

Avian Survey Methods for Use at Airports

Adverse effects and damage caused by interactions between humans and wildlife are increasing (DeStephano and DeGraaf 2003). To manage wildlife effectively—whether to mitigate damage, to enhance safety, or to reach conservation goals—wildlife biologists must identify hazards posed by or to members of a particular species (i.e., a population) or guild, and then prioritize management goals and specific actions. We examine the special problem of managing birds to reduce hazards to aviation, particularly those species known to cause structural damage to aircraft when struck and that pose problems to airport facilities (Dolbeer et al. 2000, Cleary and Dolbeer 2005, DeVault et al. 2011). Effective management of hazardous species at airports requires knowledge of species abundance and how abundance varies over time. In this context, the quality of the sampling methodology used will influence a biologist's ability to accurately quantify avian hazards and to understand the ecological interactions of populations or guilds using airport environments.

Accurate quantification of avian hazards allows biologists to calculate the relative risk presented by each population or guild for a period and habitat, and relative to management actions. A hazard (whether a resource contributing to bird use or simply incidental use of the airport by a population or guild) represents a particular state or condition within the airport environment that can affect the probability of bird strikes. In contrast, we define risk as the relative conditional probability of damage to an aircraft posed by a species, if struck, and the probability of the strike occurring (Schafer et al. 2007,

Blackwell et al. 2009). Avian survey data form the foundation for identifying management priorities, reducing risks associated with avian hazards to aviation safety, and evaluating the effectiveness of management actions.

Defensible data collection, analysis, and accurate findings are imperative to justify management options to other agencies and, increasingly, to a critical public (Anderson 2001). Lethal control of birds, although regulated, is an integral component of wildlife hazard reduction to mitigate strike risk at airports (see Cleary and Dolbeer 2005; Chapter 7). Despite this importance, public support for lethal control measures in wildlife management, regardless of the justification for their use, is declining. As a result, increased documentation is required to receive necessary permits, and there is need to directly demonstrate the efficacy of lethal control measures when used (Blackwell et al. 2002, 2009; Engeman et al. 2009; Runge et al. 2009). However, the union between direct management, particularly lethal control, and scientifically rigorous data collection has proven useful for demonstrating and justifying lethal control for endangered species recovery (Engeman et al. 2005, 2009), as well as for enhancing aviation safety (e.g., Dolbeer et al. 1993, Seamans et al. 2009). A demonstration of scientifically sound methods in the collection of survey data is increasingly necessary to justify and legally defend various management actions—particularly lethal control—even in situations involving human health and safety (Messmer et al. 1997, Reiter et al. 1999, Conover 2002).

Despite the need for scientific rigor, resource limitations often require that biologists base management

decisions on brief samples or “snapshots” of target populations. The process used to take these snapshots, if based on sound sampling theory, will yield accurate inference as to population abundance or trends, habitat influences, seasonal dynamics, and response to management actions (Morrison et al. 2008). As outlined by Cochran (1977) and adapted here for application to the airport environment, the sample survey should be based on six primary steps: (1) define the objective, (2) delineate the target population, (3) determine the data necessary to address the objective, (4) identify and correct for factors that influence accuracy of the estimate, (5) select appropriate methods of measurement, and (6) select appropriate data management and analysis procedures. The survey objective will dictate aspects of the subsequent steps, as will available resources.

In this chapter we use published sampling theory and methods to provide airport biologists with (1) the means to design and implement an avian survey at an airport that will maximize accuracy in quantifying avian hazards; (2) an understanding of bias and precision, and their influences on the quantification of avian hazards; (3) suggestions on how to quantify avian hazards and how to use these data to estimate relative risk to aviation safety posed by a particular species or guild by time period and habitat type; and (4) knowledge of how data can be used to prioritize management goals. Our recommendations are intended to compliment Federal Aviation Administration (FAA) procedures for Wildlife Hazard Assessments (WHAs) and subsequent management at airports (Cleary and Dolbeer 2005).

Define the Objective

Defining objectives for a wildlife study or assessment is the first step in the process of designing and implementing the effort. Clearly defined objectives allow biologists to delineate target populations, to collect representative data using an appropriate survey method, to manage data, and to identify appropriate analysis methods. In the context of avian surveys for hazard assessment purposes, the regulations that require the assessment often help define study objectives.

