BIRD & WILDLIFE PATTERNS AT SEATAC AIRPORT UTILIZING A FOREIGN OBJECT DEBRIS DETECTION SYSTEM

by

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ABSTRACT

Bird & Wildlife Patterns at SeaTac Airport Utilizing a FOD Detection System

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Since 1990, 143,000 reported wildlife-civil aircraft strikes have occurred in the United States. These strikes have resulted in 26 human fatalities, 174 injuries, 66 destroyed aircraft, and billions of dollars in damages. Birds and wildlife account for nearly 40% of all foreign object debris (FOD) incidents and pose a risk to both themselves and humans. New radar technologies to detect FOD are rapidly developing to replace human observation as the primary detection method. As part of the wildlife management program at Seattle-Tacoma International Airport (SEA), a FOD radar system was installed to generate a better understanding of bird and wildlife patterns and to mitigate strikes. To determine the capabilities of FOD radar, data analyses from a recently installed system SEA found large numbers of birds (n=668) and wildlife (n=4,072), which includes insects, along the center runway over a nine-month period. The current years strike database also indicates a low number of strikes (n=52) compared with the average yearly count (n=101) from 2005-2016 and the lowest in a decade. This low number suggests FOD radar successfully mitigated strikes at SEA and the collected data is useful in actively guiding future management plans.

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Introduction

Wildlife and airports have a complicated relationship. Airports are appealing to birds and wildlife for a variety of reasons. they are often located in open, flat areas, close to major rivers or water sources, providing habitat for many species. Migration paths can cross airports and be seen as an appropriate location for a feeding stop. Airports may also lie adjacent to important bird and mammal habitat, causing crossover as species move around airports.

In contrast, the threat of birds and wildlife mixing with aircraft has proven to be a recipe for disaster. In 2009, an incident involving US Airways Flight 1549, which collided with a flock of geese shortly after takeoff, resulted in loss of thrust in both engines. The pilot safely landed the aircraft in the Hudson River, preserving the life of the 150 passengers[1]. While this was not the first account of a major strike incident between birds and aircraft, it was widely reported and garnered nationwide attention. This has led to a wider awareness of the need for mitigation strategies to limit bird and wildlife interactions with aircraft.

Many steps have since been taken to minimize the impact of birds and wildlife on the aviation industry: wildlife management practices such as hazing birds, restricting entrance through fencing, and changing the physical landscape of airports through modifying grasses, covering water sources, and proper grading to reduce runoff pools. Airports have also implemented technology to provide constant monitoring of bird and wildlife movements. As the field of airport wildlife management continues to grow, The

[1] US Airways Flight 1549 was a bird strike incident that received significant media attention. Since the event, multiple books and feature films detailing the incident have been released. The complete details of the strike and crash can be found at the National Transportation Safety Board website http://www.ntsb.gov/investigations/AccidentReports/Pages/AAR1003.aspx

Port of Seattle's Seattle-Tacoma International Airport (SEA) is taking strides to remain ahead of the curve. In late 2015, SEA installed a radar system to detect and deter birds and wildlife on their center runway.

This thesis provides an analysis of the bird and wildlife distribution along the center runway, as well as an assessment of the ability of the radar system to mitigate strikes between aircraft and birds. This analysis will be conducted with data collected and documented by the Xsight FODetect radar system and Airport Operations (AO) and the (FAA) strike database. Preliminary results suggest that the radar system will reduce strikes

Seattle-Tacoma International Airport

SEA became the first airport to hire a full-time wildlife biologist in 1970s with the aim of developing an ecological approach to airport wildlife management. With its wide-open spaces and buffer areas, SEA is an appealing habitat to wildlife. Identifying and eliminating specific wildlife attractants is key to wildlife management. The airport currently employs a comprehensive wildlife management program to deter wildlife from congregating on site. In terms of runway safety, one of the most recent wildlife management tools employed by SEA is installation and use of a foreign object debris (FOD) radar system along the center runway (Appendix 1). These radar systems were installed to identify both wildlife and non-wildlife threats on and along the runway. On January 1, 2016, SEA officially became the second U.S. airport to utilize FODetect radar systems; the installation of FODetect coincides with the center runway project and seeks to increase foreign object debris (FOD) awareness.

The need for a constant runway monitoring stems from the high volume seen at the airport. SEA runs 855 daily operations with over 42 million passengers arriving and departing in 2015, an increase of 12.9 percent over 2014. These large numbers have resulted in SEA being ranked the 13th busiest U.S. airport by passengers in 2014. Operationally, SEA was ranked as the 22nd busiest U.S. commercial service airport in 2013 (Port of Seattle, 2015). Frequent air traffic also requires that SEA maintain the highest level of operations efficiency and safety. In order to increase aviation safety, developing an understanding SEA's attraction to wildlife is important.

This understanding of the attractiveness is one that has long been underway for the wildlife team at SEA, as they have developed an extensive management plan (Port of Seattle, 2004). This plan lays out ways for the airport and the wildlife team to manage and modify the attractants on Port of Seattle (POS)-owned land as well as their strategies for working with non-POS land owners in the area. The management plan also involves an in-depth description of the airport ecosystem and coinciding management practices: airfield structures, airport building projects, abandoned structures, non-airport land-use projects, water management, wetlands, lakes, stormwater and temporary pools, vegetation management, streamside vegetation, grass types and management, ornamental landscaping, and food/prey-base management. The document also includes a priority timeline for management projects. A tool of this sort would be beneficial to all airports as it describes the bird and wildlife attractants and strategies for reducing the airport's appeal.

Wildlife Foreign Object Debris

Foreign object debris (FOD) can be defined as any object in an inappropriate location that may cause damage or injury to aircraft, equipment, and airport personnel. Items often identified as FOD include rocks, loose hardware, chunks of pavement, cargo, sand, and wildlife. These items may cause damage from direct contact with aircraft, including window and body collisions or from intake into the jet engines, resulting in a variety of damage. Between 2000 and 2013, wildlife FOD resulted in 66 destroyed civil aircraft, 26 human deaths, 174 injuries to passengers and grounds crew, thousands of dead wildlife, billions of dollars in damages, and millions of hours in aircraft downtime. With this threat constantly lingering at SEA, the wildlife staff has been active in limiting bird and wildlife presence at the airport and FODetect is the most recent line of defense in mitigating bird and wildlife strikes with aircraft. They believe this will help them further develop methods for understanding the patterns of birds and wildlife along the center runway.

Xsight's FODetect

FODetect hybrid radar systems use Surface Detection Units (SDU) that utilize both a radar and camera unit to identify objects on and near runways. In general terms, radar works by sending out pulses of radio waves, which bounce off an object and return to the point of origin. Based on how long it takes for the signal to come back from the object, the user can determine the shape of the object and distance from the source. This system functions at 77 GHz, which is considered highly accurate and uses a greater bandwidth or increased object detectability and resolution. The radar unit sends a constant stream of information, with the ability to conduct a full 360° scan of the runway and the field areas alongside, while identifying objects and alerting staff of potential threats. As part of the Federal Aviation Administration's (FAA) regulations on FOD monitoring, the airport staff conduct three daily FOD checks (two more than the FAA requires). This system adds another layer of protection and efficiency with its constant scan.

A key feature of FODetect is the ability to detect birds and other wildlife. It utilizes Xsight Systems BirdWize and alerts Aviation Operations (AO) of potential threats. To increase accuracy, the system uses both a radar algorithm and image processing software to detect FOD at close-range. When an object is detected, an alarm triggers AO crews who use the unit's camera to determine threat level and whether or not further action is required (Appendix 2). If further action is required, the AO crew takes the necessary steps to ensure safe paths for aircraft. This may involve rerouting landings to different runways or sending out crewmembers to handle FOD cleanup. The system also includes a sound generator to startle birds and other wildlife.

A Review of the Literature

Introduction

Literature regarding wildlife at airports has broadly focused on management and threats to aircraft. Current findings in this research describe best practices in order to reduce wildlife populations at and around airports. While much has been explored in these areas, literature on monitoring and mitigating wildlife FOD leaves much to be desired. Since the use of radar to detect FOD on runways is a fairly recent trend, the established research focuses on the detection range and proposals for improved equipment, rather than the effectiveness of the system to deter strikes. Current and increased emphasis on FOD detection has led to the FAA creating requirements for FOD technology systems in 2009.

