2013

Understanding Animal Movements at and near Airports

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Understanding movements of hazardous wildlife species at and near airports is critical to formulating effective management strategies for reducing aviation risk. Animal movements vary daily, seasonally, and annually and are based on broad biological and ecological concepts, including foraging, reproduction, habitat characteristics, dispersal, and migration. As an energy conservation strategy, most animals minimize their movements to meet life requisites, which in turn presumably improves fitness. Animal movements in relation to airports can be direct; for example, Canada geese (*Branta canadensis*) flying onto an airfield because grass height and composition are suitable for loafing sites and as food. Animal movements in and around airports can also be indirect; for example, airports near large rivers may experience increased numbers of birds flying overhead during spring and autumn migrations, as rivers often facilitate bird navigation.

In this chapter we describe ecologically based patterns of animal movements and develop a mechanistic foundation for understanding those movements and the degree to which we can modify them to reduce corresponding hazards to aircraft. We discuss biological and ecological causes of animal movements and some of the foundational ecological theories that help explain animal movements at airports. We then discuss motivations of animal movements at airports based on resource needs, the role of spatial scale when considering animal movements, and how to apply these concepts to reduce wildlife strikes. We end with a brief description of primary techniques to quantify animal movements, summarize management of animal movements at airports, and suggest areas of future research.

Types of Animal Movements

Animal movements can be divided into six broad, ecologically based categories: foraging, movements to rest sites, reproduction, territory defense, dispersal, and migration. We generally define foraging as any animal movement to feed, to obtain free water for drinking, or to search for food. Movements to rest sites are those where animals are seeking shelter (e.g., night roosts for turkey vultures [*Cathartes aura*] or bedding sites for white-tailed deer [*Odocoileus virginianus*]). Reproduction movements are associated with individuals searching for mates during a defined breeding season (e.g., white-tailed deer during the rut). Defense movements are those in which an animal is defending either a territory or a specific resource (e.g., food) from conspecifics or other animals. Dispersal includes movements of juvenile individuals traveling from their natal range to locate new areas to occupy (Greenwood 1980, Waser and Jones 1983, Clutton-Brock 1989, Waser 1996). Migrations are typically biannual movements of animals in response to changes in resource availability and for reproduction; for example, the spring and fall migrations of many bird species (Drent et al. 2003, van Wijk et al. 2012). These categories of movement vary temporally and spatially. Foraging occurs at least daily for most species, whereas migration typically oc-

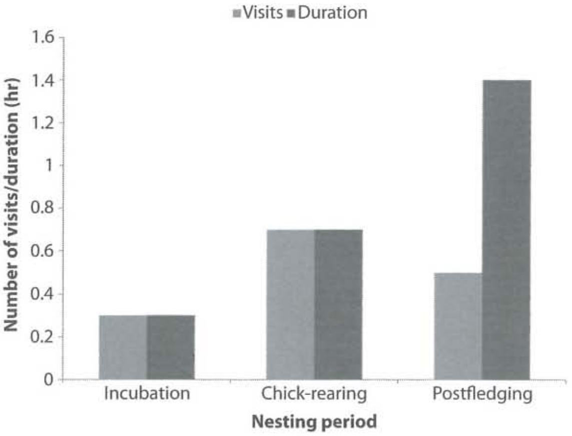

Fig. 12.1. Number and duration of visits to a landfill in northern Ohio by nesting period of radio-tagged, nesting herring gulls (*Larus argentatus*). Derived from Belant et al. (1993)

curs twice annually, and dispersal by definition occurs once in a lifetime. In a spatial context, movements for foraging tend to be more restricted than movements to rest sites (but not always), which in turn are more restricted than defense and reproduction, dispersal, and migration. These categories can also be hierarchical; for example, foraging tends to occur during reproduction, dispersal, and migration.

During the nesting and young-rearing periods, most adult birds and many mammals behave as central place foragers (Orians and Pearson 1979, Kacelnik 1984, Olsson et al. 2008, Wakefield et al. 2009), in that they return repeatedly to the nest or den site to provision young with food obtained during foraging bouts. For birds, these movements can vary in frequency and duration among incubation, chick-rearing, and postfledging periods. The mean daily number of visits to a landfill by radio-tagged, nesting herring gulls (*Larus argentatus*) generally increased in frequency and duration from incubation to postfledging periods—a consequence of energy demands of the chicks and reduced tenacity to the nest site after the young fledged (Belant et al. 1993; Fig. 12.1). These movements can in turn influence use of airports, either directly through increased foraging bouts during chick rearing or indirectly as birds fly over the airport to seek resources.

