AN ASSESSMENT OF THE RAPTOR STRIKE AVOIDANCE PROGRAM AT SEATTLE-TACOMA INTERNATIONAL AIRPORT

by

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ABSTRACT

An Assessment of the Raptor Strike Avoidance Program at Seattle-Tacoma International Airport

Hannah Leigh Trageser

Wildlife and airplanes do not mix at airports nationwide. Wildlife management at airports is crucial for maintaining pilot and passenger safety. Red-Tailed Hawks (RTHA) are one of the most numerous and problematic avian species at Seattle-Tacoma International Airport (Sea-Tac). Managing RTHA through the Raptor Strike Avoidance Program (RSAP) helps ensure aviation safety at Sea-Tac Airport. The goal of the RSAP is to capture hawks at Sea-Tac and translocate raptors 75 miles north to an agricultural area with relatively more prey. The RSAP partners with the Falcon Research Group (FRG) non-profit organization. Researchers at FRG give each individual RTHA trapped at Sea-Tac a blue or yellow patagial wing tag. Morphometric data is collected for each hawk. Blue-tagged adult hawks are migrating adult and/or subadult RTHAs that were translocated to Bow. Yellow-tagged hawks are adult hawks that are nesting Sea-Tac residents and in many cases they were also translocated to Bow. Citizen scientists collect RTHA resights with blue or yellow tags and hawk locations are given directly to airport staff. The RSAP's RTHA resight data will be used to address the research question: *Has the Raptor Strike Avoidance Program at Seattle-Tacoma International Airport succeeded in keeping raptors away from airports and airplanes in 5 airports in western Washington?* The success of the raptor program is assessed using resight data to calculate raptor return rates to Sea-Tac. Geographic Information Systems (GIS) spatial analysis is used to determine if raptors are present within five-miles of Sea-Tac, King County International Airport/Boeing Field, Snohomish County/Paine Field, Renton Municipal, and Bellingham International Airports. Analysis indicates Sea-Tac's translocated RTHAs indicate a 14.55% return rate, which indicates high program success at Sea-Tac Airport. Additionally, translocated blue-tagged hawks prefer low elevations ($\bar{x}$=47.71 meters) and show no habitat preferences.

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Chapter 1: Literature Review

This Literature Review will first discuss wildlife risks to aviation to address the importance of minimizing bird strike collisions with aircraft at airports. Birds in built environments will be explored next, and habitat management and land use planning at airports will follow. Current airport ecology research will be explored as well as wildlife deterrents at airports. Wildlife trapping and relocation will be discussed next and then issues of wildlife relocation will follow. The introduction of the thesis and methods of the research will come next. The results and conclusions will be examined with a discussion of how these findings may be used to inform airport wildlife biologists about improvements made to aviation safety through raptor relocation and conservation biology.

Wildlife Risks to Aviation

US Airways Flight 1549 collided with a flock of migratory Canada geese in 2009, causing an emergency landing on the Hudson River between New York City and New Jersey (Henkes 2009). The geese were ingested into both engines of Flight 1549 and caused significant internal damage to engine machinery, resulting in engine failure and loss of control of the aircraft. The collision over the Hudson River led to further improvements in reducing avian attractants (palatable foods for wildlife such as seeds, nuts, and berries) using a wildlife management approach at some airports in the United States. Larger bird species are of most concern to the aviation industry. Aircraft often strike birds on the runway and in the airfield. Such strikes have caused deaths among passengers and pilots in the past, and have caused significant damage to aircraft. Coccon et al. (2015) predicts that due to the projected increased air traffic in the United States, resulting from increased population demand for air travel, there will be a significant increase in wildlife strike hazard risks and high frequency of strike events at airports in the United States. Therefore, managing wildlife risks at airports is important for flight safety.

The Federal Aviation Administration (FAA) is the federal branch of the United States Department of Transportation responsible for maintaining aviation safety in the United States. The FAA aims to maximize safety for air travelers and minimize future risks of potential wildlife-aircraft strike events. In order for aviation safety standards to be met, habitats near the runway need to be unpalatable to minimize bird-airplane collisions. Eliminating shrubs and potential wildlife habitat near the airfield decreases strike events. Red-Tailed Hawks (*Buteo jamaicensis)* (RTHA) are a nuisance to aviation safety at Sea-Tac. Eliminating suitable RTHA habitat attractants would minimize strike events of aircraft with hawks at Sea-Tac and would simultaneously save the aviation industry bird strike damage costs to aircraft at Sea-Tac.

Dolbeer et al. (2000) identified RTHAs as a hazardous species to aviation in the FAA Wildlife Strike Database (database) documented from 1991-1998. The group ranked first as the most hazardous species to aviation were deer, vultures came second, and geese were the third most hazardous wildlife group to aviation. Out of a total of 21 listed species in the database, the hawks (buteos) species group ranked fourth. The buteos species group reported 452 strikes, 67 reports noted effect on flight, 22 reports estimated damage costs, 95 reports noted damage, and the estimated damage costs for hawks to the aviation industry were $389,000 (Dolbeer et al. 2000). In the database for

Sea-Tac, 58% of species struck by aircraft are unknown, 8% barn owls, 7% European starlings, 6% gulls, 6% killdeer, 6% barn swallows, 6% American kestrels, and 4% were RTHAs. Additionally, this database showed RTHAs caused substantial damage to civil aircraft at Sea-Tac in September 2014 and March 2015. Managing RTHA populations at Sea-Tac in the fall and spring months is crucial to enable aviation safety and simultaneously save the aviation industry from future bird strike damage costs.

Birds in Built Environments

RTHAs not only exist in airport habitats, but RTHAs also inhabit urban environments. In urban areas, RTHA population distribution depends on prey availability, nesting sites, and perch foraging locations (Belant et al. 2013). Hawks generally seek out habitat with lots of food such as squirrels and voles both indicative of high quality habitat (Janes 1984 and Witmer 2011). A study conducted by Stout et al. (2009) found that RTHAs in urban-suburban southeast Milwaukee, Wisconsin adapted and thrived within high-density built environments.

