ELSEVIER

International Biodeterioration & Biodegradation 45 (2000) 111–127

INTERNATIONAL BIODETERIORATION & BIODEGRADATION

www.elsevier.com/locate/ibiod

Wildlife hazard assessment for Phoenix Sky Harbor International Airport

Wendy Servoss[a], Richard M. Engeman[b,*], Steven Fairaizl[a], John L. Cummings[b], N. Paige Groninger[b]

[a]*USDA/APHIS/WS 2224 W. Desert Cove, #209, Phoenix, AZ 85029, USA*
[b]*National Wildlife Research Center, 4101 LaPorte Ave, Fort Collins, CO 80521-2154, USA*

Abstract

We examined wildlife abundance, distribution, and movement patterns at Phoenix Sky Harbor International Airport (PHX) and within an 8-km radius to assess current air-strike hazards, and to provide baseline information for projecting changes in air-strike hazards as land-use patterns around PHX change. We found that water sources at or near PHX especially induced wildlife movement patterns that put air traffic at risk. This was particularly true of the Salt River bed adjacent to the airport, which also is a natural flight corridor for birds. Compounding the problem, air traffic at PHX was the heaviest when bird abundance and activity was the greatest during migration and breeding. We feel that air strike hazards at PHX are likely to increase substantially as the Salt River bed is reclaimed to produce additional lakes and high quality riparian habitat. We offer recommendations to reduce the hazard levels currently found at PHX and to reduce additional hazards as the habitat around PHX is converted and produces more attractive wildlife habitat. Published by Elsevier Science Ltd.

1. Introduction

Collisions between aircraft and wildlife are a concern throughout the world because they threaten passengers' safety (Thrope, 1997), result in loss of revenue and costly repairs to aircraft (Milsom and Horton, 1990; Linnell et al., 1996; Robinson, 1997; Cleary et al., 1997, 1998), and can also erode public confidence in the air transport industry as a whole (Conover et al., 1995). In several instances, wildlife–aircraft collisions in the United States have resulted in human fatalities, most recently in 1995 when an Air Force E-3B AWACS aircraft ingested several Canada geese (*Branta canadensis*) on takeoff from Elmendorf Air Force Base, Alaska, and crashed, killing 24 people (Gresh, 1996; Bird, 1996; York et al., in press). Most wildlife strikes do not result in fatalities, but safety hazards exist and the proportion of wildlife strikes that result in damage is substantial.

Many actions can decrease wildlife hazards, depending on the species, time of year, and habitat characteristics on and around the airfield. Wildlife hazard assessments provide a framework through which a site-specific understanding of wildlife hazards on an airport is developed. Wildlife hazard assessments typically should cover at least one full year because wildlife populations, especially migratory birds, exhibit seasonal fluctuations in behavior and abundance.

This study developed baseline data on wildlife populations and wildlife strikes at Phoenix Sky Harbor International Airport (PHX) prior to development of the Rio Salado project, a habitat restoration plan which aims to restore the nearby Salt River to its natural state. Past strike data indicated that wildlife capable of causing damaging collisions had access to aircraft flight patterns and movement areas. The objectives of this wildlife hazard assessment were to: (1) review available wildlife strike records, (2) assess wildlife

* Corresponding author.

0964-8305/00/$ - see front matter Published by Elsevier Science Ltd.
PII: S0964-8305(00)00056-1

population parameters such as abundance and periods of activity, emphasizing the species most threatening to aircrafts' safety, (3) identify and quantify attractive wildlife features and land-use practices at PHX and in surrounding areas that may contribute to wildlife hazards on the airfield, and (4) provide recommendations for reducing wildlife hazards at PHX.

2. Methods

2.1. Airport description

PHX is a 904-ha public facility located in southeast Phoenix (and <1.6 km west of Tempe), in Maricopa County, Arizona. PHX is 345 m above mean sea level and local climatic conditions are characterized by hot summers and mild winters. Average low/high temperatures range from approximately 4.4°C/21.9°C in January to 27.5°C/36.5°C in July. The average annual rainfall is 18.1 cm.

PHX services the commercial air carrier and transport industry, general aviation, and military aircraft. PHX serves more than 27 million people annually and is the 11th busiest U.S. airport and the 17th busiest world airport. From July 1, 1997 to June 30, 1998, PHX had almost 520,000 operations (defined as any takeoff or landing by a fixed-wing aircraft). Approximately 70% of aircraft operations involved commercial passenger aircraft, 14% air transport (commercial shuttle aircraft and cargo), 15% general aviation (private aircraft, helicopters, etc.), and 1% military aircraft (Air National Guard). The annual number of operations is expected to increase upon completion of a third runway in the year 2001.

2.2. Habitat restoration near PHX

PHX was built immediately adjacent to the Salt River, which at the turn of the 20th century was free-flowing with boating and other recreation. The construction of dams and irrigation diversions upstream diverted the water from the river, resulting in an often dry bed nowadays. Much of the river bed is planned for reclamation into a lake and riparian habitat. This project, known locally as the Rio Salado project, includes the cities of Phoenix and Tempe. An 8-km stretch of the Salt River in Phoenix will be renovated to produce a river that could support native plants and wildlife. In Tempe, construction on a 324-ha park, including the establishment of Town Lake, a 3.2-km long lake in the Salt River bed, is currently being completed. Town Lake is 3.2 km east of PHX, and directly in line with the PHX runways. Wetlands created by the Rio Salado project adjacent to PHX could attract additional wildlife and increase the threat of bird–aircraft collisions.

2.3. Wildlife strike data

The definition of a wildlife strike by Bird Strike Committee, Canada (Transport Canada, 1992) has been adopted by federal, civilian, and international organizations, including the Federal Aviation Administration (FAA). A wildlife strike is recorded if: (1) a pilot reports a strike, or (2) aircraft maintenance personnel identify damage as having been caused by a bird or mammal strike, or (3) personnel on the ground report seeing an aircraft strike one or more birds or mammals, or (4) bird or mammal remains, in whole or part, are found on any airside pavement area or within 200 feet of a runway, unless another reason for the animal's death is identified. Wildlife strike data provide valuable information on wildlife hazards at airports, including the types of wildlife struck, seasonality, and time of day.

Wildlife strike rates, strikes per 10,000 aircraft operations (Blokpoel, 1976), are used as indices of wildlife hazards at airports, and for assessing hazard abatement efforts. Most airports account for less than 20% of actual strikes (Dolbeer et al., 1995). Bird strike statistics based on pilot reports generally are incomplete, because pilots either do not report strikes or the proportion of reported strikes varies due to factors such as decreased pilot acuity towards birds during critical phases of flight, size of the bird, flock size, weather conditions, time of day, or heightened pilot awareness during migratory seasons (Linnell et al., 1999). Thus, collection of dead birds from runways during routine searches provides otherwise unavailable information about strike rates (Linnell et al., 1996). During this study, PHX Airside Operations Department personnel collected injured or dead birds during runway sweeps to augment bird-strike records. We identified the wildlife species they found and supplied the appropriate information for the FAA Birdstrike Database.

2.4. Study site at PHX

We examined wildlife hazards within an 8-km radius (general zone) of the runway centerline at PHX because most bird–aircraft collisions occur when aircrafts are at low altitudes. Turbine powered aircrafts normally reach 601 m above ground level (AGL) before leaving the general zone and 88% of bird–aircraft collisions occur below 610 m AGL (Cleary et al., 1997). We emphasized areas within the 3.2-km radius of the runway centerline (critical zone) because turbine powered aircraft are usually under 150 m AGL and 72% of the national strikes occur at or below this level (Cleary et al., 1997).

PHX currently has two runways. The northern-most runway is 46 × 3354 m and the southern runway is 46 × 3140 m. A third runway, currently under construction, will be the farthest south and approximately 46 × 2378 m. The air traffic control tower, three terminals, FAA and executive offices, and other buildings are located between the two main runways. An Air National Guard unit is situated on the south side of the southernmost runway. Industrial and commercial buildings (factories, warehouses) are located along the roads directly north and west of PHX. PHX property is bordered by Air Lane Road on the north, State Routes 143 and 153 on the east, the Salt River bed on the south, and 24th Street on the west. The area consists of residential, commercial, and industrial buildings, vacant lots, sparsely-vegetated desert, riparian areas, and pooled water within the Salt River bed and the Phoenix canal system.

2.5. Wildlife habitat survey

We identified habitat characteristics near PHX and examined their relation to wildlife use patterns. Food, water, and cover are wildlife attractants. Habitat management that alters food, water and cover offers the most effective long-term solution for deterring wildlife from airports. The ultimate goal is to create an environment uniformly unattractive to the species posing the greatest aviation hazards, bearing in mind that decreasing the attractiveness for one species may increase attractiveness for other potentially hazardous species.

2.6. Time–area count survey

The time–area count survey was based on the USFWS breeding bird survey (Robbins et al., 1986). Data on bird species and numbers were collected from 18 observation sites, 0.8–1.2 km apart. Sites were chosen to sample key habitats on and directly adjacent to PHX property. Birds were surveyed once per week from July 1, 1998 to June 30, 1999. The start time of each count alternated between dawn and dusk every other week to monitor the crepuscular periods of peak bird use. The survey route was reversed biweekly. Each station was surveyed for 3 min using the naked eye, and all birds were recorded that were seen within a 0.4 km radius. Binoculars or a spotting scope were used only to verify observations and to identify questionable species. Bird numbers observed, activity (categorized according to flying, loafing, etc.), habitat type, and any other pertinent observations (time, wind speed and direction, temperature, and weather conditions) were recorded. In addition, bird species heard during the survey were recorded. Time–area count surveys assume that all birds at a site are detected by the observer. In our surveys, the numbers of small solitary birds may have been underestimated in favor of the larger, more visible flocking birds. We considered this acceptable because our objective was not to estimate density of every species, but to establish an index of abundance and activity of the most hazardous species. We categorized the 18 survey stations according to five main habitat types, described below.