The FAA (2004a) dictates that a certificated airport must take immediate action to alleviate wildlife hazards whenever they are detected, and must ensure that a WHA is conducted when specified criteria relating di-

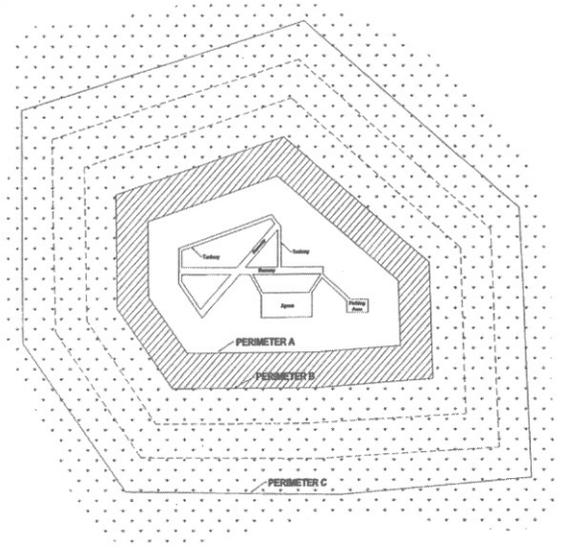


Fig. 14.1. Federal Aviation Administration (FAA) siting criteria outlining separation distances within which airports must manage attractants to hazardous wildlife. Perimeter A: for airports serving piston-powered aircraft, hazardous wildlife attractants must be 1,524 m (5,000 feet) from the nearest air operations area. Perimeter B: for airports serving turbine-powered aircraft, hazardous wildlife attractants must be 3,048 m (10,000 feet) from the nearest air operations area. Perimeter C: 8-km (5-mile) range to protect approach, departure, and circling airspace. From FAA (2007)

rectly to wildlife strikes or the potential thereof exist at the airport. The WHA must include the “identification of the wildlife species observed and their numbers, locations, local movements, and daily and seasonal occurrences” (FAA 2004a). Under this regulation, the broad objective of a survey is to identify and quantify wildlife hazards on and near airport properties, and the implication is that a management protocol (i.e., a wildlife hazard management plan; Cleary and Dolbeer 2005) will be implemented to reduce or remove the identified hazards. Airport properties include the air operations area (AOA), defined as the space designated for takeoff, landing, and surface maneuvers of aircraft (see FAA 2004a). However, wildlife attractants might also reside in areas defined by FAA siting criteria for certificated airports (i.e., within 1.5 km [1 mile] of a runway for airports servicing piston-powered aircraft only and within 3.0 km [2 miles] of a runway for airports servicing turbine-powered aircraft; FAA 2004b, 2007; Fig. 14.1).

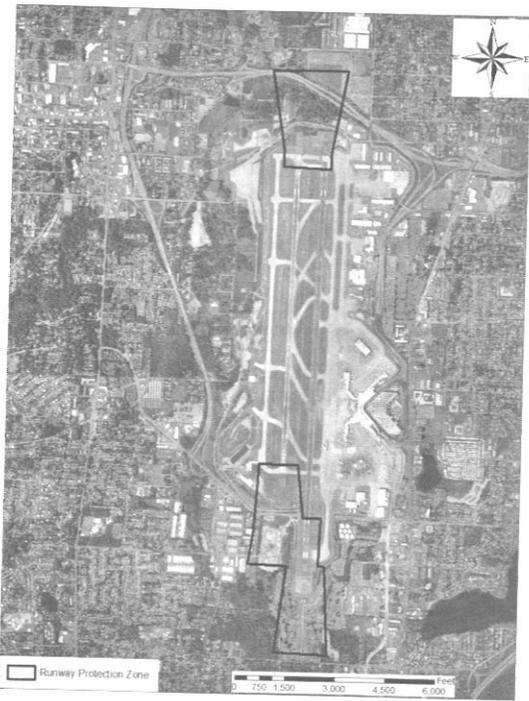


Fig. 14.2. Runway protection zones at Seattle-Tacoma International Airport, Seattle, Washington, USA. From Schafer et al. (2007)

A further implication of this broad objective is that airport biologists can, on the basis of these survey data, prioritize management goals. To this end, the survey data should allow an assessment based on calculation of risk or the probability of a damage-causing wildlife strike. The working objectives for the survey might be: (1) to quantify seasonal abundance of a population or guild within specific airport habitats or habitats immediately bordering airport property; (2) to calculate the relative risk posed by a population or guild by season, habitat type (e.g., local attractants), or airport environment (e.g., AOA, runway protection zone; Fig. 14.2); (3) to use estimates of relative risk to justify management recommendations at and near the airport; and (4) to quantify the effect of management actions on subsequent estimates of strike risk. Inherent to the survey objective are means to demonstrate risk, to enact sound wildlife management on the airport, to establish a defensible foundation for working with property owners and municipalities within the airport siting criteria, and to evaluate the effect of wildlife hazard reduction and risk mitigation.

Defining Target Populations

The target population is the population about which information is required (Cochran 1977, Morrison et al. 2008). Although numerous wildlife species are hazardous to aviation, in this chapter we focus only on avian hazards (Dolbeer and Wright 2009). Both diurnal and nocturnal bird species pose hazards to aviation, but the survey methods that apply to nocturnal species, particularly sampling equipment (e.g., forward-looking infrared cameras or avian radar systems; Chapter 13) and associated constraints, are beyond the scope of this chapter. Our focus is on quantifying use of airport habitats by diurnal bird species.

