2014

Bird Use of Solar Photovoltaic Installations at US Airports: Implications for Aviation Safety

Travis L. DeVault
USDA/APHIS/WS National Wildlife Research Center, Travis.L.DeVault@aphis.usda.gov

Thomas W. Seamans
USDA/APHIS/WS National Wildlife Research Center, thomas.w.seamans@aphis.usda.gov

Jason A. Schmidt

Jerrold L. Belant

Bradley F. Blackwell
USDA/APHIS/WS National Wildlife Research Center, bradley.f.blackwell@aphis.usda.gov

See next page for additional authors

DeVault, Travis L.; Seamans, Thomas W.; Schmidt, Jason A.; Belant, Jerrold L.; Blackwell, Bradley F.; Mooers, Nicole; Tyson, Laura A.; and VanPelt, Lolita, "Bird Use of Solar Photovoltaic Installations at US Airports: Implications for Aviation Safety" (2014). *USDA National Wildlife Research Center - Staff Publications*. 1418.
https://digitalcommons.unl.edu/icwdm_usdanwrc/1418

Authors
Travis L. DeVault, Thomas W. Seamans, Jason A. Schmidt, Jerrold L. Belant, Bradley F. Blackwell, Nicole Mooers, Laura A. Tyson, and Lolita VanPelt

Landscape and Urban Planning 122 (2014) 122–128

Contents lists available at ScienceDirect

Landscape and Urban Planning

journal homepage: www.elsevier.com/locate/landurbplan

Research Paper

Bird use of solar photovoltaic installations at US airports: Implications for aviation safety

Travis L. DeVault[a,*], Thomas W. Seamans[a], Jason A. Schmidt[a], Jerrold L. Belant[b], Bradley F. Blackwell[a], Nicole Mooers[a], Laura A. Tyson[a], Lolita Van Pelt[c]

[a] *US Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, USA*
[b] *Department of Wildlife, Fisheries and Aquaculture, Mississippi State University, USA*
[c] *US Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, USA*

HIGHLIGHTS

- Several airports have recently installed photovoltaic arrays on their properties.
- We studied bird use of photovoltaic arrays and airport grasslands in three states.
- Overall photovoltaic arrays did not increase bird hazards to aviation at airports.
- Large species hazardous to aviation were less abundant on photovoltaic arrays.

ARTICLE INFO

Article history:
Received 4 June 2013
Received in revised form
26 November 2013
Accepted 27 November 2013

Keywords:
Airport
Bird strike
Photovoltaic
Renewable energy
Solar
US Federal Aviation Administration

ABSTRACT

Several airports in the US have recently installed large photovoltaic (PV) arrays near air-operations areas to offset energy demands, and the US Federal Aviation Administration has published guidelines for new solar installations on airport properties. Although an increased reliance on solar energy will likely benefit airports from environmental and economic perspectives, bird use of solar installations should be examined before wide-scale implementation to determine whether such changes in land use adversely affect aviation safety by increasing risk of bird-aircraft collisions. We studied bird use of five pairs of PV arrays and nearby airport grasslands in Arizona, Colorado, and Ohio, over one year. Across locations, we observed 46 species of birds in airfield grasslands compared to 37 species in PV arrays. We calculated a bird hazard index (BHI) based on the mean seasonal mass of birds per area surveyed. General linear model analysis indicated that BHI was influenced by season, with higher BHI in summer than fall and winter. We found no effect of treatment (PV arrays vs. airfields), location, or interactions among predictors. However, using a nonparametric two-group test across all seasons and locations, we found greater BHI in airfield grasslands than PV arrays for those species considered especially hazardous to aircraft (species $\geq$ 1.125 kg). Our results suggest that converting airport grasslands to PV arrays would not increase hazards associated with bird-aircraft collisions.

1. Introduction

The risk of wildlife-aircraft collisions is a substantial safety concern; such incidents annually cost civilian aviation at least $677 million in the US (Dolbeer, Wright, Weller, & Begier, 2011) and $1.2 billion worldwide (Allan, 2002). Ninety-seven percent of all wildlife strikes with aircraft are caused by birds, and over 70% of wildlife strikes occur in the airport environment (i.e., at or below 152 m above ground level; Dolbeer, 2006; Dolbeer et al., 2011). Thus, management practices that reduce bird abundance in and around airports are critical for aviation safety. Gulls (*Larus* spp.), waterfowl such as Canada geese (*Branta canadensis*), raptors (Falconiformes and Strigiformes), vultures (*Cathartes aura* and *Coragyps atratus*), and smaller birds that form large flocks such as blackbirds (Icteridae) and European starlings (*Sturnus vulgaris*) are high priorities for management at US airports (DeVault, Belant, Blackwell, & Seamans, 2011).

Many management techniques are available to reduce bird use of airports (Belant & Martin, 2011; DeVault, Blackwell, & Belant,

---

[*] Corresponding author at: US Department of Agriculture, Animal and Plant Health Inspection Service, Wildlife Services, National Wildlife Research Center, Ohio Field Station, 6100 Columbus Avenue, Sandusky, OH 44870, USA.
Tel.: +1 419 625 0242; fax: +1 419 625 8465.

E-mail addresses: Travis.L.DeVault@aphis.usda.gov (T.L. DeVault), Thomas.W.Seamans@aphis.usda.gov (T.W. Seamans), JasonAlanSchmidt@hotmail.com (J.A. Schmidt), JBelant@cfr.msstate.edu (J.L. Belant), Bradley.F.Blackwell@aphis.usda.gov (B.F. Blackwell), Nicole.L.Mooers@aphis.usda.gov (N. Mooers), Laura.A.Tyson@aphis.usda.gov (L.A. Tyson), Lolita.I.VanPelt@aphis.usda.gov (L. Van Pelt).