The two most significant factors driving the increased interest of FOD detection technologies have been the safety threats to humans, birds, and wildlife and the economic impact to the aviation industry. Bird and wildlife FOD have been present on the radar since the 2009 incident with US Airways Flight 1549 and the new technologies being rolled out seek to minimize the significant events involving bird and wildlife interactions with aircraft. Reducing these events will not only increase aviation safety, it will also reduce the major economic impacts these strikes present.

The technology currently employed at SEA is a hybrid system combining radar and optical features. It is automated but allows for complete control by an operator and serves as a constant set of eyes on the runway. While the FAA produced a study assessing FODetect’s ability to detect FOD on runways, the study neglected the system’s ability to detect and mitigate potential wildlife FOD in the field areas near runways. Much is desired in the understanding of how FOD radar will serve its purpose at airports and to what degree it is capable of performing. This study will provide the data and analysis needed to fill in the gap left by the current bird and wildlife FOD studies.

This literature review summarizes and examines the available literature as it pertains to wildlife management and wildlife threats to aviation safety and how the development of technologies assists in mitigating wildlife strikes. While current management trends provide means of limiting wildlife at airports, reducing wildlife access to airports required constant adaptations and modifications. The issue of wildlife-aircraft strikes with an emphasis on birds will also be explored. Economic impacts to the aviation industry will be examined, as will current wildlife radar uses, and the abilities of FOD detection systems. It is also important to address the viability of human observation of FOD near runways to illustrate the potential for FOD detection technology to increase awareness of wildlife near runways.

Habitat and Wildlife Management at Airports

The Port of Seattle owns SEA property and the Port of Seattle’s Century Agenda (2012) was to become the greenest, cleanest, and most energy efficient port in the nation. With its wide open spaces and buffer areas, SEA is an appealing habitat for wildlife. Identifying and eliminating specific wildlife attractants is key to wildlife management. The airport currently employs a comprehensive wildlife management program to deter wildlife from congregating on site. According to the Port of Seattle’s wildlife management plan (2004), guided by several federal regulations, a variety of management practices are employed. Coyotes, dogs, deer, and other large mammals are physically excluded by fencing. However, this has minimal effect on small mammal and avian populations. Some daily airport activity, such as driving on the infields between runways, has resulted in temporary pools during times of precipitation, leading to increased duck and shorebird populations. SEA currently plans for these areas to be graded for water runoff (SEA, 2004). Nearby attractants are covered with netting to eliminate waterfowl congregations.

In order to reduce wildlife strikes, understanding the complexities of wildlife and the attractants luring them to airports is vital. One of the first steps in managing wildlife is recognizing wildlife movements, which vary daily, seasonally, and annually. Factors that contribute to variation range from broad biological and ecological characteristics such as migration, foraging, and habitat preferences (Belant, Washburn, & DeVault, 2013). Belant et al. (2013) also suggest five categories of animal movements including foraging, dispersal, migration, movement to rest locations, and territorial defense. Movements may also be dictated by resource abundance (Fretwell & Lucas, 1970) and/or niche filling (Krebs, 2001). Species will often follow the movement of prey or spread out to fill a niche in ecosystems, which may allow for successful population movements.

Lower altitude strikes with birds may result as aircraft are in the direct flight path of species known to quickly fly through lower elevations of their habitat (Klem, 1990, Klem 2010, Bayne et al., 2012). One contributing factor to bird strikes in this area involves spooked flight, which occurs when birds are startled by aircraft or loud noises. Along with spooked flight, play flight—in which birds chase one another, resulting in erratic, frantic flight paths—is likely to contribute to strikes. In more recent years, commercial aircraft have turned to quieter two-engine aircraft, moving away from three to four-engine aircraft. Two-engine aircraft, while quieter and more reliable, are also more vulnerable to the issues brought about by multiple ingestion events, much like the US Airways Flight 1549 incident.

These quieter engines may result in bird and wildlife's lack of awareness of oncoming aircraft (FAA, 2013). Past experiments involving engine recording playbacks have shown birds and wildlife would need a greater escape distance from the newer, quieter, and faster engines than the previously used and noisier engines (Solman, 1981). While some species may not be affected by aircraft noise, others may not be able to distinguish incoming aircraft from background noise at airports (Conomy et al. 1998).

As part of SEA's management plan (2004), the grass around runways and taxiway markers must be kept at a 3-inch maximum height. An abundance of grasshoppers is often found in the area, which are seen as a wildlife attractant, particularly to crows (*Corvus brachyrhynchos*) and raptors (SEA, 2004). Reducing the height of grass by mowing should serve to reduce grasshopper populations by limiting their preferred habitat of taller grass. Airport biologists believe mowing itself to be an attractant as it opens up food sources, revealing available food sources. It has been reported (Buckley and McCarthy, 1994) that laughing gulls (*Larus atricilla*) at John F. Kennedy International Airport in New York only fed on Oriental Beatles (*Anomala orientalis*) in areas with shortgrass, even though the abundance was equal in tallgrass areas, suggesting that food availability rather than food abundance is key to habitat use. Also supporting availability over abundance is the use of shortgrass areas by red-tailed hawks (*Buteo jamaicensis*) and rough-legged hawks (*B. lagopus*) to prey on meadow voles (*Microtus* *pennyslvanicus*) even though population densities in shortgrass are far less rich (Baker & Brooks, 1981). Thus, mowing is prescribed at times when birds are most inactive.

Monitoring wildlife attractants such as insects, trash, and debris is a constant activity at SEA. These types of attractants often bring in crows, European starlings (*Sturnus vulgaris*), raptors and waterfowl. SEA also has a well-established raptor monitoring and relocation program (Raptor Strike Avoidance Program) to remove potential threats from the airfield (Anderson & Osmek, 2005). Pesticides are used in instances where other methods for controlling insect, weed, small mammal, and some bird populations are exhausted. Grass seeds that are known to be unattractive to many avian species are also used as a means of reducing bird populations (SEA, 2004).

The above mentioned practices of SEA have also been recommended by many experts (Blackwell, DeVault, Fernandez-Juricic, & Dolbeer, 2009; Cleary & Dolbeer, 2005; DeVault, Belant, Blackwell, & Seamans, 2011; Cleary, Dolbeer, & Wright, 2006), though a single recipe for management across all airports is unrealistic. Emphasis on habitat management, reduction of attractants, implementation of deterrents, and the hazing and harassing of bird species are common management recommendations. Along with these practices, it is also recommended that survey data of species be used to identify management priorities and thus reduce hazards to aviation safety (Blackwell, Schmidt, & Martin, 2013). Sufficient survey data can be used in the development of runway protection zones, which allow for targeted methods of wildlife management for particular species.

Wildlife Threats to Aircraft

Wildlife, particularly birds, have been a threat to aircraft since humans first took to the sky, with the first strike being recorded by Orville Wright in 1908 and the first death from a strike occurring four years later (Thorpe, 2003). While strikes with wildlife do not always result in damage to aircraft or human injuries, predictions suggest increased frequencies in airplane/wildlife strikes (Coccon, Zucchetta, Bossi, Borrotti, Torricelli, & Franzoi, 2015). The FAA has also predicted an average increase of passenger growth by 2.1% per year over the next 20 years though the fleet growth is minimal at just 0.02% a year. However, with this minimal increase in fleet growth, aviation hours are projected at an average increase rate of 1.2% per year (FAA Aerospace Forecast, 2016).

A massive increase of reported bird and wildlife strikes can be seen in the FAA's strike database. In 1990, 1,851 wildlife strikes were reported, while 2013 had 11,315 reported strikes. This can be attributed in part to a general rise in reporting, however researchers have found that roughly 25% of all wildlife strikes are reported and attribute low reporting percentages to the pilot or aviation operators not knowing a strike occurred or to avoid logistical inconveniences (Cleary at al., 2006; Dolbeer & Wright, 2009; Linnell, Conover, & Ohashi, 1996, 1999).