In the context of a WHA, and in reference to FAA (2004a), airport biologists should anticipate gathering data on multiple avian species during a survey. The initial site visit will provide anecdotal information on species using the airport, as well as potential attractants (Cleary and Dolbeer 2005). Avian species that appear frequently in an airport's strike records or database like that maintained by the FAA, particularly those species involved in strikes resulting in substantial damage (Dolbeer et al. 2000, 2010), will be a primary focus for airport biologists. Dolbeer (2006) found that of those bird strikes occurring at ≤ 152 m (500 feet) above ground level (AGL), Passeriformes, gulls and terns (Laridae), doves and pigeons (Columbidae), and raptors were the guilds most frequently struck. For strikes at > 152 m AGL, waterfowl (Anatidae), gulls and terns, passerines, and vultures (Cathartidae) were the most frequently struck. In addition to assessing strike hazards, it is conceivable that airport biologists could be called upon to make management recommendations for species occupying habitats outside the AOA, including those deemed nonhazardous to aviation, of particular conservation concern (e.g., state or federally protected species, grassland bird species; Blackwell et al. 2009), or species of concern that pose a direct strike hazard.

Necessary Data

Biologists conducting assessments of bird communities at airports must predetermine the data necessary to address the identified objectives. If this step is ignored, one might collect unnecessary data, wasting time and resources at the expense of data necessary

to meet the objectives of quantifying avian hazards. Driving the perimeter of the airfield twice monthly can provide perspective on birds attracted to roads and edge habitats and identify other animal attractants at the airport, but this approach will never yield accurate data on population abundance within those habitats, or similar data for populations with more specific habitat requirements. Identification of the data necessary to address the specific objectives of the assessment will aid survey design and conduct, as well as data management and analysis.

Data collected by airport biologists generally comprise naive counts (i.e., counts that are uncorrected for imperfect detection; MacKenzie et al. 2002) of individual birds and flocks, including numbers of individuals within the flocks, identified to species or guild. These data are collected during avian surveys at airports using a point-transect approach (Cleary and Dolbeer 2005) that parallels the North American Breeding Bird Survey (BBS; Sauer et al. 2008). Point transects and variations thereof (e.g., Emlen 1977, Reynolds et al. 1980, Bollinger et al. 1988, Bajema et al. 2001) can offer coverage of a breadth of habitats, minimize observer effect on avian behavior (e.g., potentially "pushing" birds ahead of the observer during a transect survey), and sample within fixed areas. In the context of an airport, naive counts made via point transect or comparable methods are also an effective means of identifying habitats and land uses that potentially serve as attractants to birds that pose strike hazards to aircraft (Cleary and Dolbeer 2005). But naive count data do not allow for accurate inference of relative abundance of particular populations (i.e., one cannot rank relative hazards) unless the methods used to obtain these counts are standardized for the conditions under which they are measured (Caughley 1977).

Sampling efforts should be tied to space and time (e.g., Buckland 2006) and adjusted for biases (Link and Sauer 1998, Runge et al. 2009), particularly imperfect detection (Lynch 1995, MacKenzie et al. 2002, MacKenzie 2005). Otherwise, the count data (e.g., BBS data) can be ecologically ambiguous. Specifically, naive counts cannot be associated with a probability distribution, which is integral to assessing the accuracy and variability in an estimate of population abundance and, by extension, standardizing how management priorities are determined (see below).

Imperfect detection is essentially the inability to detect or correctly identify birds that are present (e.g., Lynch 1995, MacKenzie et al. 2002), or recording birds as detected when they are not actually present. As a result, this error or bias is introduced into the data analysis. Bias in data collection is considered a systematic error that can result in under- or overestimation of the parameter of interest, such as population abundance (Thompson 2002). Error in estimates of population abundance can subsequently influence estimates of relative risk and the prioritization of management efforts. Birds that use open areas (e.g., eastern meadowlarks [*Sturnella magna*]) might be more easily detected than species that use wooded areas (e.g., wild turkey [*Meleagris gallopavo*]), possibly resulting in higher counts for species or individuals preferring open areas (Ellingson and Lukacs 2003). Bias introduced by variability in detection due to habitat utilization might lead biologists to conclude that hazardous birds use open areas more often, or that populations using open areas are more numerous and pose a greater risk than those that use wooded areas, when the opposite could be true.

Many species hazardous to aviation are readily detectable, such as the European starling (*Sturnus vulgaris*) and rock pigeon (*Columba livia*). Still, errors can occur in estimating flock size and composition, even for the most obvious species. Factors that can influence relative numbers of observed individuals include temporal variation in flocking behavior (e.g., during breeding season), variation in individual behavior, season (e.g., leaf off versus leaf on), and response to recent management actions (Ellingson and Lukacs 2003). We caution that, without means of correcting for bias associated with imperfect detection, data obtained from avian point-transect counts will yield only an index count and cannot be used reliably to estimate risk. We discuss means of estimating detection bias in Methods of Measurement below.