Wildlife managers must consider that how, when, and where animal movements occur are based fundamentally in natural selection. Animals use resources (e.g., food, rest sites, mates) to help ensure their survival; greater survival will often result in greater recruitment of young, which is how species persist. Success is based on how resources necessary for survival are distributed across the landscape, and how well animals adapt to changing distributions. Animals in part reduce energetic costs by minimizing movements required to acquire these necessary resources, which can be a better predictor of fitness than traditional habitat selection (e.g., Ayers et al. 2013). Recently developed spatial energetic models can assess landscapes relative to a species' resource needs to better understand species' movements and distributions (e.g., Wilson et al. 2012). Spatial energetic models applied to landscapes have particular application to the evaluation of management scenarios that might reduce resources and, subsequently, wildlife risk to aircraft. Understanding species movements and distributions could be used to refine habitat management practices to reduce animal use in and around airports.

Principles of Animal Movements

There are numerous ecological theories and processes that relate to spatial and temporal aspects of animal movements. Several of the more fundamental theories have strong application to animal movements in relation to management at airports. Understanding these principles will help airport biologists and managers develop and implement strategies to reduce animal movements at airports. We provide basic definitions and demonstrate their application to airport management.

Distribution Theory

Animal distributions are grounded within two pervasive models: ideal free distribution and ideal despotic distribution. The ideal free distribution model generally applies to nonterritorial animals and states that individuals are distributed proportionately to resources (e.g., roost sites, foraging sites) available (Fretwell and Lucas 1970). In this model, animals assess the quality of available resources and move unhindered among these resources to select those considered best. In contrast, the ideal despotic distribution model applies to territorial animals whereby dominant individuals influence amount of resources available to subordinate individuals (Fretwell 1972). Subordinates' selection of

habitat is consequently constrained by the aggressive behavior and distribution of dominant animals. A practical goal of wildlife management at airports would be to follow one or both of these models to evaluate and reduce wildlife use, especially use by hazardous wildlife species. To limit movements of wildlife at airports under the ideal free distribution model, a reduction in suitable resources would be necessary. This could involve reduction or removal of food sources (e.g., Bernhardt et al. 2009, Washburn et al. 2011; Chapter 8) or roosting areas (e.g., Gordon and White 2006). In these situations, animals will seek areas other than the airport to obtain food or to locate another roost. More direct management actions (e.g., harassment, exclusion) would follow the ideal despotic distribution model, whereby humans would be the dominant individuals (i.e., despots) and constrain use of airport resources by hazardous wildlife (subordinates). This would be accomplished through aggressive behavior in the case of harassment techniques (e.g., Montoney and Boggs 1993), or through human presence (i.e., distribution) in the case of fencing to exclude wildlife (e.g., DeVault et al. 2008; Chapter 5). The relevant principle for both models is to reduce wildlife movements at airports by either reducing resource quality or constraining wildlife movements through management actions.

Niche Theory

As with distribution theory, niche theory has considerable application to animal movements at and near airports. It describes the role of an organism in its environment (e.g., predator, parasite), including its activities and interrelationships with other organisms (Krebs 2001). The set of resources that a species can use in the absence of competition or other interactions with animals has been termed the fundamental niche (Krebs 2001). Because of interactions with other animals, however, individuals and species typically are restricted to a narrower range of ecological or resource conditions. This restricted range of conditions is referred to as the realized niche (Caughley and Sinclair 1994). Essentially all animals operate within a realized niche, being constrained by competition with other animals, environmental limitations, and other factors. Finally, the range of resource conditions (e.g., number of available resting sites, amount of food available) that an animal can use and still persist in the environment has been coined the niche hypervolume (Hutchinson 1957). Reduction of animal movements (or use) in airport environments will require a great enough reduction in one or more of the resources at the airport that is within an animal's realized niche, such that the animal will no longer access the airport to search for these resources. If multiple resources (e.g., food, shelter) are available at the airport, animal movements onto airport property may be reduced only after all suitable resources are adequately managed.