2.6.1. Industrial/commercial habitat

Stations 1–5 were along the northern boundary of PHX in industrial/commercial habitat. They incorporated portions of the north runway, general aviation hangars within the airsides operations area (AOA), industrial and commercial buildings (factories, warehouses), power lines, billboards, street lights and railroad tracks across the road from PHX. Across that road from PHX, the ground was sparsely vegetated with weeds and some native and exotic shrubs and trees. Adjacent to PHX, landscaping with exotic grasses, shrubs, and trees or desert xeriscaping dominated.

2.6.2. Disturbed desert habitat

Stations 6 and 13 were disturbed desert habitat of open land with few buildings and directly under the approach path of aircraft. Station 6, located off the east end of PHX, was sparsely vegetated with weeds, low-growing bushes, and some mesquites. Station 13, located on the west side of the southern-most runway, encompassed large vacant lots that contained a minimum of exotic landscaping and were bordered by commercial buildings. The vacant lots were comprised of bare gravel with a few patches of weeds. Street lights and power lines also bordered the vacant lots.

2.6.3. Retention pond habitat

Another habitat surveyed was a water retention pond surrounded by desert xeriscaping (station 7) located east of terminal 4. Water pooled in the basin intermittently throughout the year.

2.6.4. Terminal buildings habitat

The habitat associated with the terminal buildings was surveyed at stations 8–12, located between both runways and encompassing the three terminals and parking garages, air traffic control tower, FAA and executive buildings, air cargo, and maintenance buildings. Grass and exotic plants, such as palms, constituted the majority of the vegetation at these stations. Structures, such as fences, street lights, traffic signs, and power lines, were common throughout the area.

2.6.5. Salt River bed habitat

The Salt River bed habitat (stations 14–18) was along the south side of PHX. The southern-most run-

way, Cutter Aviation, and the Air National Guard unit bordered these stations. Tracking equipment, radar towers, grass and exotic landscaping were in the area. The Salt River, adjacent to the south, was a mostly-dry river bed with intermittent pools of standing water, some of which were surrounded by riparian vegetation.

2.7. General surveys

We also examined habitats outside of the time-area count survey, but within the 8-km general zone around PHX. General survey sites were sized the same as for the time-area count survey. All birds seen at each general survey site within a 0.4-km radius or heard within a 60 minute time frame were recorded. Binoculars or a spotting scope were again used only to verify observations and identify questionable species. Bird activity (i.e. flying, loafing, nesting, etc.), numbers, habitat type, and other pertinent observations were noted. The seven sites were surveyed weekly, alternating mornings with afternoons every other week. Three sites would be surveyed one day, and the other four the next. Survey and driving time each day occupied the first 4 h after dawn or the last 4 h before dusk.

2.7.1. I-10 riparian area

The riparian area in the Salt River bed along both sides of the I-10 overpass comprised this site. Storm water run-off was routed under PHX into the Salt River bed, creating several pools of standing water that rarely dried up. Riparian vegetation, including various willows, cottonwoods, palms, cattails, and aquatic grasses and weeds, was found near this water source. Dry portions of the river bed contained sand, gravel, and river rock and were sparsely vegetated with salt cedar (*Tamarix pentandra*), mesquites, and many species of weeds and small bushes.

2.7.2. Town Lake

This site was located on the western portion of the 3.2-km long Town Lake in the Salt River bed. Town Lake was under construction during most of the study, until the lake began filling on June 2, 1999. During development of the lake, water pooled in the dry river bed around the partially-constructed inflatable rubber dams. Downstream from the lake, salt cedar stands grew in the river bottom among temporary pools of standing water. One bank of the Salt River had eroded there, exposing waste from closed solid waste landfills. Various structures with the potential to attract wildlife were present, including numerous power transmission lines on both sides of the Salt River.

2.7.3. Papago Park

A portion of Papago Park was another general survey site. A part of the park's golf course and buttes within the Phoenix Zoo could be observed to the west. Distrubed desert, containing a dry wash, was located to the south and east. A hydroelectric generating station was situated on a canal, and was surrounded by palms, cottonwoods, and other wetland plants. Canal water, dammed for hydroelectric use, created a small lake with an island vegetated with weeds and bushes. The surrounding desert was comprised of mesquites, paloverdes, saguaros, prickly pears, and other desert flora. The golf course was landscaped with exotic and native vegetation. Above ground power lines also were located here.

2.7.4. Transfer station

Located on the south side of the Salt River, the waste transfer station was a partially-enclosed warehouse in which putrescible solid waste was deposited for later transfer to a landfill. Industrial buildings bordered two sides, with vacant land and the Salt River bed bordering the other two. Power lines were situated along the river bed and native bushes and shrubs grew along one side of the transfer station.

2.7.5. Co-op

Site 5 was at a wild/domestic animal feed mill co-op adjacent to the northeast corner of PHX. The co-op was dilapidated, giving birds access to the building for loafing and roosting. Vacant lots, power lines, and railroad tracks were located on one side of the co-op, and industrial buildings bordered the other sides.

2.7.6. Encanto Park

Encanto Park was in a residential area within the 8-km radius of PHX, but not directly under the flight path. It was chosen to represent habitats analogous to large city parks. Encanto Park had a meandering lagoon with an island containing numerous palms. Landscaped grass and exotic vegetation (palms, eucalyptus) were found throughout the park and adjoining golf course. Numerous picnic tables, barbecue grills, open garbage cans, and signs were located on the park's grassy areas.

2.7.7. Grand Canal

The Grand Canal was northwest of PHX and was part of Phoenix's canal system. The canal held water throughout the survey except in December. The canal was bordered by a fence and had gravel roads on both sides. Mesquite trees and bushes lined the fence along the west side of the canal. Industrial and commercial buildings with minimal vegetation were located on both sides of the canal.

2.8. Predator survey

Scent stations (attractants with tracking plots) were used to examine the presence of predators near PHX (a coyote, *Canis latrans*, was struck in 1993). Nine scent stations (Linhart and Knowlton, 1975) were placed in or along the Salt River bed at 0.32 km intervals. Each station consisted of a 0.9 m circle of smoothed earth, with a fatty-acid scent tablet placed in the center. Surveys were conducted for five consecutive days, every 3 months, and presence/absence of predator tracks were recorded by species.

Table 1
Groupings of birds based on similar behavioral (rather than strictly taxonomic) characteristics. Species that exhibit similar behaviors and life history attributes generally require similar control methods

Birds of prey
- American kestrel (*Falco sparverius*)
- Cooper's hawk (*Accipiter cooperii*)
- Great horned owl (*Bubo virginianus*)
- Harris hawk (*Parabuteo unicinctus*)
- Merlin (*Falco columbarius*)
- Northern harrier (*Circus cyaneus*)
- Osprey (*Pandion haliaetus*)
- Peregrine falcon (*Falco peregrinus*)
- Red-tailed hawk (*Buteo jamaicensis*)
- Turkey vulture (*Coragyps atratus*)

Blackbirds/starlings
- Brewer's blackbird (*Euphagus cyanocephalus*)
- Brown-headed cowbird (*Molothrus ater*)
- European starling (*Sturnus vulgaris*)
- Great-tailed grackle (*Quiscalus mexicanus*)
- Red-winged blackbird (*Agelaius phoeniceus*)
- Western meadowlark (*Sturnella neglecta*)
- Yellow-headed blackbird (*Xanthocephalus xanthocephalus*)

Columbids
- Inca dove (*Columbina inca*)
- Mourning dove (*Zenaida macroura*)
- Rock dove (feral pigeon) (*Columba livia*)[a]
- White-winged dove (*Zenaida asiatica*)

Corvids
- Common raven (*Corvus corax*)

Finches, sparrows, vireos, warblers
- Albert's towhee (*Pipilo aberti*)
- Bell's vireo (*Vireo bellii*)
- Common yellowthroat (*Geothlypis trichas*)
- House finch (*Carpodacus mexicanus*)
- House sparrow (*Passer domesticus*)
- Lark sparrow (*Chondestes grammacus*)
- Lesser goldfinch (*Carduelis psaltria*)
- Orange-crowned warbler (*Vermivora celata*)
- Rose-ringed parakeet (*Psittacula krameri*)
- Rufous-crowned sparrow (*Aimophila ruficeps*)
- White-crowned sparrow (*Zonotrichia leucophrys*)
- Wilson's warbler (*Wilsonia pusilla*)
- Yellow-rumped warbler (*Dendroica coronata*)
- Yellow warbler (*Dendroica petechia*)

Gulls
- Ring-billed gull (*Larus delawarensis*)

Insectivorous perching birds
- Black phoebe (*Sayornis nigricans*)
- Gila woodpecker (*Melanerpes uropygialis*)
- Loggerhead shrike (*Lanius ludovicianus*)
- Northern flicker (*Colaptes auratus*)
- Northern mockingbird (*Mimus polyglottos*)
- Say's phoebe (*Sayornis saya*)
- Western kingbird (*Tyrannus verticalis*)

Shorebirds
- Common snipe (*Gallinago gallinago*)
- Greater yellowlegs (*Tringa melanoleuca*)
- Killdeer (*Charadrius vociferus*)
- Least sandpiper (*Calidris minutilla*)
- Long-billed dowitcher (*Limnodromus scolopaceus*)
- Spotted sandpiper (*Actitis macularia*)