Reproductive success is measured and driven by the amount of fledged progeny produced per year (Janes 1984) and serves as an indicator index for high habitat quality (Stout et al. 2006). Research shows that hawks have learned to adapt to urban environments and exhibit reproductive and foraging success in habitats with abundant prey-based food resources. In urban environments, RTHAs often nest on man-made structures (Stout et al. 2009). RTHAs display similar habitat preferences at Sea-Tac similar to research findings in Milwaukee. Environments with abundant habitat features such as perches serve as optimal foraging grounds for RTHAs and more perches indicate higher reproductive success among RTHA populations (Stout et al. 2009, Janes

1984). These hawks near roads demonstrated high reproductive success in urban areas. Research by Stout et al. (2009) found that perches in close proximity to freeways, highways, and local roads provide optimal hunting habitats for hawks. Roadside hunting is also dangerous for RTHAs, due to fatalities of hawks with semi-trucks or cars. When RTHAs hunt in the median and try to fly up some cannot gain altitude fast enough and sometimes get struck by vehicles. Grassy habitat margins between roads and carcasses along vehicular transportation systems provide opportunistic foraging for hawks. Similar to grassy road margins along vehicle transportation corridors, airports also have grassy margins between runways, which oftentimes supports hunting habitat for RTHAs. Many airports provide similar habitat for wildlife.

Habituation among birds in a built environment means that there is reduced (or no) behavioral response when a bird is exposed to a repeated stimulus. Some airports use various harassments to nuisance birds such as shotguns and pyrotechnic launcher harassment devices in addition are exposed to loud airplanes taking off and landing. Oftentimes these birds become accustomed to the harassment stimuli used by trained wildlife staff and birds carry on with their lives near the source of the stimuli. These species inhabit urban areas and have become habituated. Habituation is a dynamic process and illustrates how bald eagles (*Haliaeetus leucocephalus*) in the *Accipitridae* family have thrived in urban habitats and learned how to coexist with humans in built environments. Research by Guinn (2013) found that eagles have become desensitized and no longer threatened by stimuli induced from human exposure over time. Ospreys (*Pandion haliaetus*), like eagles belong to the same Accipitiformes taxonomic order, but are in two different families. Ospreys often breed and nest on man-made structures (such as telephone poles). Resident breeding pairs of RTHAs oftentimes return to the same nest site year after year and breed at Sea-Tac. Research conducted by Stout et al. (2009) found that RTHAs breeding in urban areas of Milwaukee, Wisconsin have shown to have high nest productivity and successful progeny. Like bald eagles, RTHAs belong to the *Accipitridae* family and have the potential to share similar habituation characteristics. Habituation of repeated stimuli among the *Accipitridae* family has implications for airport wildlife biologists because RTHAs have become comfortable nesters and thrived in urban airport environments despite all the noise and repeated stimuli at Sea-Tac.

Habitat Management and Land Use Planning at Airports

Airport wildlife biologists must prioritize airport management efforts towards maintaining airport habitat that decreases RTHA attractiveness and abundance through landscape planning. Implementing habitat modification land use practices at airports is an effective way to decrease wildlife hazards around the airfield. Land use strategies consider various subdisciplines of biology, including wildlife management, landscape ecology, conservation biology, geography, and sensory ecology (Blackwell 2009). Landscape manipulation at civil airports helps guide landscapers, wildlife biologists, stormwater managers, airport operations, and other airport personnel to collaboratively decide on a particular land use plan at an airport.

Habitat modification is an effective tactic to deter birds from civil airports to promote the bird strike avoidance program. Habitat modification first eliminates shrubs and other enticing habitats. Landscapers responsible for habitat modification projects also sow taste aversion plantings such as fall fescue (*Festuca arundinacea*) grass.

Human landscaping techniques to reduce attractants at airports is essential and short-planted grass, low nutrition topsoil to prevent tall grass growth, and fungicidal taste repellant aversions are also planted (Blackwell 2009).

An integrative approach is essential for effective landscape and wildlife management at airports. Martin et al. (2011) found that eliminating wildlife attractants and reducing airfield use by wildlife through an integrated approach using habitat modification paired with wildlife control tactics mitigates wildlife strike risk at airports. Barras and Seamans (2002) emphasize that an integrative wildlife management approach is one that decreases water resources, food availability, perching sites, loafing grounds, and woody vegetation, but simultaneously deters hazardous wildlife through repeated harassment methods. Additionally, tall trees, woody vegetation, and shrubs provide perching habitats for birds. Reducing tall and shrubby vegetation habitats is crucial for eliminating various avian species at airports that are reliant upon these habitat types for perching, nesting and feeding. For successful vegetation management, it is recommended that civil airports plant tall fescue grass as the primary vegetation ground cover between taxiways and runways at airports. Tall fescue is the chosen vegetation planted at airports (including Sea-Tac) because this grass seed mix incorporates a taste-repellent fungus (*Neotyphodium coenophialum*) to deter grazing avian species at the airport (Port of Seattle's Wildlife Hazard Management Plan 2004). The Port of Seattle's Wildlife Hazard Management Plan requires the restoration crew at Sea-Tac to maintain a three-inch maximum fescue grass height by mowing and mowing detracts wildlife at the airport. Similarly, research conducted by Barras and Seamans (2002) illustrate the importance of maintaining short fescue grass height year around, so mowing regimens are used on a regular basis to maintain fescue grass height between 15-25 centimeters. This length is similar to the length required by the Port of Seattle's Wildlife Hazard Management Plan.

Airport Ecology Research

The ecology of an airport is quite complex and dependent upon a trophic cascade of vegetation, insects, mammals, and raptor populations. A trophic cascade describes predator and prey relationships within a food web. Airports have their own ecology because they have wide-open grassy fields in between taxiways and runways. Airports also have built structures that may unintentionally provide habitat for wildlife. Ecological habitat has the potential to attract RTHAs. Studies that pertain to airport ecology are discussed further in this section.

Research conducted by Barras and Seamans (2002) illustrated a strong relationship between the food web dynamics of airport fescue groundcover vegetation, invertebrates, small mammals, and hazardous bird populations within an airport environment. For example, changing one organism can drastically change the abundance of another animal residing in an airport habitat.

Barras and Seamans (2002) found that longer airport vegetation encourages more invertebrates. A rise in invertebrates facilitates an abundance of small mammals due to an increased prey resource for the mammals. Small rodents such as shrews feed predominantly on invertebrates. More insects attract more small birds. Both the small mammals and small birds attract RTHAs. Attracting hazardous birds such as raptors is problematic for aviation safety at airports nationwide. At Kansas City Airport, Witmer (2011) found that tall fescue grass height attracts rodents. Witmer (2011) demonstrated that airport environments with tall and medium fescue grass heights have higher rodent carrying capacities. Airport habitat with short fescue grass supports lower rodent populations and reduced hawk populations. Reducing hawk attraction to airports involves consistent vegetation modification (Witmer 2011). At Chicago O'Hare International Airport, Guerrant et al. (2013) illustrated how mowing regimens have been used as a form of habitat modification to minimize suitable long grass habitat for rodents that attract raptors. Vegetation management and wildlife deterrents at airports go hand in hand as common management protocols implemented simultaneously to reduce wildlife at airports.