Factors That Influence Accuracy

Biologists use a sample to estimate site abundance with regard to avian hazards at airports and to determine how various factors (e.g., habitat, season, detection, management) might influence those estimates and, ultimately, relative risk. One must understand what influences the quality of observation data (e.g.,

Thompson 2002, Morrison et al. 2008). First, the estimated parameter (e.g., abundance) should be unbiased or close to the true value. Second, the estimate should be precise, whereby its value fluctuates minimally over repeated samples within an ecologically important period. Both the bias and precision associated with the collected survey data will determine the validity of the estimate.

We discussed bias due to imperfect detection in the preceding section, but other factors can introduce bias or affect the variability of the survey data (i.e., precision) and possibly accuracy. For example, bird counts are affected by observer ability, observer behavior during the survey (i.e., birds attracted to or repelled by the observer), season, time of day, temperature, wind, precipitation, cloud cover, and light intensity (Rosenstock et al. 2002, Thompson 2002). In addition, the presence of predators or other disturbances, including harassment, will affect bird behavior and variability in counts. Indices of relative abundance (e.g., naive count data), which are routinely used in WHAs, can be both precise and inaccurate due to consistent bias or consistent sampling at wrong times. Subsequently, the potential for inconsistency in bias also precludes comparison of indices of relative abundance, as these data do not provide information on how bias influences the proportion of the true, undetected value (Bart and Earnst 2002). From an ecological standpoint, we will likely never know the true value for a parameter at any given time (Burnham and Anderson 1998). However, we can approximate "ecological truth" by collecting data in a manner that allows adjustment for potential biases and that minimizes variability (i.e., increases precision) in estimates of population abundance and density within habitats or time periods, whether during an ecological season or predefined period (Thompson 2002).

Bias associated with factors that can influence accuracy of survey data and that are outside the biologist's control must be reduced through careful standardization of survey methods, as noted in guidelines for avian surveys at airports (Cleary and Dolbeer 2005). Spatial and temporal distribution of the survey effort can influence the data collected, and these factors are within the control of the biologist via careful sample design (see below). Differential availability and use of a habitat by a given population or guild can introduce variability and bias into estimates of population abundance if not

accounted for in the allocation of survey effort. Compounding such biases are temporal variation in habitat availability (e.g., winter or summer, wet or dry), period of use (e.g., migration, breeding season), and variation in daily activity of species. Some species (e.g., vultures) increase their activity later in the day as thermals increase; failure to sample these populations during periods that correspond to peak activity will result in bias (Stolen 2000, Runge et al. 2009). Differences in survey data between habitats can be more of a reflection of the distribution of survey effort between habitats (including associated influences such as distance to another habitat type) or sampling time than actual differences in abundance.

We can reduce bias associated with factors outside the biologist's control with careful standardization of survey methods. Biologists can also reduce the bias of factors within their control through careful sampling design and allocation of effort to incorporate both spatial and temporal variability in the airport environment. Such efforts will improve accuracy in the quantification of use of airport and near-airport habitats by bird populations.

Methods of Measurement

After following the preceding steps, biologists will have identified the objectives of the survey, the target populations, the necessary data to be collected, and the factors that influence the accuracy of hazard quantification and subsequent calculation of risk. The design of an avian survey also requires that biologists consider the total survey effort necessary to meet objectives as well as the allocation of the survey effort in both space and time. First, the survey should adequately sample the habitats at the airport (i.e., up to 3 km [1.9 miles] from a runway edge; Fig. 14.1) and its potential attractants. We suggest that airport biologists use a geographic information system (GIS) to systematically locate observation points for the survey, spanning the airport environment, including terminal buildings and large rooftop areas. These points represent centroids of cells whose areas correspond to the estimated sighting distance for the least detectable (e.g., because of habitat use or behavior) species of concern with regard to aviation safety. In this systematic layout of sampling points, two centroids will be separated by twice the predeter-

mined sighting distance. In addition, the complexity of airport habitats and the total area of interest determine the total number of cells (i.e., general aviation airports usually require fewer points than large, Part 139–certificated airports). The goal, however, is to systematically “cover” airport habitats and abutting properties with cells identical in area.

Given the “population” of cells across the airport, several options are available to sample these cells. If habitats at the airport are represented disproportionately by areas maintained for aesthetics (e.g., wetlands, natural grasslands, or in forest), biologists might consider stratification (e.g., see Buckland et al. 2001), an approach by which cells within predefined habitats are selected for survey relative to their proportionate representation of total airport area. However, we recommend broad classifications of habitat type (e.g., rooftop, managed grassland, runway, wetland, etc.) to avoid issues with inadequate sample size. Also, because habitats at an airport might change due to development, mitigation, or management recommendations from airport biologists, stratifications might also change.