Foraging Theory

It has been suggested frequently that animals optimize their foraging activities to increase their odds of survival (Schoener 1971, Krebs 1973). A part of optimal foraging is the marginal value theorem (Charnov 1976), which in its most fundamental form states that an animal will occupy a suitable area of habitat until resource depletion (i.e., to a particular resource density) by that individual causes it to move to another area of higher habitat quality. This response by animals has been referred to as the "giving-up density." An important point of this theorem is that the giving-up density of an area occupied by an animal will depend in part on the distance to the next suitable area. An animal is more likely to stay in the current habitat longer if the next area of suitable habitat is farther away, which has implications for wildlife harassment (methods that can increase perceived risk and therefore the giving-up density; see Brown 1999) at airports. If another suitable area is a considerable distance from the airport, animals will be less likely to disperse from the area or will be more likely to return.

Effects of Group Size

Animals congregate in groups for numerous reasons: to rear young, to reduce risk of predation, and to procure food (Heinsohn 1991, Sirot and Touzalin 2009, Thornton and Clutton-Brock 2011). Whether animals move as individuals or in groups is of great importance to airport managers, as the likelihood of aircraft damage generally increases with the number of animals struck. Biondi et al. (2011) reported that aircraft were 25 times

Fig. 12.2. European starlings (*Sturnus vulgaris*) are a moderate risk to aircraft, but the likelihood of damage increases markedly when starlings form large flocks. Starlings often flock during foraging and roosting. Photo credit: Tommy Hansen

more likely to be damaged during incidents involving multiple white-tailed deer compared to strikes with a single animal. Although individual European starlings (*Sturnus vulgaris*) are considered a moderate hazard to aircraft relative to other wildlife species, with 4% of strikes causing damage, a high proportion of damaging strikes was a consequence of aircraft colliding with multiple individuals (Dolbeer and Wright 2009; Fig. 12.2). Notably, multiple Canada geese resulted in the forced landing of US Airways Flight 1549 on 15 January 2009 (Marra et al. 2009). The primary causes for increased damage to aircraft from hitting multiple animals appear to be related to species body mass (e.g., DeVault et al. 2011) and multiple strike locations on the aircraft.

Motivations for Animal Movements at and near Airports

Motivations for animal movements at airports can be characterized into three broad categories. The first is movement in response to habitat or other features that may cause attraction (e.g., foraging or roosting site) or avoidance (e.g., avoiding aircraft or buildings) of airports. Laughing gulls (*L. atricilla*) nesting at Jamaica Bay National Wildlife Refuge apparently make daily foraging trips from the nesting colony to loaf or forage on beetles and ants at and near John F. Kennedy International Airport (JFK; Buckley and McCarthy 1994, Bernhardt et al. 2010, Kutschbach-Brohl et al. 2010). In this situation, foraging movements to obtain terrestrial invertebrates varied during summer, with greatest apparent movements during July (Bernhardt et al. 2010), presumably when adults were provisioning young (Dolbeer et al. 1993, Washburn et al. 2013). Tree swallow (*Tachycineta bicolor*) use of northern bayberry fruit during autumn at JFK resulted in extensive use of this resource by large flocks of swallows, causing a seasonal hazard to aircraft (Bernhardt et al. 2009).

The second category includes movements at or adjacent to airports that may be completely unrelated to the airport, including bird migrations or daily flights from roosting to foraging sites. Servoss et al. (2000) documented large flocks of blackbirds (Icteridae) and European starlings flying over Phoenix Sky Harbor International Airport to reach attractive habitats outside the airport boundaries. Nohara et al. (2011) documented with radar flocks of Canada geese and other bird species crossing airspace at JFK. Movements of these types can be more difficult to manage, as the cause of animal movements is not necessarily a consequence of habitat or other resources on the airport; rather, bird movements across airports are artifacts of the airport location in relation to other landscape features.