Wildlife Deterrents at Airports

Reducing these avian species through non-lethal approaches is integral to Sea-Tac's wildlife program. Exclusion devices are physical barriers (or fences) built along the perimeter of the airport to block wildlife from entering the runway. Exclusion fences are built tall and oftentimes at an angle underground to prevent wildlife such as coyotes from digging their way into airport property and colliding with aircraft.

Another example of an exclusion device used at civil airports is a stormwater detention pond with netting. A detention pond at an airport collects tarmac and aircraft chemical stormwater runoff and is usually netted to exclude waterfowl species.

Another form of wildlife damage control is harassment of birds at airports. Harassing avifauna is a deterrent used at airports to scare birds away from the runway. Harassment uses loud pyrotechnic launchers as a method to impede frequent visiting nuisance birds to improve air safety for pilots and passengers (DeVault 2013).

Loud noises generated from pyrotechnics elicit the stress and fear-induced physiological response pathway in birds. This ignited sense of fear from the loud noise harassment device in the urban environment has the potential to get passed down to future avian generations and has been an exemplary tool to minimize hawks and other birds on airport property. While it is not fully understood, aircraft avoidance through human harassment methods using pyrotechnics and shotguns may be a learned behavior.

When avian species become acclimated to harassment, a shotgun may be used for lethal removal as a last resort when invasive bird species consistently return back to the airport in flocks. Although lethal removal has been shown to be effective for decreasing wildlife abundance at airports, this method is discouraged by biologists who prefer to protect raptor populations.

Wildlife Trapping and Relocation

Wildlife biologists have turned to non-lethal methods of management such as raptor trapping and relocation as a solution to numerous RTHAs at some airports. Wildlife translocation has various goals and objectives, each different and unique. Research conducted by Griffith et al. (1989) explains wildlife trap and relocation as a method to introduce a species to a new environment. Additionally, wildlife translocation can also eliminate a species from one habitat and change the composition of another.

Issues of Wildlife Translocation

Translocation of wildlife involves using a trap that is species specific and a federal permit. Wildlife relocation has legal, ecological, and economic efficiency concerns. The primary legal concern of trapping and translocating wildlife is the necessity for a permit for any migratory bird species under the Migratory Bird Treaty Act (MBTA) or species listed as threatened or endangered under the Endangered Species Act (ESA). Under Washington State Department of Fish & Wildlife (WDFW) state law, all activities related to trapping and relocating birds require a state permit. Stricter guidelines apply for species listed under federal law under the ESA and/or MBTA. Some hawks require a permit for trapping and relocating listed birds to a more optimal habitat to reduce large avian presence in the airfield. Therefore airports oftentimes trap raptors.

Ecological concerns of relocation require understanding the impacts of the relocated wildlife to other members of the same species and other native species at the release site. Some of the risks of relocation include competition, predation of native species, and increased mortality risks of the relocated species.

Invasive species should not be trapped and relocated (Craven et al. 1998). Craven et al. (1998) describes that invasive avian species such as house finches (*Haemorhous mexicanus*), rock doves (*Columba livia*), house sparrows (*Passer domesticus*), and European starlings (*Sturnus vulgaris*) should not be trapped and relocated. The introduction of invasive species to a new release site facilitates competition among relocated invasive species and native species at the release site. Schafer et al. (2002) discussed that the relocation process can be a stressful experience for relocated wildlife and has the potential to impact native species.

There are significant financial expenditures to transport raptors from airports to the relocation site. Curtis et al. (2013) discussed the economic efficiency of raptor trap and relocation programs at airports. Raptors are often transported across geographic boundaries such as mountain ranges, 40-200 miles away, and one-two hours from the airport. The raptor transportation process includes leg banding and wing tagging raptors. Banding and tagging birds are time consuming activities for airport wildlife staff. Time spent transporting raptors cuts into an airport wildlife biologists' daily work routine. Many biologists do not have enough time to transport birds during their work shift.

Proper practice of animal care is essential for translocated raptors. Curtis et al. (2013) illustrates wildlife handling training and proper transportation methods to minimize stress of trapped and relocated RTHAs. Each RTHA should be hooded and treated with proper care throughout the duration of the trap and relocation program. RTHA's feet should be wrapped with elastic vet-wrap for restraint. Kennels that the raptors are transported in should be filled with bedding material and raptors must be released promptly after they are caught to minimize hawk stress response pathways.

Raptor trap and relocation programs are used as a means for managing nuisance wildlife at Sea-Tac, but not at all civil airports. These programs are relatively new amongst wildlife aviation operations as of the 2000's. The success of these programs are understudied since they are not yet numerous and widespread across airports nationwide. Wernaart et al. (1999) emphasized that a successful raptor program is one that lessens the likelihood of a RTHA to be hit by an aircraft.

Raptor Return Rates

Raptor return rates are indicators of program success at airports with wildlife programs. A successful raptor program at an airport has low raptor return rate percentages defined as low RTHA re-capture rates below 15.9% and low resights at airports (Schafer et al. 2002). This should result in a decrease in RTHA strike events with aircraft after a raptor program has been fully established (Schafer et al. 2002).

Studies by Wernaart et al. (1999), Schafer et al. (2002), and Anderson and Osmek (2005) have calculated raptor return rates associated with raptor relocation programs at airports; little is known about the success of airport raptor programs. Wernaart et al. (1999) found that the return rate for relocated RTHAs at Toronto Pearson International Airport was 4%. Schafer et al. (2002) found that the return rate for relocated RTHA at Chicago O'Hare International Airport (ORD) was 15.9%. Research at ORD also found a 33% return rate for relocated RTHA with attached very high frequency transmitters (Schafer et al. 2013). Previous research at ORD used very high frequency radio transmitters and satellite telemetry to track airport RTHAs using Global Positioning System (GPS) coordinates to assess raptor returns (Schafer et al. 2002). Telemetry allows airport wildlife biologists to track movement pathways of avifauna at airports post-release from the relocation site.

Research completed by Anderson and Osmek (2005) found that during the years of 2001-2005, the return rate for relocated RTHA at Sea-Tac was 0%. Since 2005, Sea-Tac has collected substantially more RTHA resighting data since this return rate was first established. The program was not reliable at 0% and the Port of Seattle has remedied this with more RTHA data collection.