The simplest approach to provide a representative sample of airport habitats—one that does not necessitate a redesign of the sampling approach as habitats change—is a basic random sample of cells delineated across the airport (as described above). Under this approach, biologists will randomly select a total of 20 cells (or as many as possible up to 20, depending upon airport size). These 20 cells will be used for each of three daily observation periods—morning (30 min before sunrise to 1000 hours), midday (1200 to 1500 hours), and evening (1600 hours to 30 min after sunset)—that would be conducted during each season or period of interest. A survey protocol involving 20 cells allows biologists to account for variance in encounter rates and for constructing confidence intervals about mean encounter rates (e.g., Buckland et al. 2004). Survey data might reveal a sudden increase in numbers of a particular population, but whether these data reflect a pulse of birds moving through the airport or a consistent pattern of use can be discerned only through adequate survey coverage of airport habitats and frequency (see below).

Because bird movements within the airport environment vary by season (e.g., breeding periods versus migration), and because it is crucial to avoid the bias

of “pushing” birds ahead of the survey (see Buckland et al. 2001, 2004), we recommend that biologists restrict the 20 cells to those with separations of at least 500 m (1,640 feet) between centroids (depending upon minimum sighting distance and therefore cell radius). This restriction necessitates a systematic examination of the location of the 20 cells and adjustment for the distance between cells. Because the initial set of 20 cells is selected randomly, we do not foresee issues with bias due to the adjustment for cell intervals. In addition, a replacement for a cell that has restricted access (e.g., whether an official or a logistical constraint) or site conditions that prevent adequate sighting of birds (e.g., a point falling within a mature corn stand) should also be selected at random and with regard to cell radius.

We base our suggestion of 20 cells on the necessity of adequate coverage of airport habitats and the constraints of time allocation. If we assume a minimum sighting distance of 200 m (656 feet; representing the radius of a cell), a random sample of 20 cells comprises 251 ha of airport and abutting properties that are surveyed. We note that the average area for a certificated airport located in the contiguous USA is 761 ha (DeVault et al. 2012). Biologists might choose to randomly select 20 cells for observations during each season. A season represents an ecologically significant time period with respect to species typically observed at the airport or those anticipated to move through the region. Whether the same 20 cells are surveyed across seasons or sets of 20 are selected randomly for each season, we suggest that surveys proceed through a full calendar year, allowing comparison of population or guild abundance estimates across seasons.

Biologists are interested in discerning how a population is represented in various airport habitats over time, thus justifying a longer period of surveys. For most populations, airport habitats likely represent a small portion of the overall range during a given season (there will be exceptions, such as with rock pigeons; see Martin et al. 2011). The presence of members of a species in airport habitats can be considered as random, and the associated survey data can be interpreted as “use” as opposed to “occupancy” (MacKenzie 2005; see also Occupancy Models, below).

The start time per survey period and starting location will also be randomized. We assume a 3-min

observation period, meaning a subset of 20 cells can likely be surveyed, considering travel time, within 2 hr. As for survey effort within season, we base our recommendation on that of MacKenzie and Royle (2005), who suggest that sampling units (cells) be surveyed a minimum of three times within a season when detection probability for a species is >50% per survey. In an airport environment, considering that data from multiple species with different detection probabilities will be obtained, we recommend that biologists plan for a minimum of three surveys per month.

After designing and allocating the survey, biologists collect data in the field. In practice, biologists start at the first cell (randomly selected from the sample of 20 cells), prepare binoculars and data sheet, spend 3 min observing the area around the centroid up to the maximum predefined radius, and record any birds that are seen. We do not recommend using aural detection at airports (i.e., identifying birds by song or call), because noise interference inevitably affects detection of sound intensity (energy content of the call or song), pitch (song frequency), or modulation (variation in pitch or intensity; see Alldredge et al. 2007, and citations therein). If a bird or flock is first detected aurally and confirmed visually to be within the cell bounds, however, that observation should be recorded. The biologists should also consider recording an activity code (e.g., loafing or foraging) for the observation, so as to inform potential hazard management decisions within the area of the cell.

The 3-min observation period minimizes the potential evasive movements and avoidance of the area by birds and attraction to the observer (e.g., some members of Corvidae; Scott and Ramsey 1981; see also Rosenstock et al. 2002). The observer should then move directly to the next preselected cell (based on proximity), maintaining as best as possible a consistent time interval between cells. We stress that surveys should never be conducted from within a vehicle (as per Cleary and Dolbeer 2005), as doing so inhibits visibility of the entire cell, thus increasing bias due to imperfect detection.

When biologists record observations from a specific centroid, it is assumed that the birds are associated with the cell bounding that observation point (i.e., observations of birds outside the immediate bounds of the cell are recorded as incidental). But not every bird

or flock observed will be on the ground within the cell. For birds that are flying and deemed to be using the habitat within the cell, assuming a vertical extension of the bounds of the cell (e.g., birds entering the cell volume to land; raptors hovering over prey), the observations are recorded as if the birds were on the ground. If possible, the observer should also estimate the birds' altitude using the height of features at the airport (e.g., the control tower; Hoover and Morrison 2005) as reference points. We acknowledge that such estimates might be possible only for flocks entering the cell at relatively low altitudes (e.g., ≤ 30.5 m [100 feet]). Soaring raptors and vultures often fly at altitudes that are impossible to associate with a specific airport habitat; such observations should, however, be recorded as incidental to the primary survey data. Although altitude estimates are not components of population abundance estimates, these data can prove useful with regard to enhancing the spatial component of risk assessments.