The physical characteristics of airports can also contribute to strike occurrence. It has been found that wildlife threats are common at airports with expansive grasslands (Dolbeer, 2000) and SEA fits this criterion. Beyond the physical characteristics contributing to strikes, Cleary et al. (2006) found that increased populations, in part from conservation efforts, has magnified wildlife threats to aircraft. Dolbeer and Eschenfelder (2003) also highlighted rising populations of species that pose a higher level of threat due to their body size (greater than 8 pounds). Using physics, one can determine the amount of energy a bird of this weight would transfer to the airplane by squaring the speed difference. As the weight increases, so does the energy. Measuring force is more dynamic as the amount of time the bird is in contact with the aircraft is considered in this equation.

Not all birds and wildlife are considered a major threat to an aircraft and there is a broad range of threat levels posed by individual species. When assessing the risks associated with wildlife species, Dolbeer et al. (2000) used 21 species or species groups that had 17 or more strikes from 1993-1998. Three variables (percent of strikes causing damage, major damage, and effect-on-flight) were determined to assess wildlife threat risks. The species listed as most hazardous to aircraft were artiodactyls (mostly deer) and large birds such as vultures (Cathartidae), geese (primarily *Branta canadensis*), hawks, and eagles. The species with the least risk were typically smaller avian species such as sparrows (Emberizidae), swallows (Hirundidae), and blackbirds-starlings (Icterinae-*Sturnus vulgaris*). It is important to note that deer and vultures, both posing high risks were also lower in strike percentage than many of the other species. While those on the lower end of the spectrum were smaller in size, they accounted for a larger strike percentage, illustrating their hazard to aircraft.

Though strikes rarely result in injury or death to humans, there have been instances of human fatalities. In 1962, a flight departing from Boston's Logan Airport struck a flock of European starlings, resulting in 62 human fatalities (USDA, 2012). In Ethiopia, 35 human fatalities were attributed to flocks of speckled pigeons (*Columba* *guinea*) and starlings in 1988 (Dolbeer et al., 2000). Globally, the FAA reports that since 1988, over 255 human fatalities have occurred and over 243 aircraft have been destroyed from wildlife strikes. SEA's wildlife biologist Steve Osmek stated that over 40% off all FOD damage is caused by wildlife (S. Oskmek, personal communication, May 2015).

An assessment of bird strikes on aircraft found that 66% of damaging strikes occurred at or below 500 feet. This range also was more likely to see strikes with raptors, gulls, passerines, pigeons and doves (Dolbeer, 2006). In the report, it was also stated that the months from July to October were the most common with strikes at or below 500 feet in altitude.

Economic Impacts of Strikes to Aviation Industry

The estimated economic impacts from wildlife strikes vary and have been estimated between $500 million (Cleary et al., 2004) to over $718 million per year by the FAA (USDA, 2012). Civil aircraft downtime hours associated with reported strikes from 1990-2013 ranged from 55.6 to 388.4 and showed a mean of 119.4 hours. Repair costs and other associated costs averaged at $167,100 and $29,852 respectively per report. In total, there were 13,497 reports that listed damage (Dolbeer, Wright, Weller, & Begier, 2014).

Avian Monitoring with Radar at Airports

A variety of radar sensors are used to monitor birds: tracking radar, weather surveillance radar, terminal Doppler weather radar, and high-resolution marine surveillance radars have been used in ornithology to gather detailed flight patterns including migration and foraging as well as population densities (Gauthreaux & Schmidt, 2013). This information can be used to guide specific management practices in anticipation of and to mitigate specific behaviors. SEA currently employs three avian radar (Sicom-Accipiter®) systems to detect potential wildlife hazards with a constant focus on attractant areas. The radar can also scan upwards and outwards to a degree that human observation cannot provide. These radar systems were installed prior to FODetect, which has just begun scanning the center runway.

In 2004, the FAA began a program evaluating FOD detection systems (FAA, 2012). During 2007, the University of Illinois Center of Excellence for Airport Technology (CEAT), which is part of the FAA's Airport Technology and Development Program, developed a performance assessment and the sensors were installed at Boston Logan International Airport (BOS) in 2008. The system, FODetect, is developed by XSight Systems, Ltd and was recently installed at SEA. The study assessed four major categories and several subcategories, the first being basic functions. Under the umbrella of detection performance was object detection, location accuracy, inspection frequency, detection response time, surveillance area, and performance in weather. System performance addressed alerts and alarms while system output covered detection data, data presentation, and data management. Each of these categories are connected with performance standards that must be met to be considered for use on the runway.

Selected targets evaluated consistency of the radar and optical target. Ten sensors were installed, five on each side of the runway and they performed a paired scan of the 150-ft wide runway (Hericks, Woodworth, & Patterson, 2012). Performance tests conducted in daylight hours on dry pavement in 2011 showed 100% detection rates and FODetect was able to identify two small items roughly 6 inches apart. Tests on the sensor provided results of initial object detection of 94% with an increase to 98% detection after use of the camera. Average detection time was 60 seconds but were as low as roughly 30 seconds in some instances. Data alerts were found to be manageable with an Xsight developed toolbox. The capabilities included location of FOD object, images of detected FOD, image and video playback, current status (detected, confirmed, and retrieved), and description of retrieved FOD (size, color, and category). The performance assessment found that FODetect met the FAA's "Airport Safety Self-Inspection" Advisory Circular requirements.

Avian surveying and rigorous data management can form the basis for appropriate management strategies and reduce avian threats to aviation safety (Blackwell et al., 2013). Using scientifically sound data collection methods may also be necessary to legally justify management actions, especially ones involving lethal control or in events that involve human health and safety (Reiter, Brunson, & Schmidt, 1999; Conover, 2002). Improving the validity of data involves increasing precision and reducing bias. Data that has been collected using tools to allow for precise measurements and accurate accounts, are often considered trustworthy and reliable. Biases are systematic errors that can influence the inaccuracies of survey data. Such biases may include observer ability, behaviors of observer (serving as an attractant or repellent), weather, time of day, and season (Blackwell et al., 2013). While Cleary and Dolbeer (2005) have outlined the guidelines for avian surveys at airports, Blackwell et al., (2013) have also offered strategies to improve survey accuracy. These strategies involve defining both an objective and target species but also include modeling and strike risk as important factors in analyzing survey data. However, variability and biases need to be taken into account to reduce imprecisions.

The current literature regarding FOD radar is slim and often centered on the main function of the radar itself. While these issues are important and justify the use of FOD radar, it is necessary to examine the use of FOD radar and how it may contribute to aviation safety as it relates to birds and wildlife. This thesis will address the lack of FOD radar's use in monitoring bird and wildlife along the runway by contributing a study of the impacts FOD radar has on strike mitigation. It will also provide suggestions for ways to use the data collected by the system to develop wildlife management plans as well as how to improve on data collection.

Methods

Setting and Study Area

The Port of Seattle's Seattle-Tacoma International Airport (SEA) lies in a particularly dense urban environment, situated near Puget Sound and located 12 miles south of downtown Seattle. With its wide open spaces and buffer areas, SEA is an appealing habitat to wildlife and identifying and eliminating specific wildlife attractants is key to wildlife management. The airport currently employs a comprehensive wildlife management program to deter wildlife from congregating on site. In terms of runway safety, one of the most recent wildlife management methods SEA is currently undertaking involves the installation of a foreign object debris (FOD) radar system along the entirety of the 9,426 feet long center runway. Each of the 101 radar/camera hybrid units is placed along the edge of the runway with a vertical spread of 200 feet between each unit. Spanning the width of the runway is roughly 137 feet between units. These radar systems were installed in November 2015, with the aim of identifying both wildlife and non-wildlife threats on and along the runway. The radar system officially began operations on January 1, 2016 with planned downtime in June and late September through October, 2016, during times of construction.

Methodology

The initial exploration of the data intends to identify the locations, frequencies, temporal change, and size ratings of the wildlife and birds along the center runway. Excel PivotTable analysis was used to answer the questions of monthly events, frequencies, and size range of the two categories. ArcGIS software was used to identify bird and wildlife hotspots and to differentiate the bird events by size, in order to identify individuals that are within a high-risk range and their locations on the runway.