0169-2046/$ – see front matter © 2013 Published by Elsevier B.V.
http://dx.doi.org/10.1016/j.landurbplan.2013.11.017

2013), and are generally most effective when used in an integrated fashion (Conover, 2002). Even so, large-scale killing of wildlife is often undesirable or impractical (Dolbeer, 1986; Conover, 2002) and nonlethal frightening techniques (e.g., pyrotechnics) can be cost-prohibitive or only temporarily effective (Baxter & Allan, 2008). Habitat management is the most important long-term component of an integrated wildlife management approach to reduce use of airfields by birds and other wildlife that pose hazards to aviation (Blackwell, DeVault, Fernández-Juricic, & Dolbeer, 2009; DeVault et al., 2011).

Habitat composition at airports depends on air-operations safety regulations, economic considerations, and wildlife management (Federal Aviation Administration, 1989, 2007). Land cover should prevent soil erosion, minimize blowing dust and debris, and require little maintenance. Wildlife managers must work under these constraints when contemplating habitat types that will not attract hazardous wildlife. Historically, the principal land cover at airports has been turf grass. However, large expanses of turf grass can attract hazardous bird species (e.g., Canada geese), and there is no consensus regarding the species composition and height of turf grass that best reduces bird hazards at airports (Blackwell et al., 2013). Regardless of species composition and height, turf grass is expensive for airports to maintain (Washburn & Seamans, 2007), and other potential land covers should be explored from a wildlife perspective to identify safe alternatives (Blackwell et al., 2009; DeVault, Begier et al., 2013; Martin et al., 2011).

A recent study estimated that airports in the contiguous US collectively contain over 3300 km^2 of undeveloped grasslands (DeVault et al., 2012). These authors suggested that with careful planning much of that area could potentially be converted to alternative energy production. Increased reliance on alternative energy would be environmentally and economically beneficial for airports (DeVault et al., 2012; Federal Aviation Administration, 2010; Infanger, 2010). Further, although accelerated development of alternative energy production has generated concerns such as reductions in wildlife habitat and competition with human food production (Cho, 2010; Fargione et al., 2009; Lovich & Ennen, 2011, 2013; McDonald, Fargione, Kiesecker, Miller, & Powell, 2009), airport lands are mostly unsuitable for wildlife conservation and commodity production due to the increased risk of wildlife-aircraft collisions associated with these land uses (Blackwell et al., 2013; Federal Aviation Administration, 2007; International Civil Aviation Organization, 2002; Martin et al., 2013). Thus, in some respects airports appear well suited for establishment of new alternative energy production facilities.

One type of alternative energy clearly gaining momentum for wide-scale implementation on airport properties is solar photovoltaic (PV) energy production. The Federal Aviation Administration recently published guidance on establishment of new PV installations at US airports (Federal Aviation Administration, 2010), and multiple airports throughout the US have already installed large PV arrays on their properties and others are in the planning phases (DeVault et al., 2012). In the airport context, PV arrays generally pose fewer potential direct hazards (e.g., penetration of airspace, glare, thermal plume turbulence) than other renewable energy technologies such as wind turbines and concentrating solar power plants (Barrett & DeVita, 2011; but see Wybo, 2013). However, despite the apparent benefits of siting PV arrays on airport properties, it is unclear how this type of land use influences bird communities on and around airports.

Photovoltaic arrays could potentially serve as attractants to birds hazardous to aviation because they provide shade and perches for birds, both of which are limited in grassland-dominated airport environments (DeVault, Kubel, Rhodes, & Dolbeer, 2009; DeVault et al., 2012). Dark glass panels such as those used to construct PV arrays also reflect polarized light, which can attract insects (Horváth, Kriska, Malik, & Robertson, 2009), and subsequently, insectivorous birds. Further, in some situations reflected polarized light may cause structures such as glass panels to be mistaken by some birds species for open water, resulting in mortalities from collisions with these structures or being stranded on surfaces from which they cannot take off (Horváth et al., 2009). However, despite this potential mortality, PV arrays are in use at US airports and there is no measure of relative hazards of these facilities to aviation safety.

Before consideration of wide-scale conversion of airport grasslands to PV arrays, the effects of this land-use change on local bird communities should be assessed (Wybo, 2013). Our purpose was to compare bird use of PV arrays to that of nearby airfield grasslands to determine whether PV arrays receive greater use by birds hazardous to aircraft and, thereby, adversely affect aviation safety. We predicted, however, that because solar development is generally considered detrimental to wildlife (Lovich & Ennen, 2011), and airfield grasslands are recognized as attractants to some birds because of food and cover resources (e.g., Blackwell et al., 2013; DeVault, Begier et al., 2013; Martin et al., 2011), airfields would receive greater use than PV arrays by birds recognized as hazardous to aviation safety.