As noted above, biologists generally record individual birds and flocks, including numbers of individuals within the flocks, as part of a species or guild. In some analytical approaches, particularly the Program Distance approach (Buckland et al. 2001; see below), analyses are based on either individuals or clusters (e.g., flocks). Animals behaving in groups, such as flocks, cannot be considered independent observations in subsequent analyses. When observing flocks, biologists record the number of birds within a flock only if the flock center lies within the cell area; if some individuals of the flock lie within the cell area but the flock's center lies beyond it, biologists record these data as incidental, and they should not be used in analyses (see Buckland et al. 2001). Birds noted during travel between points also should be recorded separately as incidental (Hutto et al. 1986).

In the event that biologists must react to a hazardous situation during the survey, including the need to disperse birds in the path of an approaching aircraft, data for the cells close enough for the birds to be affected by the disturbance should be noted as "missing," and the reason should be stated (see example in Table 14.1). Importantly, biologists should not record "zero birds" due to dispersal activities, as a "zero" represents actual data and has bearing on population or guild abundance estimates. Any increase in missing data due

Table 14.1. Sample data sheet for conducting an airport avian survey.

Date	Time	Cell	Habitat	Species ^a	Cluster size ^b	Comments
1 September 2013	1622	1	–	–	0	No birds.
1 September 2013	1630	2	Grass	EUST	20	Multiple flocks in area.
1 September 2013	1630	2	Grass	EUST	10	After count, dispersed flock as aircraft approached.
1 September 2013	1640	3	Grass	EUST	(10) ^c	Same flock as dispersed from cell 2; do not use for density.
1 September 2013	1650	4	–	Gull	Missing	Dispersal action necessary before count.

^aIndicate the species by using a four-letter code for the common name (e.g., EUST for European starling), or by listing the guild category (e.g., blackbirds, starlings) if the bird species is not identifiable.

^bList the number of individual birds observed as the cluster size. Such grouping data are used in analyses of density (see Buckland et al. 1993).

^cIdentify observations that might confound estimates of density, such as birds moving in response to the observer (noted here by parentheses).

to hazard mitigation should be offset by an increase in sampling effort.

Data Management and Analysis

Even when the objectives and target populations are clearly defined and suitable data with required accuracy are collected using appropriate methods, spurious conclusions and recommendations are possible if improper data management and analysis procedures are used. Survey data should be recorded to a spreadsheet or database as soon as possible following a survey (Table 14.1). We suggest that observations also include the appropriate family category (i.e., American Ornithologists' Union classifications) or a guild category reflecting birds documented as hazardous to aircraft (Dolbeer et al. 2010; Table 14.1). Each line of data for an observation will include the cell number, flock size (i.e., the number of individuals within the flock), population or guild, survey time, and date. These raw survey data are then available for a basic descriptive analysis that reflects an index of abundance (i.e., the total number of detections or frequency of detections) unadjusted for error (Burnham 1981; Buckland et al. 1993; Anderson 2001, 2003; see also Rosenstock et al. 2002). Observers can calculate the index for each population or guild by period and habitat, or both. Again, we caution that formal conclusions about relative habitat use by different populations or guilds or about relative abundance should not be based on raw or naive count data alone. We agree with Burnham (1981) that using the count of birds per unit effort as an index of abundance does not provide a scientifically sound or reliable estimate of abundance.

Several analytical options are available that incorporate detection histories, given attention to potential biases in survey design and conduct, and the assumptions associated with the particular analysis used to estimate population abundance (e.g., distance sampling; Buckland et al. 1993, 2001, 2004; modeling based on the relationship between detection probability and abundance distributions; Royle and Nichols 2003). These methods allow biologists to build on information gleaned from naive count data obtained from a well-designed survey to discern patterns of use relative to probability distributions. The Double Sampling approach for estimating population density, advocated and described in detail by Bart and Earnst (2002), gives density (D) as the number of individuals (N) observed per unit area (A); or $D = N/A$, if we assume all animals are detected. Because detection is rarely perfect, however, biologists must correct the number of observed individuals to account for missed detections in order to produce an unbiased estimate of density. Density estimation is a departure from the common practice of using naive WHA counts at airports (Cleary and Dolbeer 2005, Schafer et al. 2007).