Radar Data

A constant stream of data is made available by the automated radar system. The hybrid system uses a camera, which can be controlled by an operator, to further identify objects on the runway. In regard to objects identified by the radar off the runway, no images are automatically provided and it is required that an operator identify objects by taking control of the camera and shifting its focus. Imagery taken by the camera also displays a red rectangle to show the exact parameters that have been identified by the radar (Appendix 3). The lead wildlife biologist provided the data by exporting an Excel spreadsheet file from within the Xsight Systems FODetect software suite. The file was then converted to a comma delimited (CSV) text file, which allows data to be easily visualized and analyzed in ArcGIS software. The CSV contained a comprehensive list of criteria as identified by the radar. For the purpose of this study, only objects identified as birds or wildlife by the system or human operators were assessed.

Each sighting of an item by the radar is listed as a new event in the system. For consistency purposes, each item will be referred to as an event. The data used in this study spanned from January 1, 2016 through the morning of September 26, 2016. The month of June accounts for only four days of observation as the runway was periodically closed during this period. When determining the bird and wildlife hotspots, heat maps were generated within ArcGIS Online (AGOL) to visualize data and identify areas as high frequency event locations.

Results

Descriptive Data Analysis

The number of wildlife events between January 1 and September 26 was 4,072. On a monthly basis, the wildlife counts, including insects, remained relatively low through the winter and spring but spiked during the summer months (Figure 1).

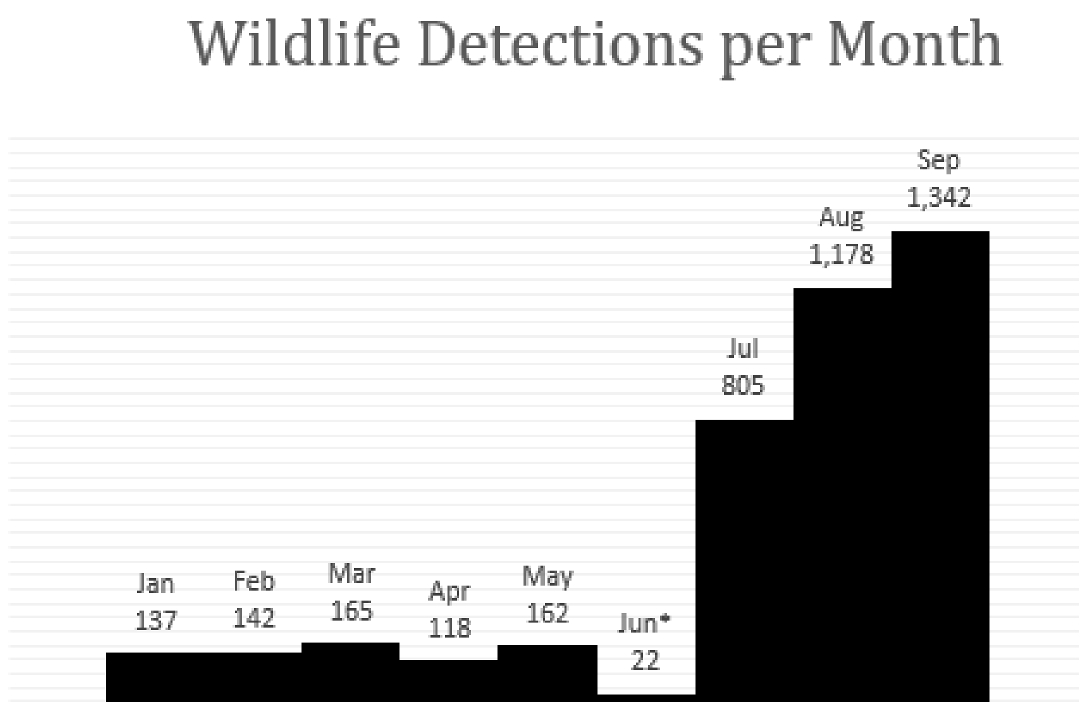

*Figure 1. Wildlife detections per month remained low through the first half of the year but quickly spiked in July (*the system was disabled for most of the month of June).*

The summer months averaged roughly 7.5 times as many events (1,108) compared to the average of winter and spring (145 excluding June). Using the system's archived images and videos, September showed an influx of Mantises (Appendix 4), which may explain the relatively low number of grasshoppers the radar and surveyors have reported this year (mantises are a natural predator of grasshoppers).

In terms of size, the average wildlife event was 1.32 in^2 (Figure 2), indicating that the majority of wildlife were likely insects (Appendix 5).

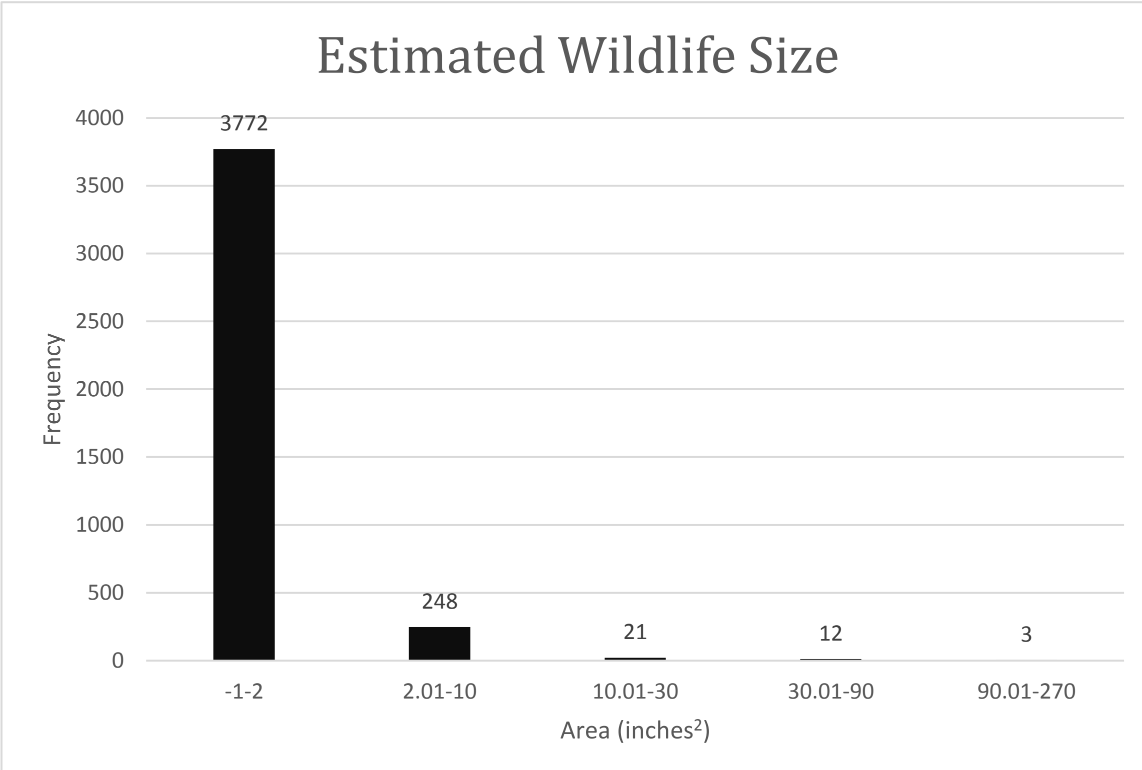

Figure 2. The size of wildlife events was mostly low and was largely made up of soft bodied insects. Some small mammals were identified and some clustering of wildlife as well as software issues accounted for outliers. Negative values can be attributed to detection box errors.

A map depicting size distribution along the runway showed the smaller size range distributed across the entirety of the runway with randomly scattered larger events

(Figure 3).

Figure 1. *Map showing size distribution along the center runway, with the largest events occurring near the center of the runway.*

Rodents and other small mammals would see a size frame of roughly 5 to 20 inches. As Belant, Washburn, & DeVault (2013) point out, understanding these changes through time will allow for better management practices and the mitigation of bird and wildlife strikes with aircraft.

Bird sightings, as determined by the system, totaled 668 events (Figure 4). In terms of monthly variance, February (129) and July (123) involved the most events with a disparity of events between the remainder of the months.