Swallows and other aerial foragers
- Cliff swallow (*Hirundo pyrrhonata*)
- Lesser nighthawk (*Chordeiles acutipennis*)
- Northern rough-winged swallow (*Steigidopteryx serripennis*)

Upland ground birds
- American pipit (*Anthus rubescens*)
- Bewick's wren (*Thryomanes bewickii*)
- Black-tailed gnatcatcher (*Polioptila melanura*)
- Cactus wren (*Campylorhynchus brunneicapillus*)
- Curve-billed thrasher (*Toxostoma curvirostre*)
- Gambel's quail (*Callipepla gambelii*)
- Greater roadrunner (*Geococcyx californianus*)
- Horned lark (*Eremophila alpestris*)
- Verdin (*Auriparus flaviceps*)

Wading birds
- American avocet (*Recurvirostra americana*)
- Black-crowned night heron (*Nycticorax nycticorax*)
- Black-necked stilt (*Himantopus mexicanus*)
- Cattle egret (*Bubulcus ibis*)
- Great blue heron (*Ardea herodias*)
- Great egret (*Casmerodius albus*)
- Green-backed heron (*Butorides striatus*)
- Snowy egret (*Egretta thula*)

Waterfowl
- American coot (*Fulica americana*)
- American wigeon (*Anas americana*)
- Buffehead (*Bucephala albeola*)
- Canada goose (*Branta canadensis*)
- Canvasback (*Aythya valisineria*)
- Cinnamon teal (*Anas cyanoptera*)
- Common moorthen (*Gallinula chloropus*)
- Domestic duck (numerous species)
- Domestic goose (numerous species)
- Double-crested cormorant (*Phalacrocorax penicillatus*)
- Eared grebe (*Podiceps nigricollis*)
- Gadwall (*Anas strepera*)
- Green-winged teal (*Anas crecca*)
- Lesser scaup (*Aythya affinis*)
- Mallard (*Anas platyrhynchos*)
- Northern pintail (*Anas acuta*)
- Northern shoveler (*Anas clypeata*)
- Pied-billed grebe (*Podilymbus podiceps*)
- Redhead (*Aythya americana*)
- Ring-necked duck (*Aythya collaris*)
- Wood duck (*Aix sponsa*)

[a] For analytical purposes, rock doves were considered separately from the other Columbids.

2.9. Small mammal survey

Rodent populations near PHX were surveyed to index their potential as an attractant for raptors (two hawks and one owl were struck during 1993–1996) and mammalian carnivores. PHX applies a seal on unpaved areas within the AOA to reduce blowing dust and weeds. The sealant also limits rodent habitat on the airport. Thus, four study sites outside the AOA with potential rodent habitat were sampled: (1) a weedy field, directly east of the southern runway; (2) disturbed, sparsely-vegetated desert on City of Phoenix–Pueblo Grande Museum property; (3) a vacant lot on the south side of PHX, inside the airport fence; and (4) a vacant lot containing minimal weed patches just west of the southern runway. All four sites were sampled once per month (one survey per week). Twenty-five rat/mouse snap traps (12 rat traps, seven medium mouse traps (museum specials), six small mouse traps) were baited with a mixture of peanut butter and oats. Traps were placed in a row on the ground, 10 m apart, and checked after 24 h. Relative abundance for each rodent species was calculated as the number of animals caught per 100 trap nights, adjusted for the number of traps sprung without a capture (King, 1989).

2.10. Nocturnal (owl) survey

The owl survey, based on Seamans (1988), examined the presence of four species of owls presumed to inhabit areas near PHX. The survey was conducted 1 h after sundown, once per month, at the riparian area located in the Salt River bed west of the I-10 overpass. Taped calls of western screech owl (*Otus kennicottii*), short-eared owl (*Asio flammeus*), barn owl (*Tyto alba*), and great horned owl (*Bubo virginianus*) were used to elicit responses from owls.

2.11. Data analyses

Wildlife species were categorized into groups (Table 1) based on similar behavioral characteristics, not on taxonomic relationships (although the species within a group often paralleled taxonomic lines), because behavioral attributes play important roles in predisposing some species of wildlife to collisions with aircraft. In addition, wildlife control strategies are often selected based on their ability to exploit specific animal behavior(s). Therefore, species that exhibit similar behaviors and life history attributes generally require similar control methods. For example, blackbirds and starlings were grouped together due to their gregarious (flocking) behavior, including intermixed flocks of these species. Rock doves (*Columba livia*) were considered separately from the other columbids for analytical purposes.

2.11.1. Time–area count survey

Separate analyses were conducted within each habitat type for each of the species groups. Each habitat within the time–area count survey, except the retention pond, was analyzed as a 2-factor factorial in a randomized block design. Stations within a habitat grouping were treated as replicates (blocks) of the habitat, upon which observations were made temporally (across months) and over time-of-day (mornings and evenings). Because the retention pond habitat was comprised of a single station (and all inferences were to that station), a 2-factor factorial analysis of variance (ANOVA) was used for analysis (rather than a randomized block).

2.11.2. General survey

Separate statistical analyses also were run for each bird group for each of four habitats identified within the general survey. Two habitats were comprised of multiple sites for which comparisons among the sites were of interest. Habitats identified among the general survey sites included (1) riparian (Papago Park, Rio Salado Town Lake, I-10 Riparian area sites), (2) industrial buildings (co-op and Sky Harbor transfer station sites), (3) Grand Canal (single site, not included with riparian sites as it had virtually no riparian habitat), and (4) Encanto Park (single site). Habitats with multiple sites (riparian and industrial building groupings) were analyzed as 3-factor factorial ANOVAs. The single site habitats (Grand Canal and Encanto Park) were analyzed using 2-factor factorial ANOVAs.

3. Results

3.1. Wildlife strike data

Forty-one dead birds were removed from the AOA and pilots reported 15 strikes (unrelated to the dead birds collected). At approximately 520,000 aircraft operations during 1998–1999, the strike rate per 10,000 operations was 1.08. Of these, 32% of species struck were medium-sized, heavy-bodied, or flocking birds, including pigeons, raptors, and waterfowl. Fifty-four percent included the smaller doves that tend to form flocks, such as mourning doves (*Zenaida macroura*), 21 of which were found dead along both runways throughout the year. Pigeons (rock doves) were observed flying over PHX to move between the feed mill/co-op and the transfer station and six dead pigeons were removed from the areas within the AOA between these two facilities. During the winter migration, carcasses of birds in the waterfowl group

(three eared grebes (*Podiceps nigricollis*), two American coots (*Fulica americana*), and one pied-billed grebe (*Podilymbus podiceps*)) were evenly distributed around both the runways. Waterfowl were observed flying over PHX in flocks of over 150 birds to move between water sources in the Salt River bed along the southern-most runway and a portion of the canal system that runs adjacent to the northeast corner of PHX. The numbers of dead birds removed from the AOA and observations of migrating waterfowl showed that birds move beyond the boundary of the Salt River bed.

3.2. Habit attractants

We describe our observations from our wildlife habitat according to the habitat features important to wildlife well-being.

3.2.1. Water

Water appeared extremely attractive to wildlife in this desert ecosystem where even small water sources at PHX attracted birds. Several areas in and around PHX contained water, including the retention pond, and areas of unlevel ground where water is allowed to pool after rains. Pools of water and riparian vegetation were located in the Salt River bed, creating attractive resting areas for migrating birds (waterfowl, shorebirds, wading birds, blackbirds/starlings, birds of prey). The Grand Canal, northeast of PHX and perpendicular to the Salt River, influenced birds to fly over (<200 m AGL) PHX from the Salt River. Ponds and lakes, such as the hydroelectric dam at Papago Park and Town Lake, also were in the general zone of PHX.

3.2.2. Vegetation

The areas of greatest concern regarding bird hazards are wetlands, crop lands, and edge areas (where two or more habitat types are juxtaposed). Most of the water sources listed above contain wetland/riparian vegetation that is attractive to wildlife. In addition, 4% (979 ha) of the general zone around PHX contained parks or open desert and 2% (542 ha) was zoned for agricultural use (although about a quarter of zoned agricultural land was vacant). Vegetation is primarily absent from the AOA, except for interspersed weed patches, although exotic landscaping and desert xeriscaping exist around buildings at PHX.

3.2.3. Structures

PHX has numerous man-made structures such as hangars, terminals, runway signs and lights, street lights, and aviation aides that provide perching habitat for birds. About three-quarters of the general zone around PHX was comprised of industrial, commercial, and residential buildings. The structure of industrial buildings (and landscaping) often attracts birds, such as pigeons, blackbirds, and doves, that are frequently involved in aircraft collisions.

3.2.4. Vacant lots

Seventeen percent (3775 ha) of land within the general zone of PHX was comprised of vacant lots. These lots and weed growth, which attract small mammals, which in turn attract the predators, such as hawks and owls, increase the risk of bird–aircraft strikes.

3.3. Time–area count survey

3.3.1. Overview

Different groups of birds (Table 1) preferred certain habitats over others, although some species groups were found in all habitats. For instance, waterfowl were only observed at stations along the river bed and others containing water. A summary of the average counts per site in each habitat across the course of the study is given in Table 2, and is intended for use with the analytical results presented in the following subsections. Overall, bird populations at PHX increased in both abundance and species diversity during winter migration, peaking in January. Species groups, such as waterfowl, shorebirds, and wading birds, exhibited higher numbers during the fall and winter months. Blackbirds peaked in January. Bird numbers began declining in March as migrants returned north. A slight increase in bird numbers was recorded in May as a result of increased activity during the breeding season and, subsequently, production of offspring. The lowest number of birds was observed during summer months because of decreased numbers of migratory birds and shortened activity periods of year-round resident birds.