Airport wildlife biologists have not reached agreement upon what return rate percentages or ranges define a successful program at an airport. Considering Toronto and O'Hare the return rates for relocated raptors back to airports range from 0%-33%. For the purposes of this thesis, rates less than 15.9% are successful. Furthermore, due to research and information gaps in the literature, the success of raptor programs at airports is understudied, as well as raptor elevation preferences, and habitat preferences of relocated raptors. Thus, raptor return rates, elevation, and habitat preferences are assessed for the Raptor Strike Avoidance Program at Sea-Tac.

Chapter 2: Introduction to Master's Thesis Research

Thesis Research Question

I assessed the effectiveness of RTHA capture and relocation as a method for decreasing avifauna at Sea-Tac. RTHA resight data from the Port of Seattle Aviation Operations Raptor Strike Avoidance Program at Sea-Tac are to address the research question: *Has the Raptor Strike Avoidance Program at Seattle-Tacoma International Airport succeeded in keeping raptors away from airports and airplanes at 5 airports in western Washington?* The null hypothesis is that translocated Red-Tailed Hawks are equally as likely to be at one airport as another of the five airports given we know Red-Tailed Hawks have ranged from British Columbia to California.

Study Introduction Site Identification: Sea-Tac Airport

The Port of Seattle owns and operates Sea-Tac Airport, located in a highly urbanized area of south Seattle, two miles east of Puget Sound. Industrial, commercial, forest, parks, lakes, ponds, and streams are a few habitat types found near Sea-Tac. At Sea-Tac Aviation Operations wildlife staff harass wildlife away from airport property and devise strategies to make airport habitat unsuitable for wildlife (especially for avian species). Aviation Operation's wildlife biologists at Sea-Tac prioritize their efforts to minimize aircraft collisions with RTHAs and maximize aviation safety through a comprehensive program devoted to raptor trapping and relocation.

The Raptor Strike Avoidance Program

The Raptor Strike Avoidance Program (RSAP) began in June 2001 at Sea-Tac Airport (Figure 3). RSAP uses raptor trap and relocation as a non-lethal biological approach to reduce raptor collisions with aircraft at Sea-Tac. Raptor trapping and relocation is one form of wildlife management implemented at civil airports in the Pacific Northwest (including Sea-Tac, Portland International Airport (PDX), Vancouver International Airport (YVR) and Salt Lake City International Airport (SLC)). Sea-Tac, PDX, YVR, and SLC civil airports have been working collaboratively on a Western Airports Raptor Research and Management (WARRM) working group to minimize strike events with RTHAs and enhance aviation safety at airports.

Study Species

Pilots can lose control of their aircraft if birds collide with aircraft engines. RTHAs are most abundant at Sea-Tac and in the past, aircraft have struck RTHAs at Sea-Tac. Aircraft can strike large birds and lose steering capabilities.

RTHAs are numerous at Sea-Tac because they are a habitat generalist species that thrives in many habitat types (Hull et al. 2008). Sea-Tac provides an abundance of suitable hunting habitat, which attracts RTHAs to prey upon voles and other small mammals at this airport. Raptors such as RTHAs are considered a “hazardous” avian species at Sea-Tac because they have a substantially large biomass and have the potential to exert a considerable force on airplane engines and other parts of the airplane.

Additionally, RTHAs are the most common raptor species trapped and documented at Sea-Tac. In order to avoid future raptor strikes to aircraft at Sea-Tac, there was significant pressure for Aviation Operations to begin a relocation program for RTHAs.

The RSAP uses up to five goshawk traps to capture hawks at Sea-Tac and relocates birds 75 miles north to Bow, Washington (Figure 1). Anderson and Osmek (2005) determined Bow as a high quality habitat for RTHAs because of its rich prey abundance and sufficient winter raptor population presence. Thus, Bow is a suitable habitat for raptors to be relocated to by airport wildlife staff.

Just prior to release, blue and yellow wing tags are attached to the hawks to indicate that the birds were originally trapped at Sea-Tac and relocated to Bow. A blue wing tag indicates that the raptor is a migrating adult and/or sub-adult at capture and a yellow wing tag indicates that the hawk is an airport resident at capture. Other raptor species translocated at the airport are given a silver United States Geological Survey (USGS) leg band and this leg band number is sent to the United States Bird Banding Laboratory. Morphological data as body mass (g), wing chord (mm), tail length (mm), hallux (mm), exposed culmen (mm), and tarsus (mm) lengths of each relocated RTHA is documented by a raptor specialist in Bow.

Citizen Science

Citizen science data collection can help reduce airport wildlife staff time and money within the limited financial budget allocated to the Aviation Operations' wildlife management division. When the RSAP was first launched by the Aviation Operations in 2001, citizen scientists actively began raptor data collection for blue and yellow tagged avifauna in western Washington. Recreational birdwatchers in the community assist with data collection. Support by the public for data collection is highly beneficial to the success of the RSAP.

Hawk identification classes are taught once in the winter by the Falcon Research Group contractor based out of Bow, Washington. The Falcon Research Group non-profit organization, led by Bud Anderson works collaboratively with the RSAP at Sea-Tac Airport. Classes are held once a year in Seattle, Mount Vernon, and Bellingham. Participants are notified about the classes through a list-serv. Classes last five weeks and occur one day a week. The hawk course includes a one-hour lecture supplemented with slides for participants to practice hawk identification skills and a full day field trip to the Skagit Valley Flats devoted to field observation experience identifying raptors.

Citizen science has been a long running and efficient method of collecting avian abundance and distribution data. Data collection involves voluntary participation among the local birding community and wildlife biologists at Sea-Tac Airport. Participation among birders in Washington State has been fundamental to RTHA resighting data collection for the RSAP at Sea-Tac. Citizen science is an efficient means of gathering numerous avifauna point counts over time and allows more eyes to look out for airport birds over an extensive territory year-round. Public eyes on airport birds increases raptor reporting rates and generates an extensive dataset with a large raptor sample size. Furthermore, due to staffing and funding constraints, data collection conducted by birdwatchers in the community is integral to the RSAP. Locally collected data by the community is especially ideal when research funding is scarce.