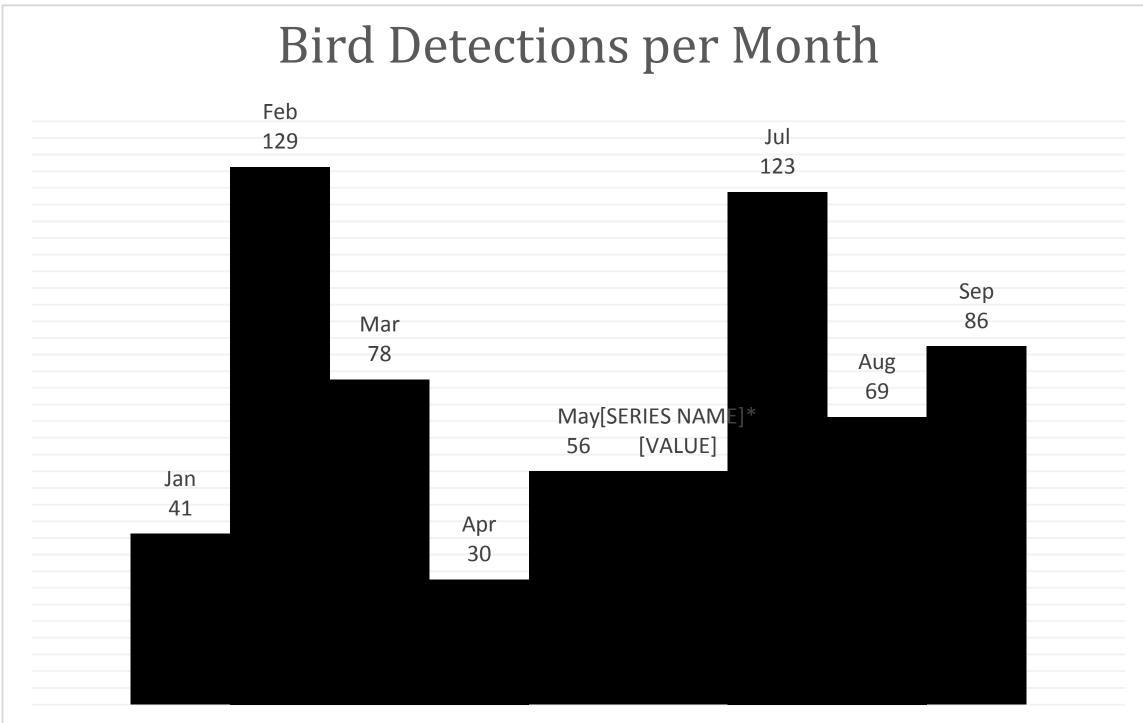

Figure 4. Bird detections per month were highest in February and July with moderate sightings throughout the remaining months (the system was disabled for most of the month of June).

Events sharply dropped from these high figures for the months of January (41), March (78), April (30), May (56), June (56), August (69), and September (86).

Regarding object size, the average bird event was 14.09 in^2 (Figure 5). While this does not indicate the actual size of the bird, it does indicate the area of the rectangle around the identified object.

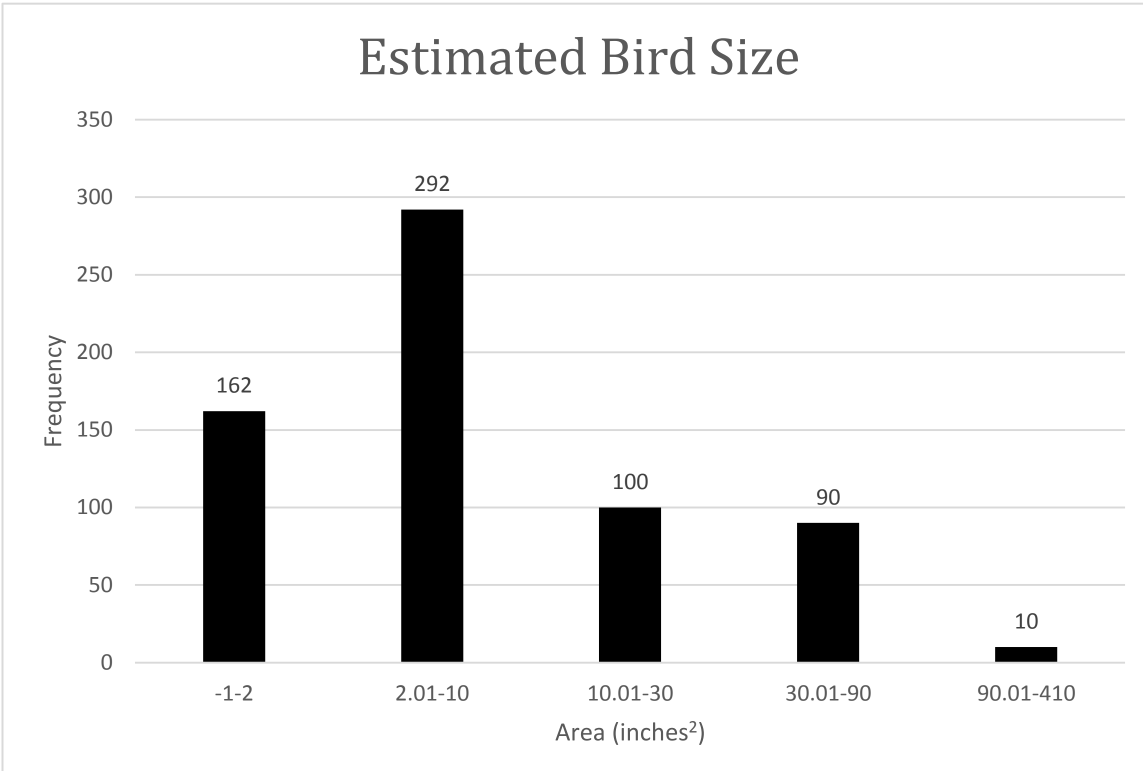

Figure 5. Bird sizes maintained low to medium values across the board, with some outliers caused by multiple individuals contained within one event. The values were binned by size ranges and frequencies are displayed atop each size range bar. Negative values can be attributed to detection box errors.

A larger event points to either a large specimen or a group of birds all within the identified rectangle, still serving as a relevant indicator of threat. The strike index outlined by Dolbeer et al. (2000) can used in conjunction with the radar's data in order to rank threats along the runway. The size distribution map shows the majority of large sightings in the north and central section of the runway (Figure 6).