3.3.2. Blackbirds/starlings

The blackbird/starling bird group, predominantly great-tailed grackles (*Quiscalus mexicanus*), red-winged blackbirds (*Agelaius phoeniceus*), and European starlings (*Sturnus vulgaris*), were distributed throughout all stations along the survey route (Table 2), and were often observed feeding on lawns and vocalizing from palms, light poles, and other structures. Populations remained relatively stable throughout the year, usually 20–40 birds per survey (all 18 stations combined), except during October when migrants congregated at the Salt River bed habitat. The industrial zone ($F = 3.81$, $df = 10, 40$, $p = 0.001$) and retention pond ($F = 2.30$, $df = 10, 22$, $p = 0.049$) habitats, while not the most heavily used, showed the strongest temporal fluctuations in observations. Highest numbers were observed in October–November, followed by February–April for the industrial habitat, whereas highest

Table 2
Average counts per site (SE) in each habitat across the course of the time–area count survey. Bird groups where sufficient observations for data analyses did not occur for any of the habitats are not included in the table (swallows and other aerial foragers, upland ground birds)

Bird group	Period	Habitat				
		Disturbed desert	Industrial/commercial	Retention pond	River bed	Terminal buildings
Birds of Prey	7–8/98	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
	8–9/98	0 (0)	0 (0)	0 (0)	0.05 (0.05)	0 (0)
	9–10/98	0 (0)	0 (0)	0 (0)	0.55 (0.40)	0 (0)
	10–11/98	0.13 (0.12)	0.05 (0.05)	0 (0)	0.40 (0.15)	0 (0)
	11–12/98	0 (0)	0 (0)	0 (0)	0.10 (0.07)	0 (0)
	12/98–1/99	0.13 (0.12)	0 (0)	0 (0)	0.10 (0.07)	0 (0)
	1–2/99	0.25 (0.16)	0 (0)	0 (0)	0.15 (0.08)	0 (0)
	2–3/99	0 (0)	0 (0)	2.25 (0.25)	0.40 (0.15)	0 (0)
	3–4/99	0.13 (0.12)	0 (0)	0 (0)	0.10 (0.07)	0.03 (0.06)
	4–5/99	0.13 (0.12)	0 (0)	0 (0)	0.05 (0.07)	0 (0)
	5–6/99	0 (0)	0 (0)	0 (0)	0.05 (0.07)	0 (0)
Blackbirds/starlings	7–9/98	0.13 (0.12)	0.40 (0.31)	2.75 (1.11)	0.10 (0.07)	3.19 (1.22)
	8–9/98	1.13 (1.12)	0.10 (0.07)	6.50 (4.03)	0.20 (0.16)	3.63 (1.18)
	9–10/98	0.13 (0.12)	0.25 (0.20)	5.00 (2.80)	0.90 (0.56)	7.75 (3.57)
	10–11/98	2.63 (1.54)	2.80 (1.19)	1.75 (1.03)	5.80 (4.76)	7.13 (2.40)
	11–12/98	0.38 (0.26)	3.85 (1.97)	1.50 (0.96)	26.3 (22.4)	3.44 (1.14)
	12/98–1/99	0.38 (0.37)	0.15 (0.08)	2.75 (2.43)	45.3 (27.7)	2.69 (0.83)
	1–2/99	1.38 (0.50)	0.85 (0.28)	0.50 (0.50)	16.6 (10.4)	5.31 (1.38)
	2–3/99	0.25 (0.25)	1.15 (0.44)	0 (0)	8.05 (5.45)	3.81 (1.39)
	3–4/99	0 (0)	1.40 (0.49)	5.00 (0.71)	2.25 (0.68)	5.44 (2.10)
	4–5/99	0.13 (0.12)	0.80 (0.28)	4.25 (1.38)	2.20 (0.77)	3.50 (0.91)
	5–6/99	0.25 (0.25)	0.50 (0.25)	0.75 (0.48)	3.90 (1.39)	3.25 (0.69)
Columbids	7–8/98	2.68 (1.81)	0.65 (0.36)	0 (0)	2.00 (1.09)	0.69 (0.39)
	8–9/98	4.25 (2.18)	1.35 (0.55)	0.50 (0.29)	2.55 (0.77)	1.06 (0.34)
	9–10/98	4.75 (1.60)	0.60 (0.31)	0.75 (0.48)	4.00 (2.52)	0.63 (0.33)
	10–11/98	1.25 (1.00)	0.20 (0.12)	0 (0)	0.15 (0.08)	23.9 (12.0)
	11–12/98	0.88 (0.40)	0.45 (0.25)	0.50 (0.50)	0.30 (0.18)	12.4 (8.36)
	12/98–1/99	0.13 (0.12)	1.60 (1.45)	2.25 (1.93)	0.20 (0.16)	0.38 (0.38)
	1–2/99	0.25 (0.25)	0.55 (0.30)	2.50 (1.66)	0.45 (0.20)	1.19 (0.37)
	2–3/99	1.75 (0.68)	1.75 (0.46)	1.50 (0.65)	1.60 (0.59)	3.69 (1.12)
	3–4/99	1.75 (0.96)	1.35 (0.44)	1.25 (0.63)	2.65 (0.65)	3.75 (1.40)
	4–5/99	2.25 (0.41)	1.20 (0.41)	0.75 (0.48)	3.25 (0.51)	1.63 (0.32)
	5–6/99	3.13 (0.72)	2.55 (0.74)	0.75 (0.48)	5.05 (1.33)	2.38 (0.48)
Rock doves	7–9/98	1.00 (1.00)	8.40 (2.86)	3.0 (2.29)	0.80 (0.56)	0.69 (0.39)
	8–9/98	0.13 (0.12)	4.70 (1.27)	4.25 (1.18)	7.05 (4.32)	0.25 (0.15)
	9–10/98	19.1 (11.0)	9.95 (2.59)	3.50 (1.19)	4.95 (3.01)	0.38 (0.32)
	10–11/98	10.5 (6.25)	10.1 (2.31)	2.25 (1.65)	3.10 (3.10)	0.88 (0.69)
	11–12/98	18.4 (9.34)	8.80 (2.33)	0 (0)	2.65 (2.27)	1.50 (0.82)
	12/98–1/99	18.4 (10.2)	8.10 (2.36)	1.00 (0.41)	0.40 (0.40)	1.31 (0.63)
	1–2/99	14.4 (6.12)	8.45 (2.17)	0.25 (0.25)	1.55 (0.85)	1.81 (0.87)
	2–3/99	12.3 (4.97)	5.85 (1.38)	1.75 (0.86)	1.65 (1.26)	1.13 (0.52)
	3–4/99	7.25 (3.45)	4.40 (1.21)	0.50 (0.50)	0.75 (0.38)	2.00 (1.39)
	4–5/99	9.00 (1.22)	5.35 (1.03)	0.75 (0.48)	0.60 (0.33)	2.06 (1.09)
	5–6/99	11.9 (8.23)	4.80 (1.08)	1.25 (0.63)	0.70 (0.26)	3.00 (1.44)
Finches, sparrows, vireos, warblers	7–8/98	0 (0)	0.25 (0.20)	0 (0)	0 (0)	2.81 (1.13)
	8–9/98	0.13 (0.12)	5.30 (2.56)	2.00 (2.00)	1.10 (0.81)	23.4 (6.50)
	9–10/98	0 (0)	1.55 (0.99)	0 (0)	0.30 (0.22)	28.3 (9.50)
	10–11/98	0.13 (0.12)	2.05 (1.07)	0 (0)	4.00 (2.13)	12.9 (4.80)
	11–12/98	1.00 (1.00)	1.75 (0.53)	3.50 (2.87)	11.8 (6.15)	4.19 (1.61)
	12/98–1/99	0.63 (0.42)	3.25 (1.03)	0.50 (0.50)	12.4 (5.48)	7.19 (2.33)
	1–2/99	1.25 (0.65)	1.40 (0.69)	0.75 (0.48)	2.55 (1.69)	9.69 (1.73)
	2–3/99	0.50 (0.50)	1.10 (0.64)	1.25 (0.95)	4.75 (2.76)	10.7 (2.12)
	3–4/99	0.13 (0.12)	1.80 (0.68)	2.00 (0.82)	2.85 (1.02)	9.19 (2.76)

Table 2 (*continued*)

