereafter, but never posed an increased risk to aircraft operating at the nearby airport (Kennamer, unpublished data). Waterfowl numbers at no time exhibited significant increases following the vegetation crushing (Kennamer, unpublished data). We suspect that a program of blackbird harassment initiated along with the vegetation crushing, while not focused on wading birds or waterfowl, served to dissuade these species from using the altered wetlands. Bird harassment teams organized by the operator of Messerly WWTP made limited use of propane cannons and hand-held shell crackers (Long 1981, Cleary and Dolbeer 2005) against remnant blackbird flocks flying over the constructed wetlands during their evening movements.

MANAGEMENT IMPLICATIONS

Perhaps the most important point demonstrated by this monitoring and research effort was that with thoughtful wildlife hazard management it may be possible to mitigate large-scale undesirable wildlife attraction associated with certain land-use activities. Furthermore, the possibility for novel ideas to successfully mitigate wildlife hazards should never be undervalued. Importantly, this success was accomplished through non-lethal means, using simple habitat alteration. Throughout the succession of these events, careful monitoring of bird-aircraft strikes, bird numbers and their movements, and an unbiased evaluation of bird mitigation efforts formed the foundation of the success that was achieved.

ACKNOWLEDGMENTS

We thank Warren (Cub) Stephens for assisting in data collection. Karen Gaines provided a GIS habitat analysis of our research area. Bird strike and wildlife incident reports for Augusta Regional Airport were provided by former Airport Director Al McDill (1998), former Interim-Director Tim Weegar (1999, 2000), and Airside Agents (wildlife hazard control) Tina Rhodes (2001–10) and Diane Vance (2011−12). James C. Beasley kindly provided comments that improved the manuscript. Funding in support of this work was provided by the City of Augusta Utilities Department to the University of Georgia Research Foundation. This work was also supported by the U.S. Department of Energy under Award Number DE-FC09-07SR22506 to the University of Georgia Research Foundation.

LITERATURE CITED

BARRAS, S. C., S. E. WRIGHT, and T. W. SEAMANS. 2003. Blackbird and starling strikes to civil aircraft in the United States, 1990–2001. Pages 91−96 *in* Management of North American Blackbirds. Proceedings of a special symposium of the Wildlife Society Ninth Annual Conference, Bismarck, North Dakota, USA.

BELANT, J. L., T. W. SEAMANS, S. W. GABREY, and S. K. ICKES. 1993. Importance of a landfill to nesting herring gulls. Condor 95:817−830.

BELANT, J. L., T. W. SEAMANS, S. W. GABREY, and R. A. DOLBEER. 1995. Gull and other bird abundance at landfills in northern Ohio. American Midland Naturalist 134:30−40.

BLACKWELL, B. F., T. L. DEVAULT, E. FERNÁNDEZ-JURICIC, and R. A. DOLBEER. 2009. Wildlife collisions with aircraft: A missing component of land-use planning for airports. Landscape and Urban Planning 93:1−9.

BRIX, H. 1994. Use of constructed wetlands in water pollution control: historical development, present status and future perspective. Water Science Technology 30:209−223.

BURGER, J., and M. GOCHFELD. 1983. Behavior of nine avian species at a Florida garbage dump. Colonial Waterbirds 6:54−63.

BURNHAM, K. P., and D. R. ANDERSON. 2002. Model Selection and Multi-model Inference: a Practical Information-Theoretic Approach. Second edition. Springer-Verlag, New York, USA.

CACCAMISE, D. F., L. M. REED, and J. ROMANOWSKI. 1996. Bird strike hazards and waste management facilities in urban landscapes. Pages 247−266 *in* Proceedings of the Twenty-Third Bird Strike Committee Europe, BSCE23/WP25, May 13−17, London, United Kingdom.

CASHIN, E. J. 2003. From Balloons to Blue Angels: The Story of Aviation in Augusta, Georgia. Center for the Study of Georgia History, Augusta State University, Augusta, Georgia, USA.

CHIMNEY, M. J., and D. E. GAWLIK. 2007. The avifauna of constructed wetlands in south Florida used for Everglades restoration. Florida Field Naturalist 35:9−21.

CLEARY, E. C., and R. A. DOLBEER. 2005. Wildlife hazard management at airports, a manual for airport personnel. Second edition. U.S. Department of Transportation, Federal Aviation Administration, Office of Airport Safety and Standards, Washington, D.C., USA.