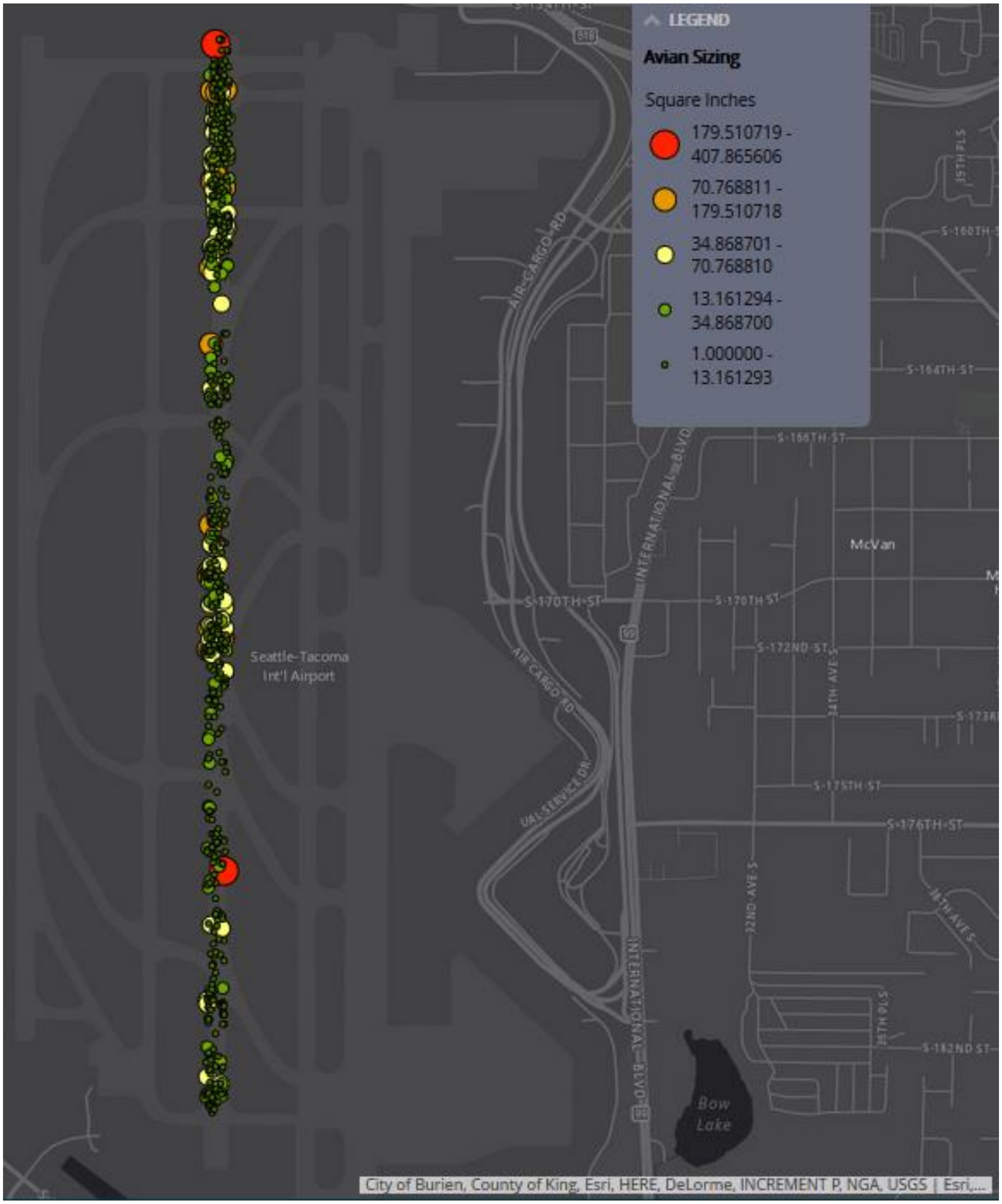

Figure 6. Map showing bird size distribution along the center runway, with the majority of larger events occurring near the center and northern portion of the runway.

In some instances, an event was identified though the rectangle failed to form and remained as a straight line. Another issue with the radar's detection ability came about when only the feet of a bird was identified, causing the system to create a new, smaller event, greatly skewing the size reading.

A key finding in the archival photos of the birds was a group of horned larks. While it is not certain if the sightings were the subspecies, streaked horned larks (*Eremophila alpestris strigata*), the wildlife team at SEA have contacted Washington's Department of Fish and Wildlife to make notice of the birds. Since streaked horned larks are listed as threatened and a ground dwelling species that prefers wide open species with little to no vegetation, the airport could be seen by the birds as a prime habitat. It was the first such sighting and the discovery could indicate the need for major management changes at SEA in the future. The use of archived photos supports Blackwell, Schmidt, & Martin's (2013) recommendation for using observational data to guide current and future avian and wildlife management.

Wildlife incidences were greatest along the southern portion of the of the runway though there was a relatively even distribution along the entirety of the runway (Figure 7).

Figure 7. A heat map displaying the 4,072 wildlife events along the center runway. The highest concentration of wildlife occurred along the bottom portion of the runway.

When the runway was divided into three vertical segments of 3,142 feet each, the distribution showed 1,239 on the north end, 1,307 in the center region, and 1,526 on the southern end.

Analysis of the bird data in AGOL (Figure 8) found the highest concentrations on the north end of the runway (303 events), followed by a similar cluster near the center of the runway (209 events), accounting for 77% of the total events between these two locations. In terms of sizing, the larger events were also found in these hotspot regions, with the middle portion of the runway containing similar values of medium to high threat events while the southern extent of the runway contained low to medium threat events.

The SEA strike database indicated a decrease of strikes since the FOD radar system came into use. Comparing 2016 to with previous years (Figure 8), the number of strikes is considerately lower. It was also the lowest year since 2006, marking a dramatic drop in strikes from 138 in 2015 to 52 as of October 2016. The average number of strikes for the past 12 years (including 2016) totaled 101.

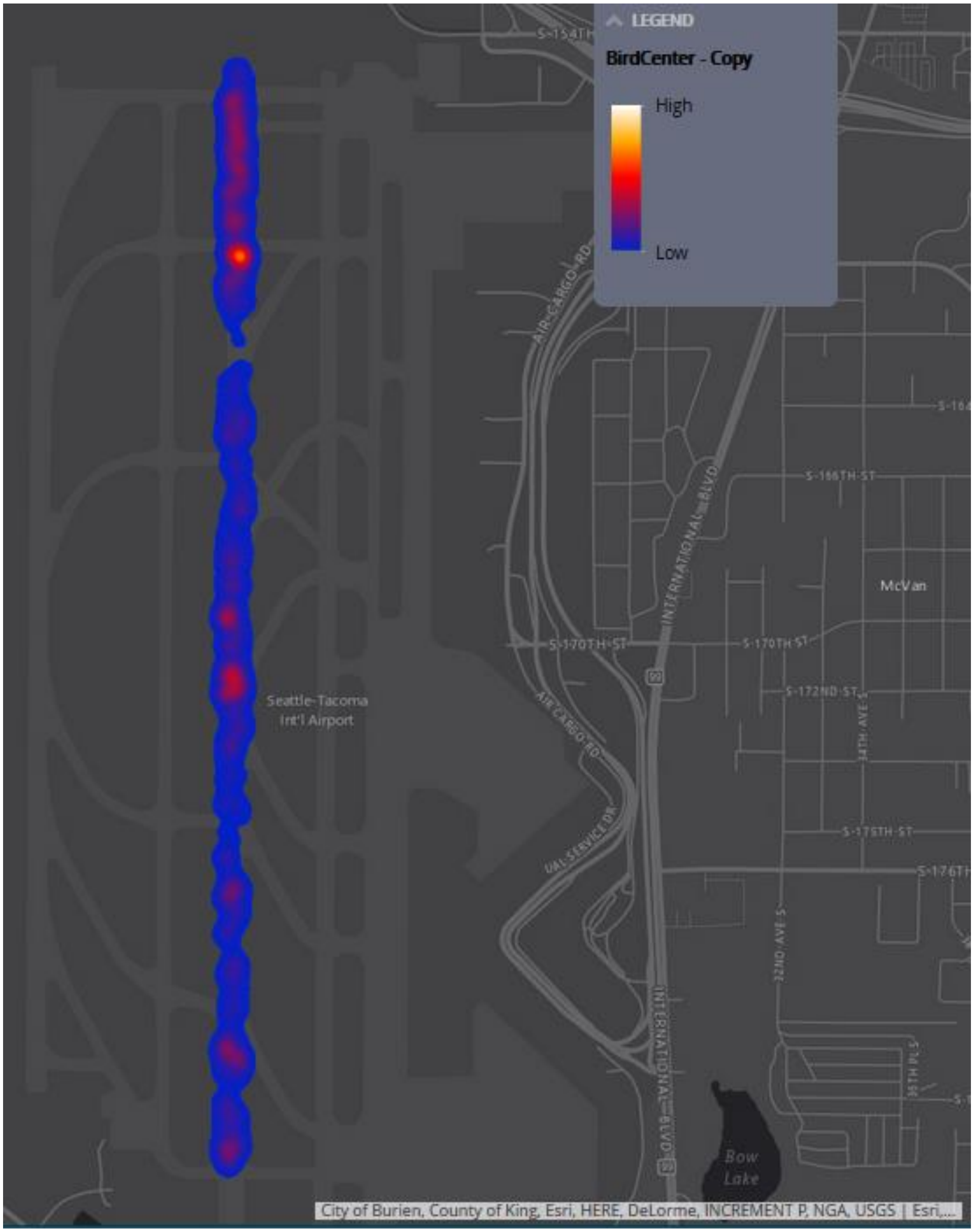

Figure 8. A heat map shows relatively even bird distribution with higher concentrations in the middle and top portion of the runway.