2. Materials and methods

2.1. Study areas

We selected five locations in the US where PV arrays were close (<20 km) to airfields: one in western Ohio (Wyandot), two in the high plains of Colorado (Denver and Ft. Collins), and two in the Arizona mountains (Prescott and Springerville). Each location consisted of an airfield–PV array pair for a total of 10 study sites. We assumed that each airfield–PV array pair potentially could contain the same bird communities, thus controlling for regional differences in species ranges. The Wyandot location consisted of the Seneca County airport (53 ha; Lat 41.015940° Lon −83.666937°) and the Wyandot solar farm (25 ha; Lat 40.880371° Lon −83.314550°). The Denver International Airport (13,540 ha; Lat 39.847135° Lon −104.617471°), which contained a solar farm (8 ha) on the airport property, comprised the Denver location. The Ft. Collins–Loveland Municipal Airport (431 ha; Lat 40.446326° Lon −104.988595°), and the Colorado State University Foothills Campus Chrisman Field Solar Plant (10 ha; Lat 40.592424° Lon −105.143371°) comprised the Ft. Collins location. The two Arizona locations were the Ernest A. Love Field (308 ha; Lat 34.656422° Lon −112.395996°) paired with the APS/SunEdison Prescott Solar Plant (7 ha; Lat 34.678777° Lon −112.382669°), and the Springerville Municipal Airport (202 ha; Lat 34.127900° Lon −109.287717°) paired with the Springerville Generating Station Solar Farm (17 ha; Lat 34.298483° Lon −109.258976°).

The airfields in Arizona and Colorado were typically mowed once per year and the Ohio airfield was mowed multiple times during the growing season. Mean vegetation height at airfields during March–May, June–August, September–November, and December–February was 20.3, 32.0, 33.5, and 23.1 cm, respectively. Mean vegetation height at PV arrays was less: 8.7, 21.0, 9.6, and 5.9 cm, respectively. Ground cover at airfields comprised a high proportion of grasses, with scattered forbs and legumes. At Denver and Prescott, ground cover at PV arrays was generally gravelled with very sparse vegetation. At Wyandot, Ft. Collins, and Springerville, PV arrays were composed of a high proportion of grasses with a small proportion of forbs, similar to their paired airfield sites. Although vegetation differed between airfield grasslands and PV arrays, our intent was to evaluate bird use of established PV facilities, not to evaluate direct effects of PV panels themselves or differentiate effects of PV panels and vegetation composition on species use of sites. We considered vegetation characteristics at our sample locations representative of airfield grasslands and solar arrays likely to be encountered across the US, and thus an important component of our comparison. Active bird control (i.e., harassment and lethal removal) occurred at the Denver location during the study; however, because the PV array at Denver was located within the airport property, we assumed that there was no disproportionate effect of bird control on the airfield vs. the PV array.

2.2. Field methods

We randomly established 3–4 300-m permanent bird survey transects at each of the airfields and 1–3 permanent survey transects at the PV arrays, depending on size. Survey transects were at least 0.5 km apart to help ensure spatial independence. Specifically, in addition to assuming that all birds occupying the transect were detected, the observer noted whether birds moved ahead in response to the observer. Count data were not included in our analyses unless these data represented birds occupying their initial position and were unaffected by the observer (see Buckland et al., 2001; Rosenstock, Anderson, Giesen, Leukering, & Carter, 2002). Each transect was surveyed 2–4 times per month (mean = 3.9) from March 2011 through February 2012. At each transect, at least one morning and one afternoon survey was conducted each month. Surveys were postponed during inclement weather (high wind and rain). Transects were marked with line-of-sight flagging to guide observers and surveyed the same direction each time. Observers scanned ahead and to the sides of the transect while walking slowly (2–3 km/h). All observations occurred in the direction the observer was heading and never behind or more than 90° left or right. Once a bird was detected, distance to the bird when first detected as well as the angle to the bird and the species were recorded. Distances were measured with Bushnell Elite 1500 rangefinders (Overland Park, KS, USA), and the observer noted locations of bird observations to prevent double counting. We identified birds to the lowest possible taxonomic level but included only individuals identified to species in our analyses (>98% of all detections). We included in analyses only birds using the focal land cover (airfield or PV array); however, birds that used the focal land cover only as a movement corridor were not included (Buckland et al., 2001). Perpendicular distance between the bird(s) and transect was calculated using the angle and the sighting distance. If birds were flocked, distance to center of flock and angle to center of flock were recorded, as was the number of birds in the flock. We defined a bird flock as a relatively tight aggregation of birds, as opposed to a loosely clumped spatial distribution of birds (Buckland et al., 2001).

2.3. Analyses

Our primary objective was comparative in nature; that is, our interest was in determining whether PV arrays attracted a greater biomass of birds than airfields, a metric that can be indexed to hazard level (see below). We examined histograms of bird observations at various distances from the observer, and subsequently truncated all records beyond 50 m perpendicular to the transect (e.g., Buckland et al., 2001). However, because of varying shapes to surveyed areas at both airports and PV arrays (due to the presence of structures or taxiways/runways), disparate observations within and between guilds of birds, and our main purpose, we did not model the observed distributions of particular taxa or guilds relative to a known distribution (e.g., via distance sampling; Buckland et al., 2001). As such, we did not formally correct for imperfect detection in our surveys (e.g., Buckland et al., 2001; MacKenzie et al., 2002). Instead, the 50-m truncation afforded us confidence that nearly all birds within this transect width were observed and recorded, especially in PV arrays. Our analysis was conservative in that we were more likely to overlook birds in airfield grasslands than in PV arrays because airfields often had taller and denser vegetation.