The third category of animal movements is a response to direct or indirect wildlife control actions (e.g., hazing birds from runways, white-tailed deer movements along perimeter fences). In these cases, wildlife movement can be considered constrained (or modified) from movements that would ordinarily occur without management. For example, suspending vulture effigies from roosts reduced vulture use of U.S. Marine Corps Air Station, Cherry Point, North Carolina, USA (Ball 2009). Each of these three movement categories varies markedly in terms of effective management techniques and strategies to reduce risk to aircraft. Consequently, understanding the causes of animal movements at airports is critical for development of appropriate management strategies.

Integrating Spatial Scale

Most of the early wildlife management techniques to reduce wildlife strikes with aircraft occurred only on airport properties. These approaches included both

harassment and habitat management techniques (e.g., maintaining a specific grass height; International Civil Aviation Organization 1991; Chapters 8 and 10). Yet few wildlife species of high risk to aviation spend all of their time on airport property. Consequently, greater emphasis has been placed in recent years on management of areas surrounding airports (see Blackwell et al. 2009, Dolbeer 2011). Martin et al. (2011) highlighted the importance of spatial scale relative to animal movements and types of movements (e.g., feeding, migration). Animal movements in relation to airports can be considered in a hierarchical structure that includes multiple spatial extents (Martin et al. 2011); these spatial extents should correspond to types of movements (e.g., foraging, dispersal) for each species considered hazardous to aircraft. Davis et al. (2003) developed a risk-based model in an effort to establish zoning criteria for land use near Canadian airports. These authors suggested a framework that considered existing land-use practices, bird species characteristics linked to aircraft safety (e.g., body size, flocking behavior), and relative risk of aircraft during varying phases of flight (see also Blackwell et al. 2009). In principle, this framework would reduce suitability of habitats near airports and consequently reduce use (i.e., movements) of animals hazardous to aircraft in these areas. Others have recognized this basic premise; for example, the Federal Aviation Administration (FAA) currently provides separation criteria for hazardous wildlife attractions (e.g., landfills) at or near airports with a maximum distance of 8 km (5 miles; Dolbeer 2006, FAA 2007). However, these guidelines do not take into account species-specific movements relative to foraging or other behaviors. Belant et al. (1993, 1998) documented herring gull and ring-billed gull (*L. delawarensis*) movements up to 26 km (16 miles) from the nesting colony to landfills to acquire food. York et al. (2000*a*,*b*) similarly determined that Canada geese in Alaska sometimes moved distances >15 km (9 miles) from molting sites to airports to loaf and forage. Although highly variable, the number of marked geese observed at Elmendorf Air Force Base declined as distance from the original molting site increased (Fig. 12.3). In all of these studies, relative use of sites (landfills or airports) decreased as distance increased from source locations (nesting colony and molting sites). Nevertheless, animal movements to acquire food or secure loafing sites were about twice the maximum distance specified by the FAA for hazardous wildlife attractions.

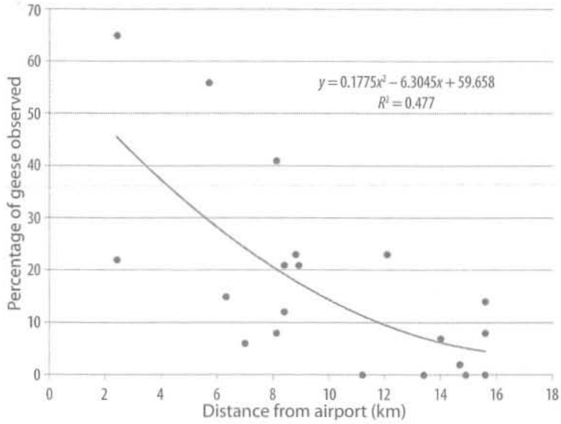

Fig. 12.3. Percentage of Canada geese (*Branta canadensis*) observed at Elmendorf Air Force Base, Anchorage, Alaska, during summer in relation to distance from the original capture site. Derived from York et al. (2000b)

An important consideration is that larger species within a taxonomic group (e.g., birds, mammals) generally have greater local movements (e.g., when foraging) as well as dispersal and migration movements compared to smaller species (Harestad and Bunnell 1979, Mace and Harvey 1983, Lindstedt et al. 1986, Basset 1995, Silva and Downing 1995, Kelt and Van Vuren 1999, Hein et al. 2012). Efforts to reduce risk to aircraft must occur at a spatial scale much larger than the airport and must consider distances moved by hazardous wildlife species. They will also require landscape-level planning that integrates information on species' movements and habitat needs from ecologists, from airport managers relative to hazardous wildlife species, and from other private and government entities relative to potential land management practices (Belant 1997, Blackwell et al. 2009).