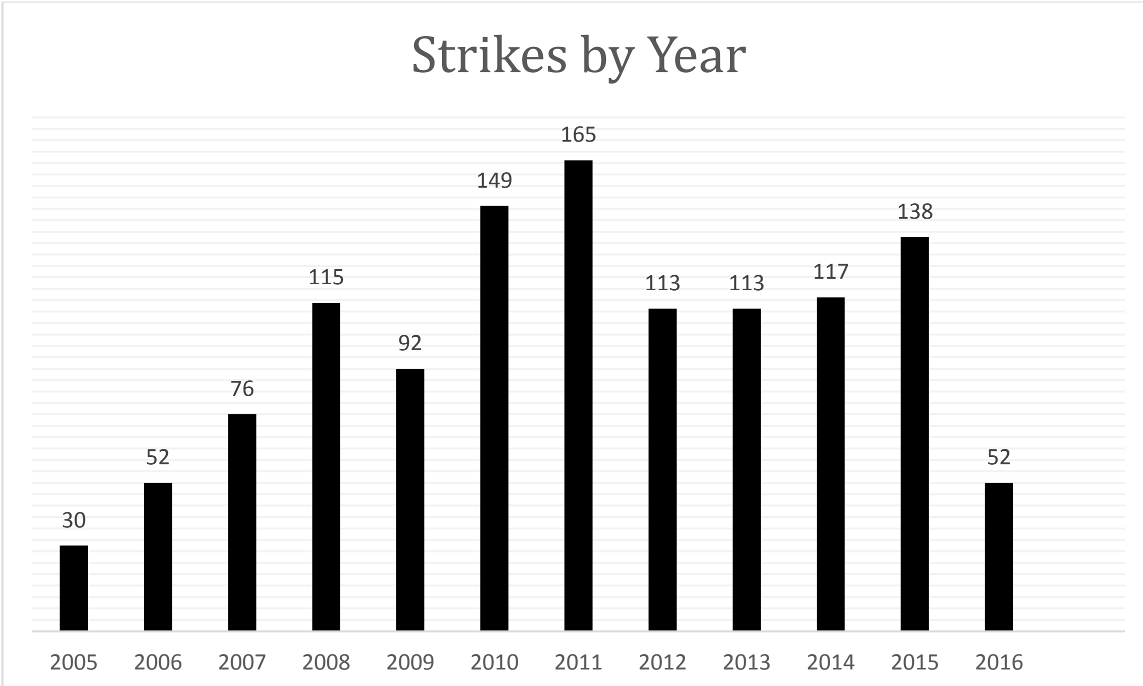

Figure 2. SEA's strike database shows a rapid decline in reported strikes since installing the FOD radar system.

Discussion and Further Research

The sheer volume of events captured by FODetect supports the claim of this paper, that the hybrid system will reduce strikes through constant monitoring and quicker response to live bird and wildlife FOD. While there are many variables to consider—overall reporting, lower bird populations due to yearly variations, and improved management—the system likely contributed to the lower strikes. This system also provides greater insights about the level of bird and wildlife activity at SEA, which will serve to guide future management decisions. While it is yet to be used for the latter, the former was confirmed throughout the data analysis, which showed high bird (668) and wildlife (4,072) counts.

Technical and Data Management Recommendations

The Xsight Systems FODetect Radar System drastically increases SEA's runway awareness and the wildlife team has a great amount of information readily available to them. That being said, there are some areas where the system can be improved on the user-side. Implementing standardized, detail-oriented operator reporting protocols would greatly increase the clarity of the data. Throughout the study, the documentation feature located in the Excel spreadsheet often included vague responses as well as mislabeled fields (vegetation classified as wildlife) and included 300 null values. While using the software the user can identify the objects using photos, but when working with the data outside of FODetect, the level of detail is lacking. Improvements could be made with the wildlife team working together with the airport operations crew to determine the best criteria for describing what the system identifies in order to give a comprehensive and useful description to work from. Creating a list of common terms and descriptors to quickly enter into the description would expedite the data entry process.

While the FodDetect Radar System does include a camera, at this point, it is only possible to export one image at a time. While working within the system or when looking for known events the user has access to all images, but when using Excel or working away from SEA, needing to access photos restricts work. However, it is possible to develop code that would allow for mass photo exporting, which would improve data analysis outside of FODetect's software. If SEA plans to continue with researching and using outside sources to help in the process, developing the ability to mass export photos is recommended. A comprehensive study of the images would allow for a more detailed the species on the runway and their abundance throughout the year.

Further Research

The temporal and geographic patterns related to bird and wildlife events identified in this study can be used to guide further data exploration. Since this program is still in its infancy, constant data collection and analysis in the future will allow for more specific and fine-tuned research. Over time, a comprehensive, multi-year look at changes in patterns in the radar data will be beneficial to the wildlife team. This may point to consistent hotspots on the runway and allow for them to identify common species. Combining the FOD radar with SEA's other avian radar may also point to connections in the flight and rest time around the airport. A more robust data set spanning several years will also help spell out any long-term seasonal and daily patterns that may occur. Looking at these patterns should allow the team to plan and execute more specific and targeted management strategies.

Bird and wildlife events along the runway also have the potential to unlock questions of relationships between the physical characteristics on and around the runway and in the areas of high-density events. Monitoring and comparing wildlife events with bird events may point to possible physical attractants along the runway and the subsequent increase of insects or insect feeding birds. Merging the bird and wildlife events by time may also help explain any wildlife bird attractants.

In terms of methodological improvements, developing a means for mass image exporting would benefit further research to allow for species identification and confirmation of bird and wildlife to aircraft strikes. Once this feature is available, an analysis of strikes between aircraft and wildlife or birds and would allow the wildlife team to determine the effectiveness of the system to harass birds and possibly limit strikes in the future.