Data Quality

Numerous publications use and cite citizen science data. The National Audubon Society launched the Christmas Bird Count (CBC), which is the longest running and continuous citizen science program. For example, both the CBC and eBird are exemplary models of citizen science because they are widely cited in peer-reviewed literature and are considered credible avian datasets by the scientific community (Dunn et al. 2005 and Sullivan et al. 2014). Cited citizen science in scientific literature points to the legitimacy of using citizens in the community as a means for collecting avian abundance and distribution data for the RSAP. Research by Dunn et al. (2005) illustrates how citizen science uses public participation to conduct avian point counts and enhances data quantity. Similarly to the CBC and eBird, the RSAP uses public participation in scientific research to gather RTHA location data. This participation facilitates public engagement and education among the local community. The program also generates a larger raptor dataset that can be used for further analysis. Like eBird and CBC, the RSAP has an extensive raptor resighting dataset, which has the potential to educate and inform the public and airport wildlife staff about raptor threats to aviation if avifauna resightings are close to airports. Additionally, a large raptor dataset can be analyzed and interpreted in various ways to determine the effectiveness of the raptor program at Sea-Tac.

This RTHA dataset is the basis of study for the thesis. Only blue-tagged RTHAs are used with a total of 144 observations over 14 years (from 2001 to 2015). The yellow marked birds were not considered in this analysis because they were resident birds so we knew they would be resighted often near Sea-Tac. It is believed that these resident birds are more airport savvy and therefore they would not get struck as frequently. These birds are also seen driving other RTHAs away as they are territorial and do perhaps help the airport from keeping the young and non-airport savvy birds from getting struck at Sea-Tac. To eliminate sample bias within the dataset, resightings from the Port of Seattle staff and yellow-tagged RTHAs were omitted. The sites of the Swedish goshawk traps used for raptor trapping at Sea-Tac were chosen because locations were far removed from aircraft taxiway traffic, near takeoff zones where aircraft are most vulnerable, and close in proximity to grassland habitats where raptors would most likely be found hunting for prey (Figure 1).

Chapter 2 Figures

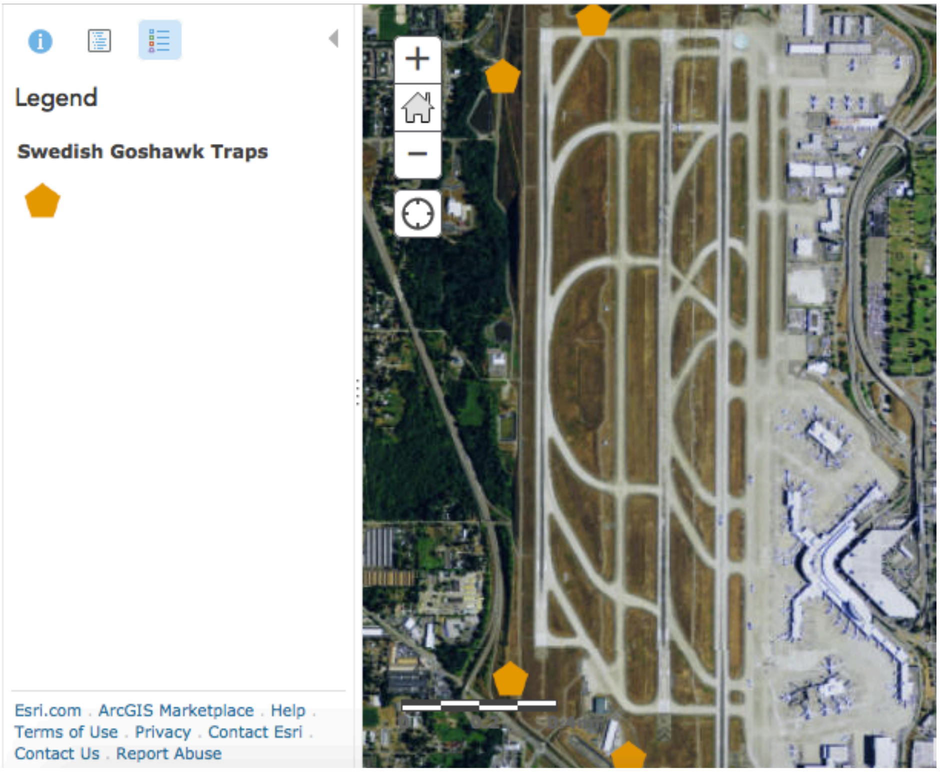


Figure 1. Swedish Goshawk Traps Used For Raptor Trapping at Seattle-Tacoma International Airport.

Chapter 3: Analysis of the Raptor Strike Avoidance Program

To understand the success of the RSAP, it is necessary to analyze the raptor resight database. The raptor resight data is analyzed to address potential RTHA risks to aviation. The program has not been assessed since 2005, when the return rate was 0%. When additional resighting data became abundant after 2005, there was an opportunity to evaluate the program for this study. Additionally, there are few established raptor programs at airports and limited research on return rates at Sea-Tac. It is possible that this research could be applied to other airports with raptor programs. Research on return rates is necessary because it is lacking within wildlife management programs at most airports and not all airports have the same internal structure.

The success of the program will be examined by looking at raptor return rates. Raptor return rates are the number of RTHA resightings within Sea-Tac Airport's six-mile airport buffer divided by the total number of RTHAs trapped at Sea-Tac and relocated to Bow, Washington. A successful RSAP will reflect low return rates (below 15.9%) back to Sea-Tac with few blue-tagged relocated hawks resighted within the six-mile radius of Sea-Tac. An unsuccessful program will reflect high return rates (above 15.9%) back to Sea-Tac with numerous blue-tagged relocated hawks resighted within the five-mile radius of Sea-Tac.

Geographic Information Systems (GIS) analysis is used to assess distance from airports. GIS is a relatively new tool used for airport safety that can combine spatially derived information. GIS spatial information is used to determine where Sea-Tac's birds are resighted once they are relocated. Additionally, GIS RTHA resight data from Sea-Tac is necessary to see how Sea-Tac's trapped and relocated birds are impacting other small regional airports. The FAA Wildlife Strike Database for struck RTHAs at Sea-Tac and King County International Airport/Boeing Field (KCIA/BF) will help to determine strike events before and after the RSAP was first established in 2001. Return rates and aircraft strikes with RTHAs are the two best indicators to determine the overall success of the RSAP.

Methodology used in this research also combines citizen science data with GIS spatial analysis of Sea-Tac's data and the FAA Wildlife Strike Database strike data (for Sea-Tac and KCIA/BF) to determine if return rates differ from previous research. If accepted by Sea-Tac, the methods may support further development of strategies to minimize raptor-aircraft collisions at other airports in the future.