Bird group	Period	Habitat				
		Disturbed desert	Industrial/commercial	Retention pond	River bed	Terminal buildings
	4–5/99	0.63 (0.50)	2.70 (0.93)	0 (0)	0.15 (0.15)	15.8 (6.00)
	5–6/99	0 (0)	0.90 (0.66)	1.25 (0.48)	0.35 (0.21)	0.75 (1.44)
Insectivorous	7–8/97	0 (0)	0.05 (0.05)	0 (0)	0.30 (0.13)	0 (0)
Perching birds	8–9/98	0 (0)	0 (0)	0 (0)	0.10 (0.07)	0 (0)
	9–10/98	0.13 (0.12)	0 (0)	0 (0)	0.05 (0.05)	0.03 (0.06)
	10–11/98	0 (0)	0 (0)	0 (0)	0.15 (0.08)	0 (0)
	11–12/98	0.25 (0.25)	0 (0)	0 (0)	0.10 (0.07)	0 (0)
	12/98–1/99	0 (0)	0 (0)	0.25 (0.25)	0.05 (0.05)	0 (0)
	1–2/99	0.50 (0.50)	0 (0)	0 (0)	0.10 (0.07)	0 (0)
	2–3/99	0.25 (0.25)	0 (0)	0 (0)	0.05 (0.05)	0 (0)
	3–4/99	0.13 (0.12)	0 (0)	0 (0)	0.10 (0.07)	0 (0)
	4–5/99	0.25 (0.25)	0.05 (0.05)	0 (0)	0.20 (0.09)	0 (0)
	5–6/99	0.13 (0.12)	0.10 (0.10)	0 (0)	0.10 (0.07)	0 (0)
Shore birds	7–8/98	0 (0)	0 (0)	1.00 (0.71)	0.70 (0.46)	0 (0)
	8–9/98	0.63 (0.42)	0.05 (0.05)	3.25 (0.25)	1.20 (0.47)	0 (0)
	9–10/98	0 (0)	0 (0)	9.50 (6.89)	2.55 (1.19)	0.06 (0.06)
	10–11/98	0 (0)	0 (0)	3.50 (1.94)	1.30 (0.60)	0 (0)
	11–12/98	0 (0)	0 (0)	1.75 (1.11)	0.50 (0.22)	0 (0)
	12/98–1/99	0.13 (0.12)	0 (0)	3.25 (2.14)	0.25 (0.16)	0 (0)
	1–2/99	0 (0)	0 (0)	0 (0)	4.85 (4.24)	0 (0)
	2–3/99	0 (0)	0 (0)	0 (0)	7.15 (5.51)	0 (0)
	3–4/99	0.25 (0.25)	0 (0)	0.50 (0.50)	7.20 (5.09)	0 (0)
	4–5/99	0 (0)	0 (0)	2.75 (0.95)	2.05 (1.06)	0 (0)
	5–6/99	0 (0)	0 (0)	0 (0)	0.60 (0.41)	0.06 (0.06)
Wading birds	7–8/98	0 (0)	0 (0)	1.50 (1.19)	0.20 (0.14)	0 (0)
	8–9/98	0 (0)	0 (0)	4.25 (0.25)	0.45 (0.26)	0 (0)
	9–10/98	0 (0)	0 (0)	3.25 (0.99)	0.30 (0.25)	0 (0)
	10–11/98	0 (0)	0 (0)	0 (0)	0.30 (0.25)	0 (0)
	11–12/98	0 (0)	0 (0)	0 (0)	0.20 (0.12)	0 (0)
	12/98–1/99	0 (0)	0 (0)	0.25 (0.25)	0.65 (0.47)	0 (0)
	1–2/99	0 (0)	0 (0)	0 (0)	0.70 (0.41)	0 (0)
	2–3/99	0 (0)	0 (0)	0 (0)	1.40 (0.89)	0 (0)
	3–4/99	0 (0)	0 (0)	0 (0)	3.05 (1.45)	0 (0)
	4–5/99	0 (0)	0.05 (0.05)	0 (0)	1.65 (0.80)	0 (0)
	5–6/99	0 (0)	0 (0)	0 (0)	3.80 (1.93)	0 (0)
Waterfowl	7–8/98	0 (0)	0 (0)	1.25 (0.75)	0.10 (0.10)	0 (0)
	8–9/98	0 (0)	0 (0)	1.50 (0.65)	0.95 (0.60)	0 (0)
	9–10/98	0 (0)	0 (0)	1.25 (1.25)	2.35 (1.16)	0 (0)
	10–11/98	0.25 (0.25)	0 (0)	1.75 (1.18)	0.25 (0.14)	0 (0)
	11–12/98	0 (0)	0 (0)	0 (0)	0.70 (0.43)	0 (0)
	12/98–1/99	0 (0)	0.75 (0.75)	1.00 (0.71)	7.60 (3.71)	0 (0)
	1–2/99	0 (0)	0 (0)	0 (0)	9.20 (4.26)	0 (0)
	2–3/99	0 (0)	0 (0)	0 (0)	22.0 (9.65)	0 (0)
	3–4/99	0 (0)	0 (0)	0 (0)	5.70 (2.48)	0 (0)
	4–5/99	0 (0)	0 (0)	0.25 (0.25)	2.80 (1.35)	0 (0)
	5–6/99	0 (0)	0 (0)	0 (0)	1.55 (0.87)	0 (0)

numbers at the retention pond were July–October followed by March–April.

3.3.3. Waterfowl

Waterfowl were primarily observed at stations containing water and/or along the Salt River bed. They were sometimes observed flying over other stations to move between the canal system and the Salt River bed. Few waterfowl were present during summer and fall. Slight increases occurred in September as fledglings dispersed to smaller populations and in May during the breeding/nesting season when offspring were observed. Substantial increases ($F = 2.14$, $df = 10,\ 40$, $p = 0.044$) in waterfowl abundance

occurred during the winter migration, peaking in February.

3.3.4. Shorebirds and wading birds

Shorebirds and wading birds were attracted to shallow water and mudflats. Therefore, highest numbers of these birds were located at habitat sites containing water (retention pond and/or Salt River bed). Peak numbers of shorebirds occurred during fledging in September and winter migration. Shorebird numbers were highest in March, while wading bird numbers peaked during the breeding season when juveniles were observed feeding on fish in pools of water in the Salt River bed. Winter rains increased the amount of standing water in the Salt River bed, and subsequently the diversity of shorebirds and wading birds stopping during migration. Wading bird numbers increased substantially at the retention pond when the site contained water ($F = 3.81$, $df = 10, 22$, $p = 0.004$).

3.3.5. Birds of prey

Birds of prey were predominately observed in the undeveloped desert habitat and along the Salt River bed. Birds of prey were observed in higher numbers during evening surveys as opposed to mornings at sites located along the river bed ($F = 8.18$, $df = 1, 4$, $p = 0.046$). Birds of prey numbers were overall low, but were slightly higher in winter months than summer months. Birds of prey frequently soared over dry parts of the river bed and the east end of PHX. Turkey vultures were not observed during winter months as a result of their migration south, but in summer months they were found circling over the river bed and transfer station.

3.3.6. Pigeons and doves

Feral pigeons (rock doves) and mourning doves were abundant at PHX and were observed at all stations along the survey route, especially in the industrial/commerical building habitat and in the disturbed desert habitat. Pigeons were present throughout the year, but were most abundant during the fall months ($F = 2.63$, $df = 10, 22$, $p = 0.028$ for retention pond; $F = 2.06$, $df = 10, 40$, $p = 0.052$ for river bed). Mourning doves often flew from the river bed at a low elevation over the AOA. Along the river bed, mourning doves were present throughout the year (tending to be higher in the evening surveys), but were highest in the fall, and decreased during the coldest winter months ($F = 2.07$, $df = 10, 40$, $p = 0.051$ for riverbed). However, doves were seen in distrubed desert habitat in highest numbers in summer-fall and spring ($F = 3.15$, $df = 10, 40$, $p = 0.042$).

3.3.7. Finches, sparrows, vireos and warblers (FSVW)

House sparrows (*Passer domesticus*) and house finches (*Carpodacus mexicanus*) comprised 99% of the FSVW observations and most frequently were observed around the terminal buildings, or perched on fences or feeding on weed seed along the Salt River bed. Numbers of sparrows and finches peaked in fall and winter for the Salt river bed and were lowest in summer ($F = 2.76$, $df = 10, 40$, $p = 0.011$). For the terminal building habitat, they were highest late summer through fall and increased again in late winter and spring ($F = 2.43$, $df = 10, 40$, $p = 0.030$).

3.3.8. Insectivorous perching birds (IPB)

Insectivorous perching birds (including loggerhead shrikes (*Lanius ludovicianus*), Gila woodpeckers (*Melanerpes uropygialis*), northern mockingbirds (*Mimus polyglottos*), Say's phoebes (*Sayornis saya*)) were observed primarily as solitary foragers, usually perched on power lines, fences, and vegetation disturbed desert habitat and in the Salt River bed. IPB birds were present at PHX in low numbers year-round.

3.3.9. Upland ground birds and swallows and other aerial foragers

Birds in these groups were observed only sporadically during the course of the survey, in numbers insufficient for analyses.

3.4. General survey

3.4.1. Riparian sites

The abundance and diversity of wildlife species differed among riparian sites (Table 3), because of variation in the pools of standing water, types and amounts of vegetation, and land-use (commercial, industrial, parks, and open desert). Sites were compared to examine habitat-use preferences for bird groups. Birds of prey, swallows, and water-dwelling birds (shorebirds, wading birds, and waterfowl) were found to prefer the I-10 riparian area to Town Lake and Papago Park ($F > 6.0$, $df = 2, 66$, $p < 0.004$ in each case). Finches and sparrows, upland ground birds, and insectivorous perching birds, however, preferred Papago Park to the other sites ($F > 2.77$, $df = 2, 66$, $p < 0.07$, in each case). Doves were most abundant at Papago Park and the I-10 riparian area, as opposed to Town Lake ($F = 3.64$, $df = 20, 66$, $p = 0.0001$). Rock doves were the only species of birds that showed preference for the Town Lake construction site over the other areas ($F = 2.25$, $df = 20, 66$, $p = 0.007$).

Most groups of birds were found in relatively equal distribution during both evenings and mornings, although dove numbers averaged higher during evening surveys (22 versus 14 birds/survey, $F = 6.80$, $df = 1, 66$, $p = 0.011$), as did birds of prey (0.89 versus 0.65 birds/survey, $F = 3.05$, $df = 1, 66$, $p = 0.86$), while finches and sparrows (9 versus 18 birds/survey,

$F = 8.72$, $df = 1, 66$, $p = 0.011$) were highest in morning surveys. In general, raptors ($F = 2.29$, $df = 20, 66$, $p = 0.0001$), waterfowl ($F = 2.48$, $df = 20, 66$, $p = 0.031$), finches and sparrows ($F = 2.05$, $df = 10, 66$, $p = 0.042$), and insectivorous perching birds ($F = 4.29$, $df = 10, 66$, $p = 0.0001$) were found in higher abundance during winter migration. Increases in blackbird populations during this time were not detected statistically ($F = 1.56$, $df = 10, 66$, $p = 0.14$). Numbers of doves, however, declined during the coldest winter months ($F = 3.64$, $df = 20, 66$, $p = 0.0001$). Shorebirds, wading birds, and swallows were found in higher numbers during breeding season ($F > 4.25$, $df = 10, 66$, $p = 0.0001$, for each group). Pigeons and upland ground birds were found in relatively equal abundance throughout the year, except at Town Lake where pigeons were found in higher numbers during summer months when construction activities were low ($F = 2.25$, $df = 20, 66$, $p = 0.007$).