Bird species vary substantially in terms of hazard level to aircraft (i.e., the likelihood of causing aircraft damage or negative effect on flight when struck), with hazard level increasing as body mass increases (DeVault et al., 2011; Dolbeer, Wright, & Cleary, 2000). For example, 51% of all strikes with Canada geese (mean body mass = 3564 g) cause aircraft damage, whereas only 2% of strikes with barn swallows *Hirundo rustica* (16 g) cause aircraft damage. In an analysis of 66 bird species and >14,000 aircraft strikes, DeVault et al. (2011) determined that 76% of variance in relative hazard level was accounted for by species body mass. As such, the most straightforward approach to our analysis—comparing bird abundances across treatments (airfield vs. PV arrays)—was not pursued because it would not have adequately characterized relative hazard level of birds associated with these habitat types. Instead, we created a bird hazard index (BHI) response variable based on the combined species body masses of birds observed during surveys (individuals and flocks). Specifically, BHI (expressed as combined bird mass [kg]/ha/month/location) was calculated by multiplying the number of birds observed (as described above) per ha surveyed by body mass (Dunning, 1993; masses for males and females were averaged) for each species, then summing across species. Bird hazard index was normalized with a log transformation: $y' = \log_{10}(1 + y)$.

We assumed no undue correlation or variance issues associated with repeated visits to a site because of the interval between visits per site (i.e., 1–2 weeks), as well as the observational aspect of our study. Therefore, we used the general linear model procedure in SPSS 20.0 (SPSS, 2011) to evaluate the effects of treatment (airfield vs. PV array), season of observation (spring = March–May, summer = June–August, fall = September–November, winter = December–February), location, and all interactions on BHI. Treatment and season were specified as fixed effects, location was specified as a random effect, and we used Satterthwaite's approximation for degrees of freedom. We used a Type III sum of squares and $\alpha = 0.05$. Post hoc analysis was conducted using the Tukey HSD procedure in SPSS 20.0.

In addition to overall bird use of airfields and PV arrays, we were interested in use by larger (and thus more hazardous) species only. However, because of a relative lack of data (see below), we were unable to evaluate BHI for this subset of birds using a general linear model. Instead, we compared BHI (without log transformation) of birds from species ≥ 1.125 kg (median species body mass for birds involved in damaging strikes with aircraft; DeVault et al., 2011) between treatments, for all locations and seasons combined, using a nonparametric Mann–Whitney *U* test.

3. Results

We conducted 1402 bird surveys (887 on airfields and 515 on solar fields) during the one-year period (March 2011–February 2012). Across locations, we observed 46 species of birds in airfields and 37 species in PV arrays (Table 1). Overall, we observed slightly more than twice the number of birds per ha surveyed in PV arrays (mean across locations = 3.468) than in airfields (1.598). However, BHI was similar for airfields and PV arrays ($F_{1,4} = 0.067$, $P = 0.808$; Fig. 1). Likewise, we found no effect for location ($F_{3,1.381} = 6.513$, $P = 0.210$), treatment x location ($F_{4,12} = 1.044$, $P = 0.425$), treatment × season ($F_{3,12} = 1.378$, $P = 0.297$), season × location ($F_{12,12} = 0.696$, $P = 0.730$), or treatment × season × location ($F_{12,80} = 1.824$, $P = 0.058$). However, we found an effect for season ($F_{3,12} = 4.358$, $P = 0.027$), with BHI greater

Table 1
Number of birds per ha surveyed at airfield grasslands and solar photovoltaic (PV) arrays at five locations in Arizona, Colorado, and Ohio, USA, Mar 2011 through Feb 2012. Values represent totals across 12 months of surveys.

Species	Airfield					PV array				
	Prescott	Springerville	Denver	Ft. Collins	Wyandot	Prescott	Springerville	Denver	Ft. Collins	Wyandot
American crow *Corvus brachyrhynchos*	–	–	–	–	0.035	–	–	–	0.017	–
American goldfinch *Carduelis tristis*	–	–	–	–	0.005	–	–	–	0.102	–
American kestrel *Falco sparverius*	0.033	0.010	0.006	0.018	–	0.011	–	–	0.017	–
American robin *Turdus migratorius*	0.006	–	0.015	0.034	0.100	–	–	0.050	0.425	0.146
Bank swallow *Riparia riparia*	0.002	–	–	–	–	–	–	–	–	–
Barn swallow *Hirundo rustica*	0.012	0.010	0.019	0.023	–	–	–	–	–	–
Black phoebe *Sayornis nigricans*	0.002	–	–	–	–	–	–	–	–	–
Blue jay *Cyanocitta cristata*	–	–	–	–	–	–	–	–	0.085	–
Brewer's blackbird *Euphagus cyanocephalus*	–	0.076	–	–	–	–	–	1.074	–	–
Brown-headed cowbird *Molothrus ater*	–	–	–	–	0.019	–	–	0.017	–	0.006
Canada goose *Branta canadensis*	–	–	–	–	0.016	–	–	–	–	–
Cassin's kingbird *Tyrannus vociferans*	0.002	–	–	–	–	0.006	–	–	–	–
Cliff swallow *Petrochelidon pyrrhonota*	–	0.033	0.028	0.013	–	–	0.009	0.033	–	–
Common grackle *Quiscalus quiscula*	–	–	0.002	0.095	0.002	–	–	0.083	–	0.038
Common raven *Corvus corax*	0.021	0.793	–	–	–	0.011	0.009	–	–	–
Dark-eyed junco *Junco hyemalis*	–	–	–	–	–	–	–	–	0.102	0.016
Eastern bluebird *Sialia sialis*	–	–	–	–	–	–	–	–	–	0.035
Eastern kingbird *Tyrannus tyrannus*	–	–	–	0.002	–	–	–	–	–	0.006
Eastern meadowlark *Sturnella magna*	–	–	–	–	0.007	–	–	–	–	0.006
Eurasian collared-dove *Streptopelia decaocto*	–	–	–	0.007	–	–	–	–	–	–
European starling *Sturnus vulgaris*	–	–	0.013	–	0.021	–	–	–	–	0.196
Grasshopper sparrow *Ammodramus savannarum*	–	–	–	–	0.023	–	–	–	–	0.006
Great blue heron *Ardea herodias*	–	0.002	–	–	–	–	–	–	–	–
Herring gull *Larus argentatus*	–	–	–	–	0.002	–	–	–	–	–
Horned lark *Eremophilia alpestris*	2.610	1.585	0.106	0.462	0.005	6.379	0.201	–	0.017	0.003
House finch *Carpodacus mexicanus*	0.123	0.080	0.034	0.016	–	0.738	1.296	2.380	0.459	0.019
Killdeer *Charadrius vociferus*	0.066	–	0.007	–	0.016	–	–	0.033	–	0.022
Lark bunting *Calamospiza melanocorys*	–	–	0.223	0.009	–	–	–	–	–	–
Lark sparrow *Chondestes grammacus*	–	–	–	–	–	–	0.027	–	0.068	–
Lesser goldfinch *Carduelis psaltria*	–	–	–	–	–	–	0.023	–	–	–
Lincoln's sparrow *Melospiza lincolnii*	–	0.002	–	–	–	–	–	–	–	–
Loggerhead shrike *Lanius ludovicianus*	–	–	0.002	–	–	0.045	0.005	–	–	–
Mallard *Anas platyrhynchos*	–	–	0.002	–	0.005	–	–	–	–	–
Mountain bluebird *Sialia currucoides*	–	–	–	–	–	–	0.037	–	–	–
Mourning dove *Zenaida macroura*	0.008	0.085	0.041	0.127	–	0.201	1.310	0.050	0.255	0.019
Northern flicker *Colaptes auratus*	–	–	–	–	–	–	–	–	0.323	–