Materials & Methods

Study Area: Western Washington Airports

Washington State Department of Transportation (WSDOT) releases annual aviation reports and these reports were relevant to this thesis to determine study design. Initially thirteen airports were chosen for this research, but after speaking with the United States Department of Agriculture (USDA) Wildlife Services Wildlife Biologist at WSDOT the research scope narrowed further to five study site locations. The five study site locations were determined using page thirty-nine of WSDOT's Statewide Airports Profile Reports for 2015:

(1) Seattle-Tacoma International Airport

(2) King County International Airport/Boeing Field

(3) Snohomish County Airport/Paine Field

(4) Renton Municipal Airport

(5) Bellingham International Airport

These airports were chosen because they have high operations, but also have staff devoted to bird species identification (Table 1). Methodologies addressed in this section include data collection patterns between western versus eastern Washington, air traffic volumes, and data quality.

Raptor Data Collection

Avian surveys began in the summer of 2000 and four avian surveys are conducted each week in the early mornings and evenings at many locations for twenty minutes (Figures 3-4). Wildlife biologists at Sea-Tac drive on the airport Perimeter Road to conduct regular scheduled avian surveys during the week. Avian surveys are conducted when the vehicle is stopped and the wildlife biologist is on foot in a stationary position looking through binoculars and/or using a spotting scope for raptors (specifically RTHAs) and other problematic airport avifauna. The bird species, age, location, time, perch type, flight activity, and estimated sex are documented by airport biologists. The RTHA data was the only avian dataset analyzed for this thesis. Additionally, another portion of the RTHA data was collected by citizen scientists. Citizen scientists were either trained individuals or random public participants in the community. These sightings document the location of Sea-Tac's blue or yellow-tagged RTHAs throughout western Washington. Each RTHA resight location from the public was emailed to the Aviation Operations Wildlife Hazard Mitigation & Conservation office.

GIS Data Management for Airport Operations

Figure 2 explains the basic GIS data management workflow components of this research. An Excel spreadsheet was made for the five chosen airports and translocation site. Web maps were created for Sea-Tac, Paine Field, Renton Municipal, Boeing Field, and Bellingham airports to depict airport locations.

GIS Data Management for Red-Tailed Hawk Resights

All email resight written locations were compiled into a Microsoft Excel spreadsheet and uploaded into a web map in ArcGIS (Figure 5). The web map shows each resight and its associated location. Each resight is symbolized by a blue circular raptor symbol. A slope terrain layer was added to the map to indicate RTHA elevation preferences after hawks were trapped at Sea-Tac and relocated to Bow, Washington (Figure 6). Mean hawk elevations were documented. Next, each resight was categorized into a preferred habitat type including urban/residential, agricultural, road, forest, grassland, airport, Puget Sound, river, or wetland (Figure 25).

GIS Spatial Data Analysis of Red-Tailed Hawk Resights

Manager wildlife biologist Steve Osmek identified the five-mile radius surrounding Sea-Tac Airport as a "danger zone". This five-mile danger zone indicates high potential for aircraft collisions with hawks entering crucial flight zones for plane takeoff and landing. Distance measurements of raptor resights were documented to determine the proximity of resights to its nearest airport within the five-mile buffer and resights within five-miles of the translocation site (Figures 13-14 and Figure 20). A hawk density map was generated to show concentrations of RTHA population densities and indicated population clustering (Figure 22). The density tool shows where RTHA clusters occur, but does not indicate if statistically significant clustering exists in the data.

Statistical Analysis

A table was created in Excel and pivot table analysis was used to categorize and count the number of dead, injured, resighted, shot, struck, and trapped RTHAs. Pivot tables were also used to manipulate the FAA Wildlife Strike Database and query for struck RTHAs at Sea-Tac and Boeing Field Airports (Figures 23-24). The resight dataset provided by Sea-Tac Airport was continuous, the research question pertains to relationships, and there are dependent and independent variables. Additionally, bar graphs with error bars were used to show the resight distances of each hawk to each resightings' nearest airport and translocation site (Figures 15-19 and 21). A box plot depicts RTHA elevation preference means, which include summary statistics (standard deviation, standard error of the mean, upper 95% mean, lower 95% mean, and sample size). The box plot also includes maximum, lower quartile, median, upper quartile, and minimum value quantiles (Figure 7).

Results

Pivot Table Analysis

Pivot table analysis of the blue tagged hawk resight data revealed 3 dead, 3 dead on road/runway, 1 injured, 144 resighted, 3 shot, 0 struck and 69 trapped and relocated RTHAs. The sample size of the blue-tagged RTHAs in the dataset was 59 hawks (n=59).

Repeat Red-Tailed Hawks

BL10, BL15, BL50, BR57, BR9, BL31, BL7, and BL82 hawks were considered repeatedly sighted hawks in the dataset. A repeat bird was a hawk that was resighted more than four times in the dataset. A story was written for each repeat bird to visually depict its flight path after the hawk was trapped at Sea-Tac Airport and released north in Bow, Washington (Figures 27-33).

Habitat Preferences Among Blue-Tagged Red-Tailed Hawks

The dataset revealed that translocated raptors did not have a particular habitat preference. Of the total resightings, 26% of the hawks favored agricultural habitats, grasslands followed with 16%, forests and roads (15%), urban/residential areas (14%), airports (10%), river habitats (2%), Puget Sound (1%) and wetlands accounted for 1% (Figure 25).

Elevation Preferences Among Blue Tagged Red-Tailed Hawks

The elevation summary statistics for all blue-tagged RTHAs were as follows: Mean ($\bar{x}$ = 47.71 meters), standard deviation (s= 47.50 meters), standard error of the mean (SE= 1.23 meters), upper 95% mean= 50.13, a lower 95% of mean= 45.29 meters, for a sample size of 59 hawks (n=59). Box plot quantiles revealed a maximum value of 194.93 meters, upper quartile of 88.6 meters, median of 30.44 meters, lower quartile of 8.96 meters, and a minimum value of 1.94 meters (Figure 7).

Birds in Airport Buffers

Zero blue-tagged RTHAs were resighted within the five-mile buffer of Paine Field (Figure 11). The mean distance of blue-tagged RTHAs to Sea-Tac Airport was 1.15

miles of the 8 total blue-tagged birds within the five-mile Sea-Tac Airport danger zone (Figures 12 and 15). The mean distance of blue-tagged RTHAs to Renton Municipal Airport was 4.88 miles of the 7 total blue-tagged birds within the five-mile Renton Municipal Airport danger zone (Figures 12 and 16). The mean distance of blue-tagged RTHAs to Boeing Field was 3.92 miles of the 11 total blue-tagged birds within the five-mile Boeing Field danger zone (Figures 12 and 17). The mean distance of blue-tagged RTHAs to Bellingham International Airport was 4.00 miles of the 17 total blue-tagged birds within the five-mile Bellingham International Airport danger zone (Figures 10 and 18). The mean distance to blue-tagged RTHAs to the translocation site in Bow, Washington was 3.48 miles of the 23 total blue-tagged raptors within the five-mile translocation zone.