Under the Double Sampling method, biologists use the sampling approach described above as an initial "rapid" survey. In addition, they choose six of the 20 randomly selected cells (described in Methods of Measurement, above) for an intensive survey to be conducted soon after the previous rapid survey. The intensive survey entails a systematic "walk-through" of the fixed-radius cell, noting all birds or flocks observed in the cell (as described above) or flushed from within the cell. The intensive survey data represent the actual number of birds using the cell at that time. The esti-

mate of density (D) is obtained as per Bart and Earnst (2002):

$$D = (\bar{x}') / (\bar{x} / \bar{y}),$$

where \bar{x}' represents the mean number of birds or flocks of a particular population or guild recorded per cell during the rapid survey; \bar{x} is the mean number of birds recorded per cell across the subsample of six cells during the rapid survey; and \bar{y} is the mean number of birds actually present per cell across the subsample of six cells (i.e., counted during the intensive survey). This approach works best when results from the rapid survey are highly correlated with actual density. Specifically, if \bar{y} is biased, then D will also be biased. We recommend that the intensive survey be conducted immediately following the rapid survey.

The ratio of the mean count per cell in the subsample obtained during the rapid survey to the actual mean density as determined via the intensive survey of the cells in the subsample is used to adjust the results from the rapid survey. Bart and Earnst (2002) provide further detail about estimating standard errors about D , precision of the index ratio (\bar{x} / \bar{y}) in the subsample, and incorporating cost estimates. Although Bart and Earnst (2002) note that for their study the surveyors conducting rapid surveys of plots included in the intensive surveys had no prior experience with the plot, such a division of duties is not logistically feasible due to the constraints associated with staffing biologists at airports. Further, the authors focused on nest detection, whereas airport biologists obtain count data of individuals and flocks within the cell. Despite these differences in the Bart and Earnst (2002) field protocol and conditions found at most airports, we contend that the Double Sampling method would enhance the accuracy of density estimates for bird populations or guilds using airport environments.

Alternative Approaches

Distance Sampling

Distance sampling uses the distance from the observation point to an individual bird or flock to estimate a detection probability, which is then used (in the Distance software package) to calculate density (Buckland et al. 1993, 2001, 2004). Distance estimates for each

bird or flock are collected at the time of observation. The collection of additional covariates such as habitat variables allows for the calculation of more accurate detection probabilities and in turn more accurate density estimates. Covariates may be collected at the time of observation or at a later date using GIS or other stored data sets. Distance sampling requires few extra resources when compared to naive counts, but relies on several assumptions:

1. Objects at the line or point are detected with certainty. This assumption should be achievable in the airport environment, except under special circumstances such as species emitting calls only out of the observer's line of sight when noise interference is high.
2. Objects do not move in response to the observer or before detection, an assumption that can be met with proper field protocols such as undisturptive movements to and from survey locations. Additionally, if survey periods are kept short (e.g., ≤ 5 min), birds are not likely to move.
3. Distance measurements are exact. With the aid of laser range finders and given that most detections at airports are visual, this assumption is achievable. Furthermore, if cells have a small area, distances will be truncated to reduce bias. We recommend taking a spot-mapping approach, where bird locations are placed on an aerial image (or a map produced via the GIS; noted above) and relative to the transect or point to aid in distance calculations.

As noted above with regard to birds aerially foraging over sampled habitat, one must assume a vertical extension from the bird to a point on or off the line (noted by the observer relative to a particular landscape feature). The distance to that point from the line is then measured as described above.

Distance sampling can be a robust approach to estimating abundance or density for birds. In general, however, >60 observations are needed for each population or guild to gain reliable density estimates (Buckland et al. 2001). Alldredge et al. (2007) provide an applicable approach for combining multiple populations or guilds into a common framework to produce more reliable estimates for those groups lacking suf-

ficient data to be modeled alone. This approach holds promise if distance sampling is used in the airport environment.

Mark-Recapture Approaches and Extensions

Mark-recapture methods using marked animals (e.g., bands) are not feasible for airport monitoring, but extensions to the mark-recapture framework that involve indirect "marking" and "recapturing" are feasible. These are based on repeated or replicated observations and are used to estimate detection probabilities. Multiple observer methods make use of two or more observers working either independently or collaboratively to account for individuals missed by each observer (Nichols et al. 2000). Removal models delineate the survey into distinct time periods (e.g., 0–3, 4–5 min) and use detections (i.e., captures) within time periods to develop a capture history across the entire sampling unit (Farnsworth et al. 2002). Time-to-detection methods use multiple, discrete vocalizations of individuals to develop a detection probability within a mark-recapture framework (Allredge et al. 2007). There are many combination methods that attempt to further refine estimation of density, as well (e.g., double-observer distance sampling). The removal and time-to-detection methods are advantageous when estimating availability probabilities is needed (Diefenbach et al. 2007). Such cases are likely rare, considering again that we suggest visual detections in the airport environment. For species of conservation concern, such as some grassland birds, collecting data in a manner consistent with removal and time-to-detection models would be prudent, especially considering that this approach requires very little extra effort.