Table 1 (*Continued*)

Species	Airfield					PV array				
	Prescott	Springerville	Denver	Ft. Collins	Wyandot	Prescott	Springerville	Denver	Ft. Collins	Wyandot
Northern harrier *Circus cyaneus*	–	0.003	0.004	–	–	–	–	–	–	–
Northern shrike *Lanius excubitor*	–	–	–	0.002	–	–	–	–	–	–
Red-tailed hawk *Buteo jamaicensis*	–	0.002	0.002	0.004	0.007	–	–	0.083	–	–
Red-winged blackbird *Agelaius phoeniceus*	–	–	0.114	0.055	0.002	–	–	0.165	0.017	0.114
Rock dove *Columba livia*	–	–	–	0.002	–	–	–	–	–	–
Sage sparrow *Amphispiza belli*	–	–	–	–	–	–	0.009	–	–	–
Savannah sparrow *Passerculus sandwichensis*	0.004	–	–	–	0.023	–	–	–	–	0.016
Say's phoebe *Sayornis saya*	0.012	–	–	–	–	0.017	–	0.099	–	–
Song sparrow *Melospiza melodia*	0.002	–	–	–	–	–	–	–	–	0.010
Swainson's hawk *Buteo swainsoni*	0.002	–	–	0.005	–	0.006	–	0.033	–	–
Townsend's solitaire *Myadestes townsendi*	–	–	–	–	–	–	0.005	–	–	–
Turkey vulture *Cathartes aura*	–	0.002	–	–	0.009	–	–	–	–	–
Vesper sparrow *Pooecetes gramineus*	–	0.010	0.002	–	–	–	–	–	–	–
Western bluebird *Sialia mexicana*	0.004	–	–	–	–	–	–	–	–	–
Western kingbird *Tyrannus verticalis*	0.025	0.005	0.039	0.030	–	0.106	0.014	0.033	–	–
Western meadowlark *Sturnella neglecta*	0.068	0.031	0.108	0.283	–	0.006	0.092	–	0.017	–
Western scrub-jay *Aphelocoma californica*	0.002	–	–	–	–	–	–	–	–	–
Wood duck *Aix sponsa*	–	–	–	–	0.002	–	–	–	–	–
Yellow-headed blackbird *Xanthocephalus xanthocephalus*	–	–	–	–	–	–	–	0.083	–	–
Zone-tailed hawk *Buteo albonotatus*	0.004	0.002	–	–	–	–	–	–	–	–

in summer than in fall (mean difference = 0.630, $P = 0.021$) and winter (mean difference = 0.832, $P < 0.001$; Fig. 1).

Across treatments, 92.8% of all birds surveyed were of species <1.125 kg. Only nine individual birds of species ≥1.125 kg were observed at PV arrays, compared to 489 at airfields (Table 1). This effect was driven predominantly by the presence of common ravens (*Corvus corax*; 1.199 kg) at the Springerville location in fall ($n = 230$) and winter ($n = 204$). Bird Hazard Index (without log transformation) of birds from species ≥ 1.125 kg was greater at airfields (range = 0–30,724.370; $U = 2269$) than at PV arrays (range = 0–4094.540; $U = 1331$, $P < 0.001$).