Program Success Evaluation

Of the total of 144 resighted blue-tagged RTHAs, 8 blue-tagged RHTAs were found in Sea-Tac's six-mile airport buffer and 55 birds were trapped so the RTHA return rate for Sea-Tac was (8/55) 14.55%. 15.9% was the return rate threshold found in the literature. A return rate lower than 15.9% was a measure of program success.

Discussion

Since there were no resights in the five-mile airport buffer for Paine Field Airport wildlife biologists have a lower likelihood of risk for Sea-Tac's birds impacting aircraft at Paine Field. Paine Field is an important site to discuss because of the lack of sightings (low observer effort) in its airport buffer, given one would predict this region to have more resights because of its populated area. Although the void of hawk resightings near

Paine Field was surprising, there is the potential that Paine Field has habitat differences. We thought the habitat would be better for hawks at Paine Field than near other airports in south Seattle. Paine Field, however, is farther from Interstate-5 (I-5), a corridor where RTHAs perhaps tend to be sighted there less frequently than the four other airports. Since Paine Field is located 3.3 miles from I-5, while the other airports are less than a mile or less from I-5 or a heavily traveled freeway. One would expect sightings near Paine Field airport, however because it is a populated region and airport employees there know how to look for and report these marked birds to the Port of Seattle.

Since some resights appear in Sea-Tac, Boeing Field, and Renton Municipal Airport five-mile buffers, biologists should be more concerned about flight paths of birds to aircraft at these airports. Since there are not standardized avian survey protocols at all airports in the Pacific Northwest and not every airport participates in bird strike reporting, it is difficult to conclude if Sea-Tac's translocated hawks are directly impacting flight paths of nearby airports. In the future, it would be beneficial for each airport to have specialized wildlife staff familiar with avian species identification to conduct standardized bird surveys on a regular basis as well as improve the ability of airports to report strikes and sightings into a reliable information system at all airports.

It also appears that there is mortality associated with handling and tagging airport RTHAs. This may encourage quicker release of the raptors (shorter holding time) from trapping process, better handling practices in the future by biologists, and more funding allocated to wildlife programs for future research to assess the impacts of wing tags on relocated RTHAs. For example, research by Clay (2016) tested the impacts of wing tags on airport snowy owls and this research could be replicated for airport RTHAs at Sea-Tac.

More outreach and education opportunities for local rural communities by qualified airport wildlife staff could enhance data quality of the RTHA dataset. For example, more bird identification courses open to the public and taught year around could improve species identification within in the RTHA dataset. More eyes looking for RTHAs in less populated areas will enhance randomization and data quality in rural communities.

Additionally, another area for improvement within the RSAP could include better data management of the resightings since much of the data is not current and has not been updated in several months.

Chapter 3 Figures

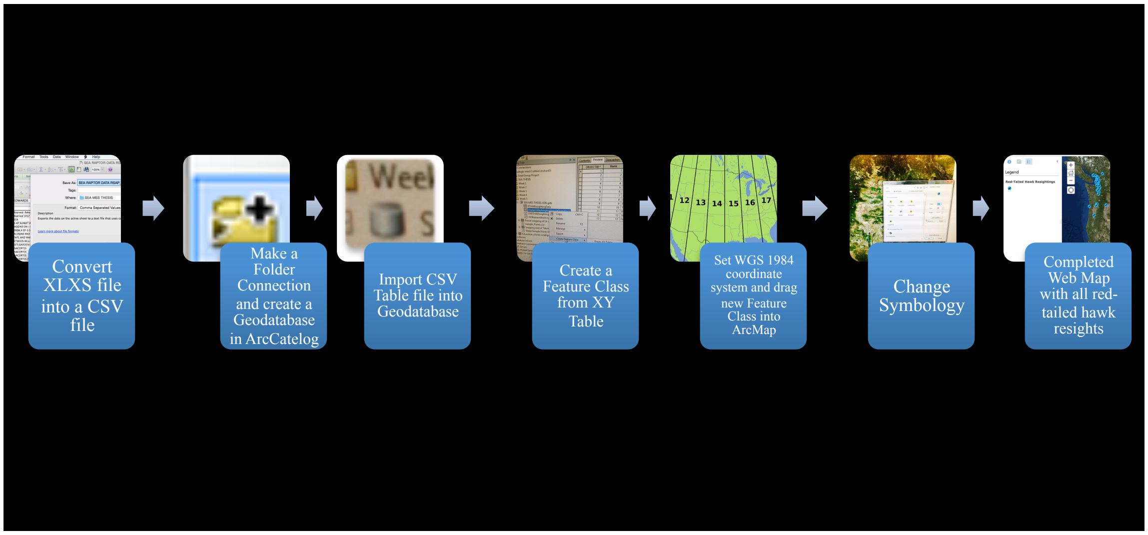


Figure 2. GIS Data Management Workflow For Red-Tailed Hawk Resight Data.

Figure 3. Weekly Avian Survey Locations at Seattle-Tacoma International Airport.

Figure 4. Tyee Valley Golf Course Avian Survey Locations at Seattle-Tacoma International Airport.