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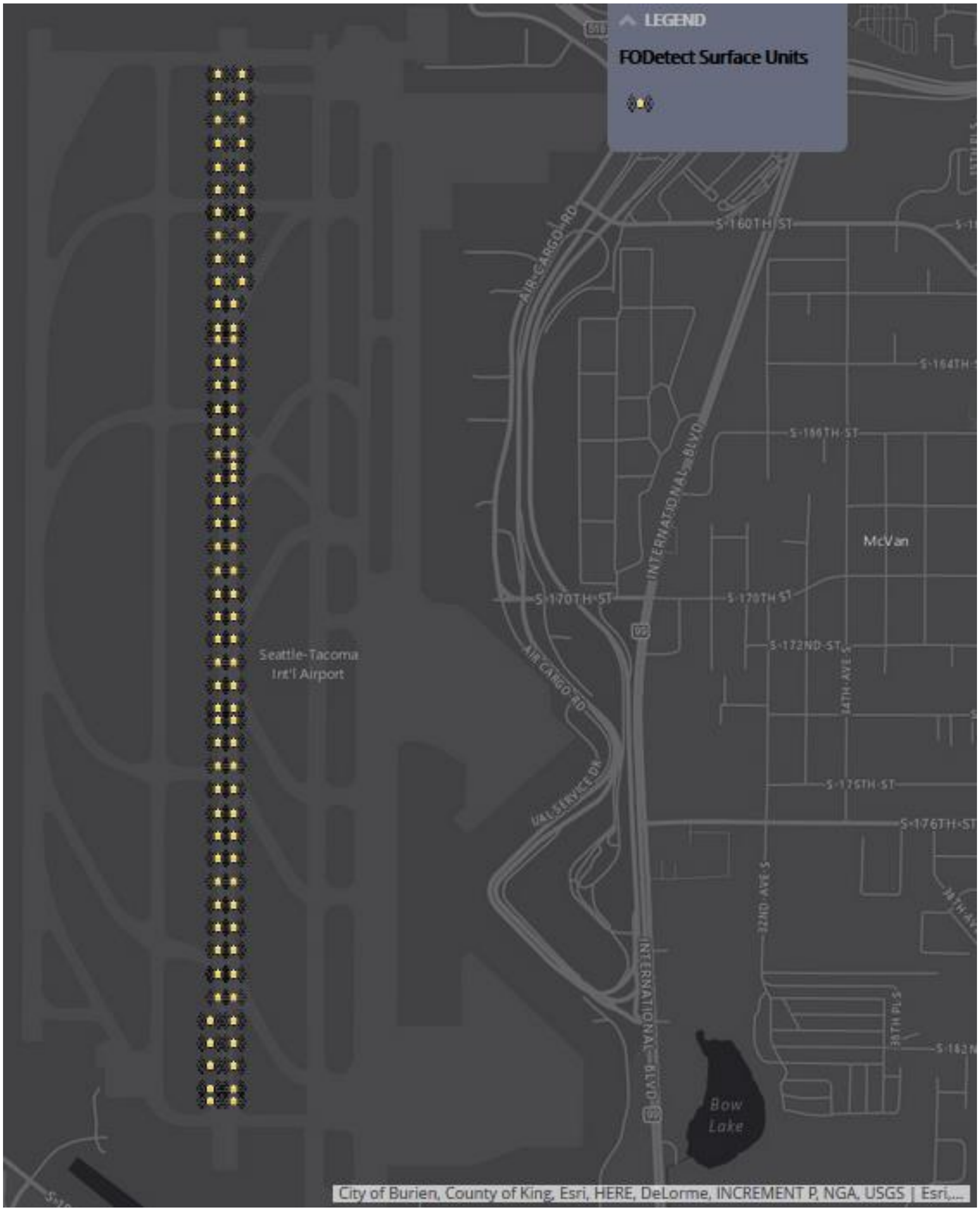
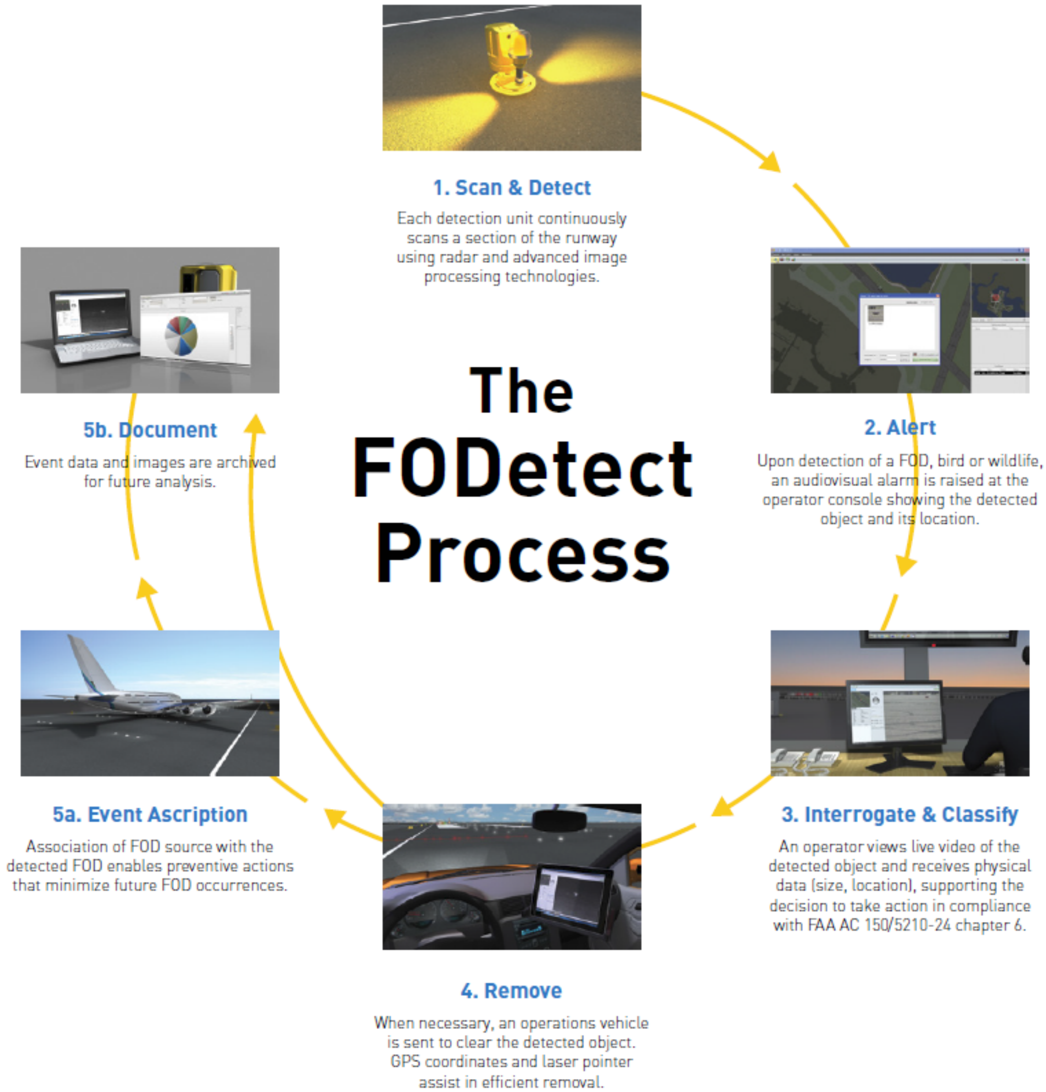
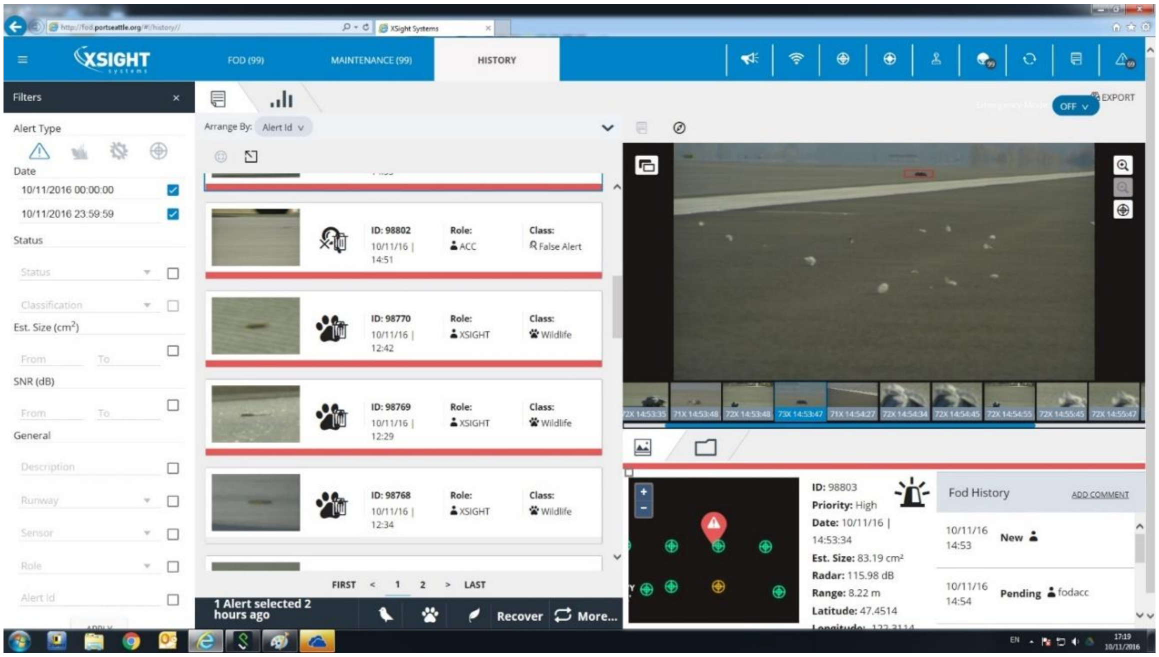
Appendices



Appendix 3. Map showing the 101 hybrid surface detection units along the center runway at SEA. Each unit is placed roughly 200 feet apart vertically and 150 feet across the runway.



Appendix 4. The FODetect process involves both the autonomous hybrid camera/radar system as well as human operators. If the unit detects FOD, an alert is created and the operator can take control of the unit to determine the threat level and any necessary actions. Image: Xsights



Appendix 5. A screen grab from the Xsights software showing a strike. The red rectangle around the struck bird highlights the object as detected by the automated system.

Appendix 4. One of the many mantises spotted by the FODetect system. The rise in mantises coincided with a decrease and overall low value of grasshoppers.

Appendix 5. A worm discovered by the FODetect system. Worms were often a precursor to increased bird activity, specifically gulls.