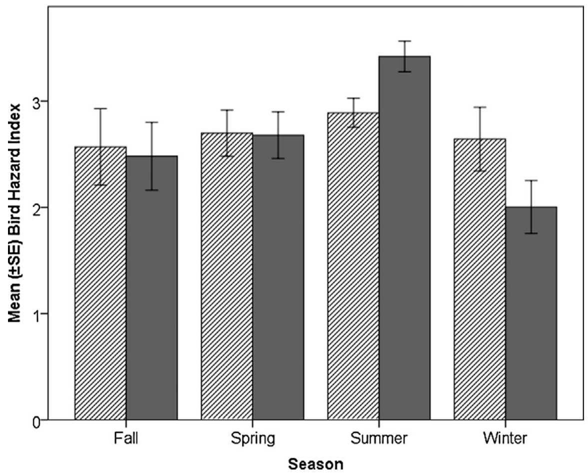

Fig. 1. Mean (±1 SE) bird hazard index (expressed as combined bird mass [kg]/ha/month/location, log transformed) across seasons at airfield grasslands (hatched bars) and solar photovoltaic arrays (solid bars) at five locations in Arizona, Colorado, and Ohio, USA, March 2011 through February 2012.

4. Discussion

To the best of our knowledge, ours is the first study to report bird use of PV arrays in comparison to adjacent habitats, thus characterizing potential changes in bird communities when converting to PV arrays. There is little information available on the effects of solar energy development on wildlife, but it is generally assumed to be negative, largely because of destruction and modification of wildlife habitat (Lovich & Ennen, 2011). Although we observed more birds per area surveyed in PV arrays than in airfields, we found fewer bird species in PV arrays than in airfields. Overall, the level of bird use we observed at PV arrays appears low (Table 1), especially considering that airfield grasslands are managed to be largely free of wildlife (Belant & Martin, 2011; Cleary & Dolbeer, 2005; DeVault, Begier et al., 2013). Also, bird species diversity is generally greater in native grasslands than in monoculture grasslands and airfield grasslands (Robertson, Doran, Loomis, Robertson, & Schemske, 2011; Schmidt, Washburn, DeVault, Seamans, & Schmidt, 2013; see also Blackwell et al., 2013). Thus, our study supports the view that solar development is generally detrimental to wildlife at the local scale.

The apparent negative effects of solar energy development on bird communities could hamper efforts aimed at reconciling increases in alternative energy production with wildlife conservation (Lovich & Ennen, 2011). Even so, at a more local scale the relative lack of bird use of PV arrays should facilitate solar development at airports, especially in regions where solar development is most promising (DeVault et al., 2012). Because airport habitats are generally not conducive to simultaneous management for aviation safety and wildlife conservation (Blackwell et al., 2013; Martin et al., 2013), establishment of PV arrays at airports should not be construed as conservation opportunities foregone for energy development; aviation safety must also be considered. Wildlife strikes are increasingly being viewed as a major safety threat to aviation (e.g., Marra et al., 2009) and pose obvious deleterious consequences for birds struck. As a result, regulations worldwide discourage or prohibit the establishment of land uses that attract wildlife at airports (Federal Aviation Administration, 2007; International Civil Aviation Organization, 2002). Based on our findings, we suggest that establishment of PV arrays will not conflict with safety regulations concerning wildlife at airports, and that establishment of PV arrays could play a major role in efforts to design and operate "greener" airports (McAllister, 2009). Even so, we acknowledge that our sample of five paired locations might not be representative of all areas where PV arrays could be established. Airport biologists should consider the potential for changes in wildlife communities any time major habitat alterations are made at airports on an individual basis.

Although we found no difference in BHI between PV arrays and airport grasslands, BHI was greatest in summer. Our observations suggested that some small birds used PV arrays in summer, and to a lesser degree in spring, for shade and perches. For example, at Wyandot red-winged blackbirds (*Agelaius phoeniceus*) breeding in a nearby wetland occasionally perched on PV panels to sing, and small birds often used shade under PV arrays at the other four locations in Arizona and Colorado during the warmest parts of the day in summer. It is clear that perches (McClanahan & Wolfe, 1993) and, in arid environments, shade (Dean, Milton, & Jeltsch, 1999; Williams, Tieleman, & Shobrak, 1999), can influence local bird abundance. Thus, biologists and others charged with wildlife management at airports should monitor bird activity at PV arrays at times when shade and perches are most important to birds. In situations where PV arrays are frequently used for perches, we note that there are multiple perching-deterrent devices available (e.g., Seamans, Barras, & Bernhardt, 2007), some of which might be suitable for use on PV panels.

We found little evidence that birds using PV arrays responded to polarized light reflected by the PV panels or by increased abundance or availability of insects attracted to the panels. We observed no bird casualties obviously caused by stranding or collision with panels, and we rarely observed birds foraging on or near PV arrays (see below). Also, several strongly insectivorous bird species (e.g., swallows and flycatchers) were, in general, at least as abundant at airfield grasslands as at PV arrays (Table 1). Even so, food resources are primary determinants of bird movements on and near airports (DeVault & Washburn, 2013), and new potential food resources at airports should be investigated to determine whether they serve as attractants to hazardous birds.

Although PV arrays were not devoid of birds, our observations indicate that PV arrays will likely not increase the risk of a damaging bird strike at most locations. In the context of bird strikes, risk is defined as the likelihood of a damaging strike multiplied by the hazard level of the species involved (e.g., Martin et al., 2011). Although birds might be present in a PV array (or any other habitat), they do not present risk to aircraft when they are perched—either on panels or under panels. Activity patterns and behavior ideally should be considered when wildlife use of airport habitat types is evaluated. Because most observations of birds using PV arrays in our study were of perched individuals (i.e., they rarely used PV arrays for foraging or nesting), the true risk to aviation associated with these birds potentially could be very low. Thus, considering (1) our analyses might have underestimated bird use of airfield grasslands compared to that of PV arrays (see Section 2), (2) there is uncertainty concerning the risk to aviation of birds using PV arrays for shade and perches, and (3) birds using PV arrays were almost exclusively of smaller (<1.125 kg) species which are less hazardous to aircraft, PV arrays appear to pose less bird-strike risk than airfield grasslands.