Occupancy Models

Occupancy sampling and modeling is an approach that uses repeated (more than two) observations of sites (e.g., cells) to estimate the state parameter (e.g., probability of occupancy, abundance) and the observation process (i.e., detection probability; MacKenzie et al. 2002). The simplest form of occupancy sampling is presence/absence data; however, these methods have been extended to model abundance (Royle and Nichols 2003). These methods can also be used to model

resource use depending on objectives and the assumptions of the sampling endeavor. The main advantage of these general classes of models is their overall flexible utility and intuitive interpretation. The major disadvantage is the necessity to repeat surveys, which increases effort. Not all surveys must be repeated, however. For example, if 20 cells are to be sampled, only 10 might need to be repeated. Additionally, stopping rules can be initiated when animals are detected, further reducing effort. The number of repeated surveys is negatively correlated with detection probability and probability of occupancy. Mackenzie and Royle (2005) provide a thorough treatise on survey allocation and design. In general, for highly detectable species, two to three survey occasions are needed for reliable estimates per season. If multiple ecologically relevant seasons exist (e.g., breeding and nonbreeding), it will be necessary to sample within each season.

Strike Risk

Once estimates of population or guild densities relative to habitat (e.g., short grass) and time period (e.g., breeding season, migration) have been obtained, biologists can more accurately quantify relative hazard. But we contend that quantification of hazards alone is inferior as a means of prioritizing management goals, because it does not account for the likelihood that a hazardous bird will be struck or for the damage caused by that strike, and one should not assume local population density to be correlated directly and positively with the probability of a bird being struck. In most cases we would not expect snow geese (*Anser caerulescense*) to be as locally dense as savannah sparrows (*Passerculus sandwichensis*), yet between 1990 and 2007, 68 strikes of snow geese were reported to the FAA (Dolbeer et al. 2010). Of those strikes, 78% caused damage, 38% had a negative effect on flight, and 54% involved strikes of more than one animal (Dolbeer and Wright 2009). Based on these data, snow geese were ranked as the third most hazardous wildlife species struck by aircraft and the most hazardous bird species struck. In contrast, for the same time period, 68 strikes of savannah sparrows were reported; of those strikes, 1% caused damage, 0% had a negative effect on flight, and only 7% involved strikes of more than one animal (see also DeVault et al. 2011).

We suggest that effective prioritization of population management at airports entails an assessment of the risk of damage from wildlife strikes (see Schafer et al. 2007). In this context, a risk assessment would reflect an estimate of a population's frequency of occurrence within critical locations at and near the airport (see also Martin et al. 2011) and associated strike damage metrics. A risk assessment has the following components (Graham et al. 1991): (1) a conceptual understanding of the sources of the problem (e.g., habitat attractive to hazardous wildlife at and near the airport); (2) realistic end points or potential events (e.g., a hull loss; Dolbeer et al. 2000, 2010); (3) mechanisms by which the sources contribute to the defined end points (e.g., is substantial strike damage related to a particular aircraft type or species struck at the airport?); (4) a spatiotemporal estimate of exposure to the problem sources (population or guild density data by habitat and time obtained via the avian survey); and (5) a quantification of potential effects (i.e., the calculation of risk based on components 1–4). Again, in the context of airports, seasonal demographic cycles of populations using particular habitats (e.g., agriculture near an airport) should be evaluated relative to population density estimates within critical airspace to better discern the contribution of habitat to bird-strike risk (Baxter and Robinson 2007). The bird-strike risk assessment should include, at a minimum, population or guild density estimates from the survey and associated strike statistics for those guilds, such as strike frequency for the specific airport and associated damage or damage statistics from the FAA (see Blackwell et al. 2009, DeVault et al. 2011). Other components might include data on aircraft types serviced by the airport and number of aircraft movements relative to seasonal abundance estimates of hazardous populations, as well as spatiotemporal associations of populations (Martin et al. 2011) and aircraft movements relative to altitude (J. Belant and J. Martin, unpublished data). In its most basic format (i.e., without incorporation of concurrent data on aircraft movements and spatiotemporal aspects of bird use of the AOA), however, risk can be expressed as the product of the relative frequency of each guild (i.e., its seasonal density estimate) and the proportion of bird strikes involving the guild that have resulted in damage to aircraft (across U.S. civil airports and civil aircraft).

Summary

We have purposely focused our recommendations on the quantitative aspects associated with design and conduct of an avian survey, with unique application to the airport environment. We have stressed the need for survey data to be ecologically relevant and accurate, such that management guidelines are based on defensible data. However, "real world" issues—regulatory, labor, and financial constraints, as well as the dynamics of airport environments—will inevitably influence survey methods. Though we do not advocate the use of naive count data in estimating relative abundance or habitat use, for example, we recognize that animal observations obtained by airport biologists outside of a standardized sampling protocol are important for identifying potential hazards to aviation safety. We recommend developing training materials for airport biologists that incorporate information provided in this chapter relative to constraints affecting survey design and conduct, so as to move effectively from concept to practice.

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