Applications for Reducing Wildlife Strikes

Understanding the types and causes of movement can improve our ability to manage wildlife at and near airports, which in turn can reduce risk to aircraft. Bernhardt et al. (2009) conducted an excellent example of incorporating a mechanistic understanding of animal movements to reduce hazards to aircraft at JFK. Tree

swallows were involved in 109 strikes with U.S. civil aircraft in airport environments from 1990 to 2009 (DeVault et al. 2011). Although their relative hazard score to aircraft is low (Dolbeer and Wright 2009, DeVault et al. 2011), large flocks of tree swallows represent a hazard to aircraft at JFK, especially during autumn (Dolbeer et al. 2003). To address this issue, Bernhardt et al. (2009) determined that the diet of tree swallows during autumn was predominantly northern bayberry fruit (*Myrica pensylvanica*). The airport initiated a bayberry removal program, removing 75% of bushes within 0.8 km (0.5 miles) of the runway and about 50% of bushes elsewhere on the airport. During the seven years following initiation of bayberry removal, aircraft collisions with tree swallows were reduced by 75% (Bernhardt et al. 2009). The reduction in bayberry bushes reduced food availability for tree swallows, which in turn reduced swallow movements at the airport.

An example of reducing wildlife risk to aircraft, where birds crossed the airfield to forage and loaf at sites beyond airport property, involved gulls (particularly laughing gulls) at JFK (Dolbeer et al. 1989, 1993). Gulls were involved in 87% (laughing gulls 52%) of aircraft strikes at JFK from 1988 to 1990 (Dolbeer et al. 1993), with most strikes occurring during May–September and peaking during June–July, when laughing gulls were nesting (Washburn et al. 2012). An integrated gull-strike reduction program with a lethal control component (i.e., shooting program) has been implemented at JFK since 1991; this program reduced the number of laughing gull–aircraft collisions by 62% in 1991 and 76–99% annually from 1992 to 2008, compared with the mean of 157 strikes per year from 1988 to 1990 (Dolbeer et al. 1993, Washburn et al. 2009; Chapter 7). Attempts to change gull movement patterns by reducing suitability of foraging and loafing sites was considered untenable, because laughing gulls access these sites throughout the metropolitan New York City area (Griffin and Hoopes 1991, Washburn et al. 2013). Of interest is that movements of laughing gulls did not suggest avoidance of JFK during the first years of lethal control (Dolbeer et al. 1993); however, gulls in later years of the control program altered their flight patterns in response to control efforts (Dolbeer et al. 2003). Gulls apparently recognized shooters as a risk, as evidenced by their avoidance of people standing with guns at the airport boundary but not shooting (Barras et al. 2000). Avoidance of animals due to predation risk is a learned behavior (Sirot 2010) that allows species to rapidly identify predators and to invoke antipredator strategies (Lonnstedt et al. 2012), in this case by avoiding shooters on the airport (see also Chapters 2 and 4).

Techniques for Investigating Animal Movements at Airports

Numerous techniques are available to estimate and model animal abundance and distributions that can be applied to airport environments; however, far fewer techniques are available to estimate animal movements. Most wildlife survey and monitoring techniques emphasize one or more elements of species occurrence (e.g., MacKenzie et al. 2006; Chapter 14), from which animal movement can be inferred but not directly measured. The two primary techniques to study animal movements involve direct use of radiotelemetry (Millspaugh et al. 2012) and radar (Chapter 13). Radiotelemetry can provide finer spatial resolution and is based on information obtained from individual animals. In contrast, radar often results in slightly coarser spatial resolution of animal movements and species identification (Beason et al. 2010). The best technique will depend on the specific goals and objectives for each airport.