3.4.2. Co-op/transfer station

The co-op and transfer stations were similar in structure (i.e., industrial buildings) and attracted the same groups of birds. Flocks of birds were frequently observed flying between and using both facilities, and therefore implied a natural comparison between the sites. The most hazardous (and abundant) species or groups of birds found at these sites included pigeons, doves, and blackbirds. The blackbird/starling group abundance was substantially higher at the transfer station throughout the length of the assessment ($F = 3.18$, $df = 9, 41$, $p = 0.0001$), averaging 46 birds per survey (versus eight birds per survey at the co-op), with numbers at the transfer station highest during December–January. In contrast, pigeon and dove populations were higher at the co-op ($F > 18.2$, $df = 1, 41$, $p = 0.0001$, for both groups of birds) than at the transfer station. Rock dove numbers averaged 71 birds per survey at the transfer station and 178 birds at the co-op, while other doves averaged one bird per survey at the transfer station and 40 birds at the co-op. Dove numbers fluctuated at the co-op during the length of the assessment, resulting from their winter migration south ($F = 2.30$, $df = 9, 41$, $p = 0.034$). Populations of rock doves, however, remained relatively constant at both facilites throughout the year. Abundance of other doves was greater during evening than morning surveys around the co-op (58 versus 21 birds/survey, $F = 4.09$, $df = 1, 41$, $p = 0.050$), indicating that they may use the area as an evening roost, but pigeons were in similar abundance during both evening and morning surveys at the co-op (one bird/survey at each site).

3.4.3. Encanto Park

Numbers of birds at Encanto Park were highest during the winter migration, peaking in November with an average of 375 birds per survey, while averaging 100 birds per survey during summer months. Blackbirds/starlings, especially European starlings, increased in numbers during the winter migration ($F = 2.85$, $df = 10, 22$, $p = 0.020$) with a peak of 180 birds per survey, while in other months blackbird numbers averaged 20 birds per survey (primarily consisting of great-tailed grackles). Usually, blackbirds were observed in higher numbers during evening surveys as opposed to mornings. Other groups of birds were observed in relatively equal numbers during both morning and evening surveys. Throughout the study, pigeons comprised the largest percentage of the total population, except during the peak of migration. Pigeon numbers averaged 60 birds per survey in summer months and 130 birds per survey in winter and spring months. Because pigeons are a feral bird and generally do not migrate, differences ($F = 2.02$, $df = 10, 22$, $p = 0.081$) in numbers of pigeons during the course of the study were likely due to changes in their activity periods depending on weather (i.e.,

Table 3
Average number (SE) of birds from each species group observed per survey at each of the three rparian survey sites in the general zone around PHX

Species group	I-10 Riparian	Papago Park	Town Lake
Birds of prey	1.07 (0.20)	0.48 (0.12)	0.77 (0.13)
Blackbirds/starlings	57.5 (18.3)	30.2 (7.14)	58.4 (17.8)
Columbids	22.8 (3.98)	22.41 (3.08)	10.3 (1.42)
Rock doves	2.65 (0.82)	1.41 (0.66)	50.4 (4.75)
Finches, sparrows, vireos, warblers	14.1 (3.26)	17.8 (3.12)	8.84 (1.63)
Upland ground birds	1.25 (0.46)	5.95 (0.90)	5.23 (1.02)
Insectivorous perching birds	0.70 (0.12)	2.27 (0.26)	0.73 (0.12)
Swallows and other aerial foragers	15.9 (4.44)	3.13 (1.30)	4.91 (2.54)
Shore birds	20.4 (4.93)	1.07 (0.29)	1.61 (0.30)
Wading birds	7.50 (1.08)	0.77 (0.52)	0.45 (0.37)
Waterfowl	26.4 (5.23)	9.68 (1.67)	4.18 (3.54)

shorter periods of activity and longer periods of loafing in palms where they were not visible led to decreased abundance in hot summer months). Encanto Park is home to many domestic waterfowl that also do not migrate. An average of eight domestic ducks and geese were observed per survey throughout the length of the study. While nonmigratory, domestic waterfowl are live decoys that may attract migrating waterfowl to an area. Waterfowl (primarily mallards (*Anas platyrhynchos*) and American coots (*Fulica americana*)) increased during the winter migration and breeding season, averaging 24–38 birds per survey in winter months and 13–20 during the spring ($F = 3.85$, $df = 10, 22$, $p = 0.004$).

3.4.4. Grand Canal

The canal received visits by pigeons, probably because of this canal's juxtaposition to the co-op's attractive roosting and nesting areas. Birds were attracted to the canal for drinking and bathing and no crepuscular period appeared preferred over another. Generally, wildlife visits to this site were lowest during summer months, but increased during cooler weather, with the arrival of winter migrants and heightened activity period of resident birds. During December, the canal was drained and cleaned, resulting in minimal usage, although small pools of water in the canal bed continued to allow drinking and bathing by a limited number of birds. The blackbird/starling group (primarily red-winged blackbirds) abundance increased substantially during fall migration ($F = 16.72$, $df = 9, 19$, $p = 0.0001$), peaking at an average of 120 birds per survey. By March, most red-winged blackbirds had migrated from the area, leaving an average of only 10 birds per survey. During spring and summer months, blackbird populations primarily consisted of great-tailed grackles, averaging < 10 birds per survey. Pigeons were the most common birds at this site, peaking in winter with an average of 265 birds per survey.

3.5. Predator survey

Through the course of the surveys, scent stations were found positive 10 times for dog tracks, 17 for coyote tracks, 16 for fox tracks, and 2 for cat tracks.

3.6. Small mammal survey

Only one mouse was collected from site 1, and no rodents were captured at sites 3 and 4. However, rodents were captured consistently at site 2, with captures ranging from 5 to 17 rodents captured per 100 adjusted trap nights.

3.7. Nocturnal (owl) survey

The only response was a great horned owl during the March survey. The owl was perched on a concrete ledge under the I-10 overpass next to a nest containing three owlets. However, Mexican free-tailed bats were observed hawking insects over pools of water at the I-10 riparian area during this survey.

4. Discussion

Nearly the same number of strikes were reported during our one-year assessment period (56) as during the previous 7 years in the FAA airstrike database (59), likely due to large part of the collection of dead birds during runway sweeps. This implies that strikes have been under-reported at PHX, as elsewhere (Cleary et al., 1997; Linnell et al., 1999), and demonstrates the importance of collecting injured and dead birds during runway sweeps and educating airport personnel and pilots on the importance of reporting strikes.

4.1. Overview

Because water is a limiting factor in the desert, an increased abundance and diversity of wildlife species were observed around water sources. Throughout the study, the Salt River bed contained some standing water surrounded by riparian habitat, which was where the highest abundance and diversity of birds occurred. Similarly, the water retention pond accommodated large numbers of birds when it contained water, otherwise it did not attract many birds. The riverbed sites holding water would be reasonable representations of the habitat to be found along the western reach of the Rio Salado project. Wildlife species hazardous to aircraft operations, such as blackbirds, waterfowl, wading birds, and raptors, were attracted to these stations and can also be expected to inhabit portions of the river bed after restoration.

The Rio Salado project involves restoration of desert riparian habitat along the Salt River within the general zone of PHX. The proposed project will include cottonwood/willow stands (33 ha), mesquite bogs (21 ha), marshes (12.5 ha), water (9 ha), parking lots and bridges (4 ha), islands (2 ha), and low flow areas (67 ha). This high-quality wetland habitat could support a diverse assemblage of wildlife directly under the flight path of aircraft using PHX. Development of high quality wildlife habitat along the western path of approach for aircraft likely will produce a substantial increase in the abundances and movements of birds, and consequently increase the risk of collisions. Compounding this problem, aircraft operations at PHX tend to be

highest when our observations indicated the greatest abundance and activities for birds, during winter migration and breeding.

4.2. Risks by species groups at PHX

4.2.1. Blackbirds and starlings

Blackbirds and starlings can pose significant threats to aviation safety as they often form large flocks, and we found much habitat attractive to these birds in the critical and general zones around PHX. During winter migration, flocks of red-winged blackbirds, numbering 450 birds or more, were observed flying over the southeast corner of PHX and the Salt River. Additional wetlands and other habitats attractive to blackbirds could result from the Rio Salado project. Efforts should be taken to minimize attractive blackbird roosting, feeding, and nesting areas near PHX.

4.2.2. Waterfowl

Waterfowl were observed flying beyond the Salt River over portions of PHX, including the southernmost runway. Flocks of waterfowl generally were seen flying just after dawn at approximately 200–400 feet in elevation. In addition to the attractiveness of the Salt River as a flight corridor, increases in standing water in the river bed during winter and spring months resulted in newly sprouted vegetation, which attracted an abundance and diversity of waterfowl to feed, bathe, and loaf in the river bed. Flocks of 50–150 waterfowl were observed flying over the Salt River during January–March. The numbers of waterfowl flying over or using portions of the Salt River bed in proximity to active runways at PHX is a major concern of ours.