CUMMINGS, J. L., and M. L. AVERY. 2003. An overview of current blackbird research in the southern rice growing region of the United States. Pages 237−243 in Proceedings of the Tenth Wildlife Damage Management Conference. K. A. Fagerstone and G. W. Witmer, editors. April 6–9, Hot Springs, Arkansas, USA.

DOLBEER, R.A. 1984. Blackbirds and starlings: population ecology and habitats related to airport environments. Pages 149−159 *in* Proceedings: Wildlife Hazards to Aircraft Conference and Training Workshop. M. J. Harrison, S. A. Gauthreaux, Jr., and L. A.

Abron-Robinson, editors. U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., USA.

DOLBEER, R.A. 1990. Ornithology and integrated pest management: red-winged blackbirds and corn. Ibis 132: 309−322.

DOLBEER, R. A. 1994. Blackbirds. Pages E25−E32 *in* Prevention and Control of Wildlife Damage. S. E. Hyngstrom, R. M. Timm, and G. E. Larson, editors. University of Nebraska Cooperative Extension Service, Lincoln, USA.

DOLBEER, R. A., and P. ESCHENFELDER. 2003. Amplified bird-strike risks related to population increases of large birds in North America. Pages 49−67 *in* Proceedings of the Twenty-Sixth International Bird Strike Committee, IBSC26/WP-OS4, May 5−6, Warsaw, Poland.

DOLBEER, R. A., S. E. WRIGHT, J. WELLER, and M. J. BEGIER, 2012. Wildlife Strikes to Civil Aircraft in the United States, 1990−2011. U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., USA.

EIDSON, G. W., and O. P. FLITE. 2005. Multi-year research on the use of constructed wetlands for advanced wastewater treatment. *In* Proceedings of the 2005 Georgia Water Resources Conference. K. J. Hatcher, editor. Institute Ecology, University of Georgia, Athens, USA.

FAA. 2007. Hazardous wildlife attractants on or near airports. Advisory Circular Number 150/5200-33B, Airport Safety and Operations Division AAS-300, U.S. Department of Transportation, Federal Aviation Administration, Washington, D.C., USA.

FAA. 2013. FAA Air Traffic Activity System, Airport Operations <http://aspm.faa.gov/opsnet/sys/opsnet-server-x.asp>. Accessed 5 Feb 2013.

US-EPA. 1993. Constructed Wetlands for Wastewater Treatment and Wildlife Habitat: 17 Case Studies. U.S. Environmental Protection Agency Publication EPA 832-R-93-005, September, 1993.

FREDERICK, P. C., and S. M. MCGEHEE. 1994. Wading bird use of wastewater treatment wetlands in central Florida, USA. Colonial Waterbirds 17:50−59.

GABREY, S. W. 1997. Bird and small mammal abundance at four types of waste-management facilities in northeastern Ohio. Landscape and Urban Planning 37: 223−233.

KADLEC, R. H., D. L. TILTON, and K. C. EWEL. 1979. The use of freshwater wetlands as a tertiary wastewater treatment alternative. Critical Reviews in Environmental Science and Technology 9:185−212.

KNIGHT, R. L. 1997. Wildlife habitat and public use benefits of treatment wetlands. Water Science Technology 35:35−43.

LONG, G. L. 1981. Pyrotechnics for bird control. Great Plains Wildlife Damage Control Workshop Proceedings pp. 278−282.

PRICE, T., and D. PROBERT. 1997. Role of constructed wetlands in environmentally-sustainable developments. Applied Energy 57:129−174.

ROUSSEAU, D. P. L., E. LESAGE, A. STORY, P. A. VANROLLEGHEM, and N. DE PAUW. 2008. Constructed wetlands for water reclamation. Desalination 218:181−189, (doi:10.1016/j.desal.2006.09.034).

SOKAL, R. R., and F. J. ROHLF. 1995. Biometry: The principles and practice of statistics in biological research. Third edition. W. H. Freeman, New York, USA.

THULLEN, J. S., J. J. SARTORIS, and S. M. NELSON. 2005. Managing vegetation in surface-flow wastewater treatment wetlands for optimal treatment performance. Ecological Engineering 25:583−593.

US CENSUS BUREAU. 2013. USCB State and County QuickFacts. <http://quickfacts.census.gov/qfd/states/13/1304204.html>. Accessed 5 Feb 2013.

US-EPA. 1999. Treatment Wetland Habitat and Wildlife Use Assessment. U.S. Environmental Protection Agency Publication EPA 832-S-99-001, June, 1999.