5. Conclusions

Appropriate siting of new energy developments is essential for minimizing impacts on biodiversity (McDonald et al., 2009). Because of the inherent potential risk of wildlife to aircraft, energy developments that adversely affect biodiversity may be appropriate at airports. Our data, combined with other recommendations (Barrett & DeVita, 2011), suggest airports offer opportunities for establishment of new PV installations that do not conflict with safety priorities. Siting PV installations at airports offers the immediate benefit of increased use of alternative energy. In addition, we suggest that conversion of airfield habitat to PV arrays in some locations could decrease bird-strike risk relative to current grass or other natural land covers used on airports.

Acknowledgements

We thank the US Department of Agriculture and the Federal Aviation Administration for funding our research, and D. Bergman, K. Cross, A. Franklin, and S. Shriner for help with various aspects of this study. We also thank the personnel at airports and solar facilities who allowed us to access their properties to collect data. E. Poggiali provided critical logistical assistance during our study, and M. Tobin reviewed an earlier version of this manuscript. Opinions expressed in this study do not necessarily reflect current Federal Aviation Administration policy decisions regarding the control of wildlife on or near airports.

References

Allan, J. R. (2002). The costs of bird strikes and bird strike prevention. In L. Clark, J. Hone, J. A. Shivik, R. A. Watkins, K. C. Vercauteren, & J. K. Yoder (Eds.), *Human conflicts with wildlife: Economic considerations. Proceedings of the third NWRC special symposium* National Wildlife Research Center, Fort Collins, CO, USA, (pp. 147–152).

Barrett, S. B., & DeVita, P. M. (2011). *Investigating safety impacts of energy technologies on airports and aviation. Airport Cooperative Research Program Synthesis 28*. Washington, DC, USA: Transportation Research Board of the National Academies.

Baxter, A. T., & Allan, J. R. (2008). Use of lethal control to reduce habituation to blank rounds by scavenging birds. *Journal of Wildlife Management*, *72*, 1653–1657.

Belant, J. L., & Martin, J. A. (2011). *Bird harassment, repellent, and deterrent techniques for use on and near airports. Airport Cooperative Research Program Synthesis*. Washington, DC, USA: Transportation Research Board of the National Academies.

Blackwell, B. F., DeVault, T. L., Fernández-Juricic, E., & Dolbeer, R. A. (2009). Wildlife collisions with aircraft: A missing component of land-use planning for airports. *Landscape and Urban Planning*, *93*, 1–9.

Blackwell, B. F., Seamans, T. W., Schmidt, P. M., DeVault, T. L., Belant, J. L., Whittingham, M. J., et al. (2013). A framework for managing airport grasslands and birds amidst conflicting priorities. *Ibis*, *155*, 18–193.

Buckland, S. T., Anderson, D. R., Burnham, K. P., Laake, J. L., Borchers, D. L., & Thomas, L. (2001). *Introduction to distance sampling: Estimating abundance of biological populations*. New York, NY, USA: Oxford University Press.

Cho, A. (2010). Energy's tricky tradeoffs. *Science*, *329*, 786–787.

Cleary, E. C., & Dolbeer, R. A. (2005). *Wildlife hazard management at airports* (second ed.). Washington, DC, USA: Federal Aviation Administration, Office of Airport Safety and Standards, Airport Safety and Compliance Branch.

Conover, M. R. (2002). *Resolving human–wildlife conflicts*. Boca Raton, FL, USA: CRC Press.

Dean, W. R. J., Milton, S. J., & Jeltsch, F. (1999). Large trees, fertile islands, and birds in arid savanna. *Journal of Arid Environments*, *41*, 61–78.

DeVault, T. L., Begier, M. J., Belant, J. L., Blackwell, B. F., Dolbeer, R. A., Martin, J. A., et al. (2013). Rethinking airport land-cover paradigms: Agriculture, grass, and wildlife hazards. *Human–Wildlife Interactions*, *7*, 10–15.

DeVault, T. L., Belant, J. L., Blackwell, B. F., Martin, J. A., Schmidt, J. A., & Burger, L. W., Jr. (2012). Airports offer unrealized potential for alternative energy production. *Environmental Management*, *49*, 517–522.

DeVault, T. L., Belant, J. L., Blackwell, B. F., & Seamans, T. W. (2011). Interspecific variation in wildlife hazards to aircraft: Implications for airport wildlife management. *Wildlife Society Bulletin*, *35*, 394–402.

DeVault, T. L., Blackwell, B. F., & Belant, J. L. (Eds.). (2013). *Wildlife in airport environments: Preventing animal-aircraft collisions through science-based management*. Baltimore, MD, USA: Johns Hopkins University Press.

DeVault, T. L., Kubel, J. E., Rhodes, O. E., Jr., & Dolbeer, R. A. (2009). Habitat and bird communities at small airports in the midwestern USA. *Proceedings of the Wildlife Damage Management Conference*, *13*, 137–145.

DeVault, T. L., & Washburn, B. E. (2013). Identification and management of wildlife food resources at airports. In T. L. DeVault, B. F. Blackwell, & J. L. Belant (Eds.), *Wildlife in airport environments: Preventing animal-aircraft collisions through science-based management* (pp. 79–90). Baltimore, MD, USA: Johns Hopkins University Press.

Dolbeer, R. A. (1986). Current status and potential of lethal means of reducing bird damage in agriculture. *Acta International Ornithological Congress*, *19*, 474–483.