Wildlife radiotelemetry has been one of the most effective techniques in understanding animal ecology, including information on animal locations and movements. The types of radiotelemetry most applicable to understanding animal movements at airports include very high frequency (VHF) transmitters and satellite telemetry platforms. For VHF systems, transmitters are attached to animals and emit a unique radio frequency that personnel can locate manually by using a specialized receiver. Satellite-telemetry units rely on a constellation of satellites to obtain animal locations and offer the ability to estimate locations of animals on the ground and in the air (Tomkiewicz et al. 2010, Washburn and Olexa 2011). Radiotelemetry has been used to estimate animal movements in relation to aviation risk on several occasions. Schafer et al. (2002) used VHF and ARGOS satellite radiotelemetry to estimate the effectiveness of translocating red-tailed hawks (*Buteo jamaicensis*) from Chicago O'Hare International

Airport, Chicago, Illinois, USA. Similarly, Schumacher et al. (2008) estimated movements of translocated immature bald eagles (*Haliaeetus leucocephalus*) in relation to aviation risk using Global Positioning System (GPS) satellite telemetry. York et al. (2000*b*) estimated movements of Canada geese between molt sites and an Alaskan airport using VHF radiotelemetry. Washburn and Olexa (2011) used information from GPS satellite telemetry units attached to ospreys (*Pandion haliaetus*) to develop three-dimensional airspace risk models and to quantify the risk of osprey collisions with military aircraft during both breeding and migratory seasons.

In some situations, radar can be used to estimate timing, trajectories, flock size, altitudes, and speeds traveled (Klope et al. 2009, Nohara et al. 2011; Chapter 13). Radar has been used to estimate the distribution of birds over airfields as well as the frequency of near misses between birds and aircraft (MacKinnon 2006, Klope et al. 2009, FAA 2010; Chapter 13). A potential advantage of using radar at airports is a move toward near-real-time detection of birds, which could help alert airport biologists of developing threats (Blokpoel and MacKinnon 2011, Nohara et al. 2011; Chapter 13).

Managing Animal Movements at Airports

Effective management of hazardous wildlife at airports requires sound information on species presence and abundance (or relative abundance) in relation to the relative hazard each species represents to aircraft (e.g., Dolbeer et al. 2000, 2010; Biondi et al. 2011; DeVault et al. 2011; Chapter 14). In addition, detailed information on actual wildlife strikes at individual airports is necessary. Once this information is obtained, it can help managers understand the ecological reasons (e.g., to forage) hazardous species use airport property. It is typically recommended that airports direct management efforts toward the species most hazardous to aircraft (Dolbeer and Wright 2009).

Managing wildlife at airports generally involves use of indirect (e.g., fences) or direct (e.g., harassment) actions to discourage animal use of resources. Indirect management techniques include reducing food availability (Chapter 8) or the presence of water (Chapter 9), manipulating existing vegetation (e.g., turfgrass; Chapter 10), and using exclusion devices (Chapter 5). Direct management actions include the use of visual, chemical, tactile, or auditory deterrents (Chapters 2–4) and translocation of hazardous wildlife (Chapter 6). Using multiple methods often maximizes the effectiveness of wildlife control techniques (Conover 2002) to reduce animal movements at airports. Clearly, it is desirable for airport managers to reduce the attractiveness of airports to wildlife species, particularly those most hazardous to aircraft or airport infrastructure. Reducing the attractiveness of airport resources to hazardous species further enhances the effectiveness of direct control measures by weakening animal tenacity or motivation to use those resources.

Summary

The management of animal movements is directly tied to animal resource needs, including food (Chapter 8), water (Chapter 9), and habitat needs (Chapters 10 and 11). These resource needs are inextricably linked to ecological principles such as natural selection and distribution theories. Animal movements associated with acquiring necessary resources occur at multiple spatial and temporal scales and are linked to physical traits (e.g., body size), biological traits (e.g., reproduction), and ecological traits (e.g., diet, dispersal). Management of wildlife hazards at airports, as well as management of human–wildlife conflicts in general, is frequently most effective through the integration of multiple techniques (Conover 2002). We suggest that current and future practices of wildlife management at airports will benefit from better incorporation of ecological information, including animal movements. This will require an improved understanding the mechanisms responsible for movements of animals hazardous to aircraft, the array of resources (e.g., food and shelter) deemed necessary for persistence of these species, and the spatial constraints or limitations for species acquiring these resources.

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