4.2.3. Shore birds and wading birds

These two groups of birds were considered a serious threat to aircraft operations as a result of their relative abundance in the river bed and close to the southernmost runway. Shallow pools of water provided a supply of fish and invertebrates and were attractive habitat for these birds, especially as a stop along migration routes. Shorebirds, while typically small in size (15–36 cm), tend to flock in large numbers. Least sandpipers (*Calidris minutilla*), for instance, commonly were seen circling around pools of water during winter and spring months, often at 50–120 birds per flock. Great egrets (*Casmerodius albus*) and great blue herons (*Ardea herodias*) are large birds that tend to fly in loose flocks. Egrets and herons were observed flying at about 30–90 m over the Salt River during winter and spring months in flocks as great as 15 birds. Populations of these birds can be expected to increase close to PHX with the development of high-quality riparian habitat in the Rio Salado project.

4.2.4. Birds of prey

Birds of prey are a hazard to aircraft because they are typically large in size and their soaring behavior predisposes them to collisions with aircraft. Although raptors were observed only in low numbers during our surveys, they are found in the air-strike records for PHX. Removing or eliminating access to structures used for perching, such as light poles and signs, and controlling prey populations, such as rodents and rabbits, should reduce the risk of a strike around PHX.

4.2.5. Pigeons and doves

The loose flocking behavior, dense body structure, and overall abundance of pigeons increase their potential to damage aircraft. Although doves are small in size, their loose flocking behavior and relative abundance predisposes them to collisions with aircraft. Pigeons and doves in large numbers were found adjacent to and crossing PHX, and this was reflected in the air strike data.

4.2.6. FSVW

Most sparrows and finches remain close to shrubs, trees, and structures where they are afforded protection from predators and are, therefore, infrequently struck by aircraft. Because members of this group are small in size, they rarely result in damage to an aircraft when struck.

4.2.7. IPB

Although members of this group are generally small in size and usually solitary foragers, the hunting behavior of some species (darting out to capture flying or ground-dwelling insects and returning to a perched position) and the undulating flight of others makes them vulnerable to strikes. Controlling populations of these birds can be accomplished by removing or eliminating access to structures used for perching and implementing a pesticide program during insect outbreaks.

4.2.8. Ground birds

These birds typically are infrequent flyers and were present in low densities, their risk to air safety appeared to be low.

4.2.9. Predators

The predator species identified around PHX represent a strike hazard because of their moderate to large size. Both dogs and coyotes can easily damage the landing gear of an aircraft. Furthermore, canids will commonly cross runways and taxiways to access feeding grounds. They will also use gravel and paved areas as movement corridors for ease of traveling. Managing food sources, such as carrion (dead birds on runways), garbage, and rodents will help to minimize

the attractiveness of the airfield to carnivorous species. In addition, the perimeter fence should be inspected routinely for holes dug by predators and repaired.

4.2.10. Small mammals

Small mammals, such as rodents, are often an indirect hazard at airports as they attract larger animals, such as hawks and coyotes, to the area. In addition, they may chew on runway lights and electrical wires, creating fire hazards and other risks to flight safety. Although overall results indicate a low abundance of rodents at PHX, the presence of birds of prey remains a threat to air safety. Existing rodent populations around PHX can be reduced by habitat modification, such as removing brush and weeds, abandoned machinery and pipes, and rock piles.

4.2.11. Nocturnal animals

Bats were observed while conducting owl surveys. Insectivorous bats are partial to open landscape and may present a threat to aviation. They appear at dusk and search for flying insects over extensive areas of land, such as airfields. If bats become a noticeable wildlife hazard over the airfield, habitat modification, such as standing water removal and prey-base management with insecticides, could reduce numbers of bats frequent visits of them in the area.

4.3. Bird hazards within the general zone of PHX

4.3.1. Riparian sites

Few of the most hazardous bird groups were attracted to the dry, sparsely-vegetated river bed before and during development of Town Lake. However, most bird groups were attracted to habitat containing some type of water source. Town Lake now contains a large, permanent supply of water and it probably will attract many more birds, especially waterfowl. Continued monitoring could identify changes in wildlife-use at the Town Lake site and help project the wildlife hazards created as a result. Furthermore, the western reach of the Rio Salado project is proposed to contain habitat comparable to that within the I-10 riparian area. Because Rio Salado habitat will encompass a much larger area than the I-10 riparian area, similar bird species can be expected in higher abundance, increasing wildlife hazards along PHX, especially during the migration and breeding.

4.3.2. Co-op/transfer station

Although blackbirds, doves and pigeons were found at both sites, differences occurred in their use-patterns, possibly as a result of variations in habitat and food sources. Municipal waste, attractive to scavengers such as blackbirds and pigeons, was collected during the day at the transfer station. Also, the facility was adjacent to a patch of riparian habitat in the Salt River bed, often used by roosting blackbirds. The co-op was in disrepair which allowed access inside to perching areas and spilled grain along the length of the building. These features attracted large numbers of pigeons and doves. Because pigeons used both facilities consistently and blackbirds and doves migrated through during different seasons, wildlife hazards were present throughout the year.

4.3.3. Grand Canal

Because the canal runs perpendicular to the Salt River bed, birds will continue to fly over PHX to move between water sources, and between water sources and roosting and nesting sites at the co-op. Lower numbers of birds at the co-op also should decrease the movement of birds around the canal.

4.3.4. Encanto Park

Although Encanto Park is within the general zone, it is not located along the flight path of aircraft. However, the western portion of the Rio Salado project will be located 1.5–5 km directly south of Encanto Park along the western approach corridor of PHX. The Rio Salado project may produce habitats similar to those found at Encanto Park which subsequently may attract similar species of birds. Waterfowl and other birds associated with Encanto Park could move between the two areas to use natural resources for nesting, roosting, and feeding. Migratory flocks of birds, such as waterfowl and blackbirds, are attracted to individuals or flocks of birds already present in an area. This decoying effect could increase the risk of bird–aircraft collisions.

4.4. Recommended management practices

Reduction of wildlife hazards at airports generally follows four approaches: (1) habitat modification (altering habitat to make it less attractive to wildlife); (2) exclusion (installing physical barriers to exclude certain wildlife species); (3) behavior modification (dissuading wildlife from performing objectionable activities); and (4) population reduction (reducing the abundance of offending wildlife populations or species). In this section, we examine what approaches might be applied to the various hazard situations identified around PHX.

4.4.1. Airport participation in land-use planning

Participation by airport personnel in land-use projects or changes, on or off airport property, that could increase wildlife hazards at PHX, could reduce hazards before they develop. For example, new buildings should be designed in a manner that should discourage use by wildlife. Companies that produce refuse could

be encouraged to use disposal methods that do not attract wildlife. Projects to restore wildlife habitat for potentially hazardous species, such as the Rio Salado project, possibly could be modified with aircraft safety in mind. The nearer new projects are to PHX, the more involved airport personnel should be.

4.4.2. Runway sweeps

Runway sweeps should continue as standard protocol. Accurate strike data provides information on the need to manage hazards and on the efficacy of airstrike abatement efforts. Also, dead animals attract scavengers, such as vultures and ravens, that also may become hazards to aircraft.

4.4.3. Co-op/transfer station

The transfer station owner should be contacted concerning the possible wildlife hazard and any potential liability created as a result of exposed waste disposal practices. Preferably, a blackbird/starling hazing program could be initiated during the winter months and pigeon exclusion or removal conducted if refuse cannot be covered or enclosed. The feed mill/co-op was an attractive roosting and staging area for pigeons, doves, and blackbirds and would be best removed if no longer in use. However, if facility removal is not an option, birds should be excluded from the building and food sources should be made inccessible. Bird hazing and reduction would complement these efforts.

4.4.4. Retention pond

Consideration should be given to filling the water retention pond east of terminal 4 with boulders or river rock, as it attracted numerous birds when it contained water. This will permit water to drain into the area appropriately, but will not allow access to wildlife. Another approach might be to cover the pond with a wire grid to deter use by waterfowl and herons, although it would not keep birds from investigating the site.

4.4.5. Prohibit feeding of birds and reduce trash

We observed flocks of birds feeding on handouts directly west of the Operations Department in the rental car area. Handouts were repeatedly placed on the ramp leading under terminal 2 and included bunches of grapes, piles of bird seed, loaves of bread, and bagels. Airport employees and patrons should not be allowed to feed wildlife at PHX. Signs could be posted to educate PHX personnel and patrons on associations between feeding animals and creating wildlife hazards. Litter also attracted flocks of birds, including pigeons and great-tailed grackles. Maintaining litter-free grounds with lids secured on garbage cans would help to resolve this problem.

4.4.6. Nest removal and exclusion in facilities and airfield structures

Pigeons roost and loaf in structures in and around PHX, which also may present health and safety hazards or nuisance. PHX should locate and remove any bird nests found. Birds that have young in the nest usually are more bold in their feeding habits and will increase the number of feeding forays onto the airfield than those without young. Exclusion probably would be the most cost-effective, long-term measure for reducing nesting activity in buildings. Bird netting, tacked under caves and other areas where pigeons roost, will exclude pigeons from using the area. Airfield structures, such as ramp and taxiway signs, light poles, and runway lights, can be used as perches for raptors and insect-eating birds. These structures possibly could be fitted with wire coils or porcupine wire to deter birds from landing on them.

4.4.7. Timing landscaping operations and controlling weeds and invertebrates

Mowing and watering lawns are quite attractive to several species of birds. Food, such as insects, rodents, and seeds become exposed during and after mowing and bathing and drinking opportunities become available during sprinkler system use. When possible, mowing and watering lawns should be conducted at night or during the middle of the day when birds are less active. Pesticides are often used at airports to minimize insect and weed outbreaks. Weeds, especially those that produce seed, should be controlled using the appropriate herbicides. Populations of insects should be regulated where necessary, especially around standing water used as breeding grounds, with the appropriate insecticide.