Dolbeer, R. A. (2006). Height distribution of birds recorded by collisions with civil aircraft. *Journal of Wildlife Management*, *70*, 1345–1350.

Dolbeer, R. A., Wright, S. E., & Cleary, E. C. (2000). Ranking the hazard level of wildlife species to aviation. *Wildlife Society Bulletin*, *28*, 372–378.

Dolbeer, R. A., Wright, S. E., Weller, J., & Begier, M. J. (2011). *Wildlife strikes to civil aircraft in the United States, 1990–2010*. Washington, DC, USA: Federal Aviation Administration, Serial Report No. 17.

Dunning, J. B. (1993). *Avian body masses*. Boca Raton, FL, USA: CRC Press.

Fargione, J. E., Cooper, T. R., Flaspohler, D. J., Hill, J., Lehman, C., McCoy, T., et al. (2009). Bioenergy and wildlife: Threats and opportunities for grassland conservation. *BioScience*, *59*, 767–777.

Federal Aviation Administration. (1989). *Airport design. Advisory Circular 150/5300-13, Washington, DC, USA*.

Federal Aviation Administration. (2007). *Hazardous wildlife attractants on or near airports. Advisory Circular 150/5200-33B, Washington, DC, USA*.

Federal Aviation Administration. (2010). *Technical guidance for evaluating selected solar technologies on airports. Report FAA-ARP-TR-10-1, Washington, DC, USA*.

Horváth, G., Kriska, G., Malik, P., & Robertson, B. (2009). Polarized light pollution: A new kind of ecological photopollution. *Frontiers in Ecology and the Environment*, *7*, 317–325.

Infanger, J. F. (2010). The pros, cons of solar, wind. *Airport Business*, *24*(9), 18–19.

International Civil Aviation Organization. (2002). *Land use and environmental control. Airport Planning Manual 9184 AN/902, Part 2*.

Lovich, J. E., & Ennen, J. R. (2011). Wildlife conservation and solar energy development in the Desert Southwest, United States. *BioScience*, *61*, 982–992.

Lovich, J. E., & Ennen, J. R. (2013). Assessing the state of knowledge of utility-scale wind energy development and operation on non-volant terrestrial and marine wildlife. *Applied Energy*, *103*, 52–60.

MacKenzie, D. I., Nichols, J. D., Lachman, G. B., Droege, S., Royle, A., & Langtimm, C. A. (2002). Estimating site occupancy rates when detection probabilities are less than one. *Ecology*, *83*, 2248–2255.

Marra, P. P., Dove, C. J., Dolbeer, R. A., Dahlan, N. F., Heacker, M., Whatton, J. F., et al. (2009). Migratory Canada geese cause crash of US Airways Flight 1549. *Frontiers in Ecology and the Environment*, *7*, 297–301.

Martin, J. A., Belant, J. L., DeVault, T. L., Burger, L. W., Jr., Blackwell, B. F., Riffell, S. K., et al. (2011). Wildlife risk to aviation: A multi-scale issue requires a multi-scale solution. *Human–Wildlife Interactions*, *5*, 198–203.

Martin, J. A., Conkling, T. J., Belant, J. L., Biondi, K. M., Blackwell, B. F., DeVault, T. L., et al. (2013). Wildlife conservation and alternative land uses at airports. In T. L. DeVault, B. F. Blackwell, & J. L. Belant (Eds.), *Wildlife in airport environments: Preventing animal-aircraft collisions through science-based management* (pp. 117–125). Baltimore, MD, USA: Johns Hopkins University Press.

McAllister, B. (2009). The greener, the better. *Airport Business*, *23*(8), 13–15.

McClanahan, T. R., & Wolfe, R. W. (1993). Accelerating forest succession in a fragmented landscape: The role of birds and perches. *Conservation Biology*, *7*, 279–288.

McDonald, R. I., Fargione, J., Kiesecker, J., Miller, W. M., & Powell, J. (2009). Energy sprawl or energy efficiency: Climate policy impacts on natural habitat for the United States of America. *PLoS ONE*, *4*(8), e6802.

Robertson, B. A., Doran, P. J., Loomis, L. R., Robertson, J. R., & Schemske, D. W. (2011). Perennial biomass feedstocks enhance avian diversity. *Global Change Biology Bioenergy*, *3*, 235–246.

Rosenstock, S. S., Anderson, D. R., Giesen, K. M., Leukering, T., & Carter, M. F. (2002). Landbird counting techniques: Current practices and an alternative. *Auk*, *119*, 46–53.

Schmidt, J. A., Washburn, B. E., DeVault, T. L., Seamans, T. W., & Schmidt, P. M. (2013). Do native warm-season grasslands near airports increase bird strike hazards? *American Midland Naturalist*, *170*, 144–157.

Seamans, T. W., Barras, S. C., & Bernhardt, G. E. (2007). Evaluation of two perch deterrents for starlings, blackbirds and pigeons. *International Journal of Pest Management*, *53*, 45–51.

SPSS. (2011). *SPSS for Windows, Release 20.0*. Chicago, IL, USA: SPSS Inc.

Washburn, B. E., & Seamans, T. W. (2007). Wildlife responses to vegetation height management in cool-season grasslands. *Rangeland Ecology and Management*, *60*, 319–323.

Williams, J. B., Tieleman, B. I., & Shobrak, M. (1999). Lizard burrows provide thermal refugia for larks in the Arabian Desert. *Condor*, *101*, 714–717.

Wybo, J.-L. (2013). Large-scale photovoltaic systems in airport areas: Safety concerns. *Renewable and Sustainable Energy Reviews*, *21*, 402–410.