4.4.8. Bird hazing at PHX

Birds using the Salt River as a flight corridor did not restrict their movements to the boundaries of the river and were frequently recorded flying over PHX. In addition, the Grand Canal, located adjacent to the river bed and northeast of PHX, is an available water source that attracted waterfowl and other birds. Many bird frightening methods are available, and a hazing program that integrates the use of various pyrotechnics, bioacoustics, and other frightening devices could be employed to deter birds from flying over PHX to and from various water sources (Cleary and Dolbeer, 1999; Marsh et al., 1991). However, while these techniques may move birds from one area to another, they seldom are effective immediately and persistence is required. Besides efficacy, a variety of considerations must be weighed when selecting methods to repel birds. Some methods may distrub people nearby, and adverse public reaction often is encountered. Many bird species are very adaptable and minimization of

habituation may require special application methods, such as distress calls from moving vehicles rather than stationary positions (Cleary and Folbeer, 1999). Habituation to hazing methods also is minimized by application only when needed, integration with multiple methods, and occasional reinforcement with lethal control (Cleary and Dolbeer, 1999). A multi-faceted and integrated approach would be required in the complex environment around PAX, especially with the realization of the Rio Salado project. If such an integrated approach is contemplated, then planning, testing, and evaluating hazing techniques, as well as training and educating employees, management personnel, and the public should begin now.

4.4.9. Management of water within the Salt River bed

Several pools of standing water were located along dry portions of the river bed within the critical and general zones of PHX and provided attractive resting areas for birds. The most hazardous species observed included waterfowl, wading birds, birds of prey, and blackbirds. Eliminating water drainage into the river bed would deplete the supply of fish and invertebrates and hinder the growth of surrounding riparian habitat, thereby making the river bed less attractive for migrants and limiting waterfowl movement between water sources. If removal of the water source is not possible, then other methods, such as exclusion devices and hazing, could discourage waterfowl and other birds. Waterfowl will most likely continue to use the dry river bed as a flight corridor. Because the canal is located northeast of PHX and also was observed to attract waterfowl, some movement of waterfowl across active runways will persist. Therefore, an active bird abatement program may be required to alleviate this current and persistent problem. Furthermore, development of wetlands within the Rio Salado project, similar to the habitat found at station 15, will likely increase the abundance of waterfowl using the Salt River bed. Additional waterfowl movement, directly in the approach path for aircraft arriving at PHX, will greatly increase the threat of a serious collision. If wetland habitat must be developed, a proactive bird hazing program should be implemented in addition to exclusionary methods.

4.4.10. Bird hazing at Town Lake

The new Rio Salado Town Lake is located in the Salt River bed and is a flyway for migratory birds. It can be expected to attract high numbers of water-dwelling birds, especially during winter migration. Because aircrafts are only 650 feet above Town Lake during the approach into PHX, wildlife hazards increase dramatically. Once birds become established in an area, they become increasingly difficult to disperse, especially as they begin nesting. The airport should work with the City of Tempe to implement a proactive bird hazing program. In addition, several pools of water have formed in the river bed, probably as a result of lake-supplied groundwater movement and percolation to other locations. Eliminating or managing this water source is necessary for decreasing bird use of the Salt River bed.

4.5. Conclusions

The purpose of this study was to document general occurrence, land-use patterns, and population characteristics of wildlife at PHX and within its general zone, prior to construction of the Rio Salado project. Wildlife abundance and use patterns on airfields are affected by a host of variables that are rarely the same in consecutive years. Because, the development of the Rio Salado project will create additional habitat and increase water availability, changes in wildlife patterns and movements, and species diversity and abundance can be expected. Aircraft arriving at or departing from PHX follow the Salt River bed during approach and take-off, and movement of birds within the flight path of aircraft significantly increases the threat to air safety. Furthermore, as the Rio Salado project is incorporated into the river bed, additional water and riparian habitat will increase the numbers of birds and other wildlife using the area, consequently increasing the risk of a serious collision. Implementation of methods to reduce wildlife hazards at PHX could benefit human health and safety by reducing the probability of aircraft collisions with wildlife. During this assessment, survey routes and methods were established in a replicable manner. Future monitoring would provide information on wildlife-use patterns over time and enable PHX to gauge the effectiveness of wildlife hazard abatement efforts and assess the impacts of the Rio Salado project.

Acknowledgements

A number of individuals assisted this wildlife hazard assessment. Kevin Grant provided invaluable insight regarding survey methods and locations and support throughout the study. Michael Linnell and Phillip Robinson supplied numerous documents and other materials essential for the completion of this assessment and offered advice on the content and structure of this paper. Kurt VerCauteren provided an outstanding review of the manuscript. Tom Hall summarized life history attributes and control methods of many key species. We thank Carl Newman and the PHX Airside Operations Department personnel for their cooperation in removing injured and dead animals from within the AOA, reporting possible wildlife hazards,

and allowing us access to the airfield. Joe Yarkin compiled information on the wildlife species found in Maricopa County and Arizona T & E species, and for his support throughout the development of this document. Wendy Hodgson identified numerous native and exotic plant species found near PHX. The authors and illustrators of the "Prevention and Control of Wildlife Damage" manual published by the Cooperative Extension, University of Nebraska, provided some references and information used in this paper. Funding for this project was provided by the City of Phoenix Aviation Department through a contract with Coffman Associates.

References

Bird, J., 1996. Birds-crash puts new focus on old problem. Air Force Times. Jan 29, 1996.

Blokpoel, H., 1976. Bird Hazards to Aircraft. Books Canada, Buffalo, NY, p. 236.

Cleary, E.C., Wright, S.E., Dolbeer, R.A., 1997. Wildlife strikes to civil aircraft in the United States 1992–1996. Report DOT/FAA/AS/97-3. 30 pp.

Cleary, E.C., Wright, S.E. Dolbeer, R.A., 1998. Wildlife strikes to civil aircraft in the United States 1991–1997. Report DOT/FAA/AS/98-4. 34 pp.

Cleary, E.C., Dolbeer, R.A., 1999. Wildlife hazard management at airports. Federal Aviation Administration and U.S. Dept. Agriculture/Wildlife Services, Washington, D.C. 248 pp.

Conover, M.R., Pitt, W.C., Kessler, K.K., Dubow, T.J., Sanborn, W.A., 1995. Review of data on human injuries, illnesses, and economic losses caused by wildlife in the United States. Wildl. Soc. Bull. 23, 407–414.

Dolbeer, R.A., Wright, S.E., Cleary, E.C., 1995. Bird and other wildlife strikes to civilian aircraft in the United States, 1994. Interim report DTFA011-91-Z-02004. US Dept. of Agric. For Fed. Aviation Admin., FAA Technical Center, Atlantic City, NJ. 37 pp.

Gresh, T.J., 1996. Aircraft accident investigation report. E-3B Aircraft #77-0345. Assigned to 3rd Wing, Elmondorf AFB, Alaska, 22 Sept. 1995. AFI 51-503, PACAF/CG Hickman AFB, Hawaii. 19 pp.

King, C.M., 1989. The Natural History of Weasels and Stoats. Cornell University Press, Ithaca, NY, p. 253.

Linhart, S.B., Knowlton, F.F., 1995. Determining the relative abundance of coyotes by scent station lines. Wildl. Soc. Bull. 3, 120–124.

Linnell, M.A., Cornover, M.R., Ohashi, T.J., 1996. Analysis of bird strikes at a tropical airport. J. Wildl. Manage. 60, 935–945.

Linnell, M.A., Conover, M.R., Ohashi, T.J., 1999. Biases in bird strike statistics based on pilot reports. J. Wildl. Manage. 63, 997–1003.

Marsh, R.E., Erickson, W.A., Salmon, T.P., 1991. Bird hazing and frightening devices. Univ. Calif., Davis, CA. 233 pp.

Milsom, T.P., Horton, N., 1990. Birdstrike: an assessment of the hazard on UK civil aerodromes from 1976 to 1990. UK Bird Strike Avoidance Team. 355 pp.

Robbins, C.S., Bystrack, D., Geissler, P.H., 1986. In: The Breeding Bird Survey: Its First Fifteen Years, 1965–1979. US Dept. Int., Fish and Wildl. Serv. Res. Publ. 157 196 pp.

Robinson, M., 1997. The Potential for Significant Financial Loss Resulting from Aircraft Bird Strikes in or Around an Airport. Bird Strike Committee, Boston, MA 20 pp.

Seamans, T.W., 1988. Summary of owl censuring techniques using taped owl calls. US Dept. Agric., Denver Wildl. Res. Cent., Sandusky, OH. Bird Section Research Report No. 423. 10 pp.

Thrope, J., 1997. The Implications of Recent Serious Bird Strike Accidents and Multiple Engine Ingestions. Bird Strike Committee, Boston, MA 11 pp.

Transport Canada, 1992. Operating definitions — bird and mammal control. Environmental Services, Airports Group. Transport Canada, Ottawa, Ontario. Rep. AKP5158-36-20-51.

York, D.L., Cummings, J.L., Wedemeyer, K.L., in press. Movements and distribution of radio-collared Canada geese in Anchorage, Alaska. Northwestern Naturalist.

Further reading

Linnell, M.A., Conover, M.R., Ohashi, T.J., in press. *Wedelia trilobata*: an alternative ground cover for excluding birds from tropical airfields. J. Wildl. Res.

Michael, R.A., 1986. Keep your eye on the birdie: aircraft engine bird ingestion. J. Air Law and Comm. 51, 1007–1035.