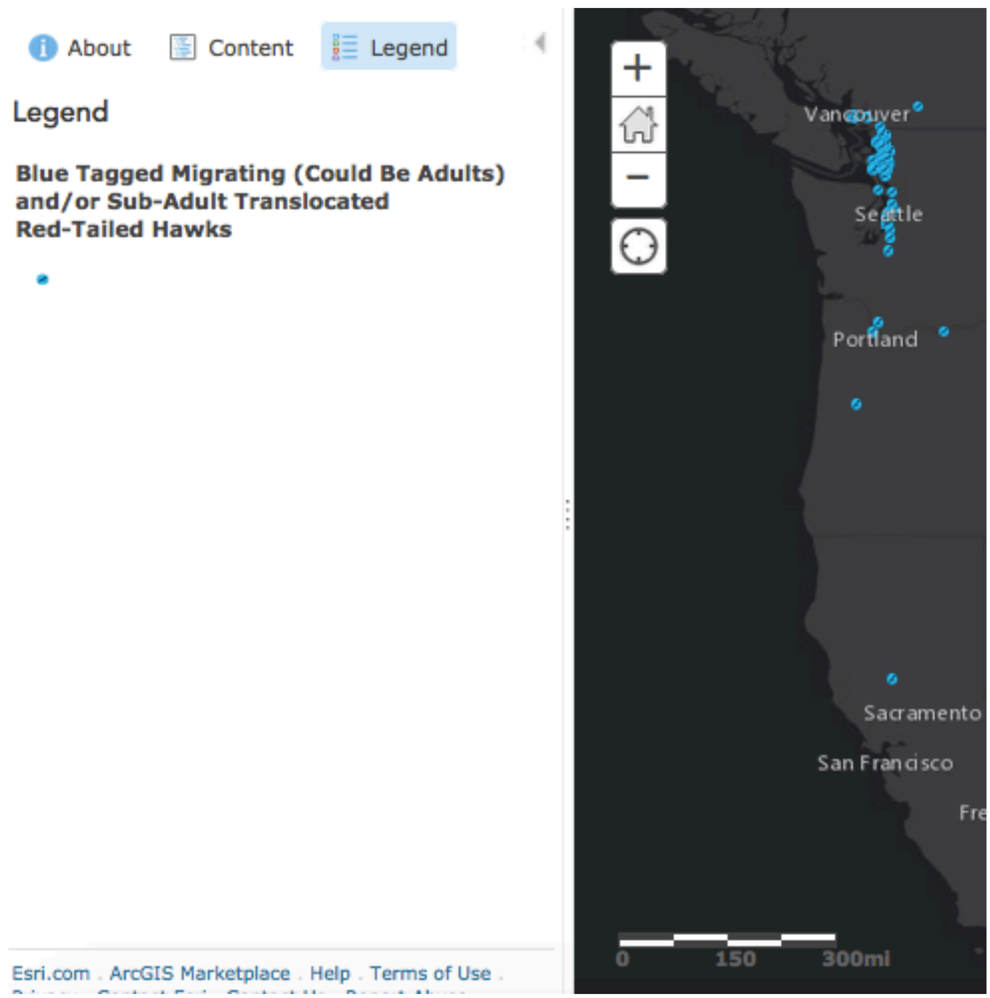


Figure 5. Blue-Tagged Red-Tailed Hawk Resights From the Raptor Strike Avoidance Program.

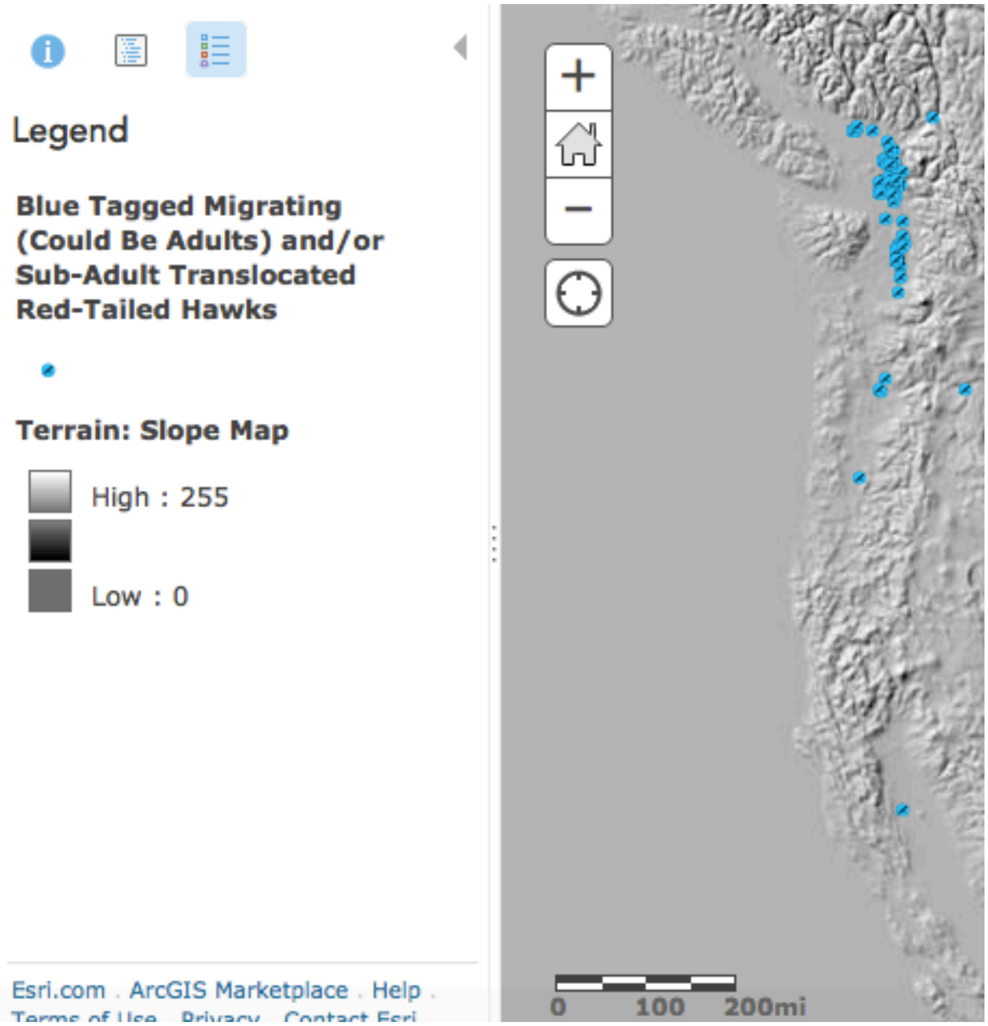
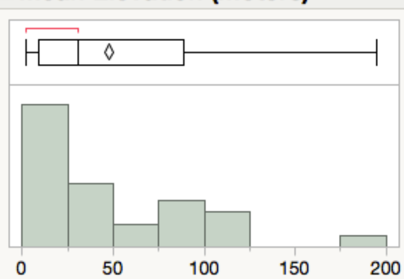


Figure 6. Red-Tailed Hawk Elevation Preferences (USGS Terrain_Slope layer).

Distributions

Mean Elevation (Meters)



Quantiles

100.0%	maximum	194.93
99.5%		194.93
97.5%		194.93
90.0%		120.14
75.0%	quartile	88.6
50.0%	median	30.44
25.0%	quartile	8.96
10.0%		4.48
2.5%		2.0195
0.5%		1.94
0.0%	minimum	1.94

Summary Statistics

Mean	47.713057
Std Dev	47.504692
Std Err Mean	1.2327451
Upper 95% Mean	50.131165
Lower 95% Mean	45.294949
N	1485

Figure 7. JMP Output Elevation Preferences Among Blue-Tagged Red-Tailed Hawks.

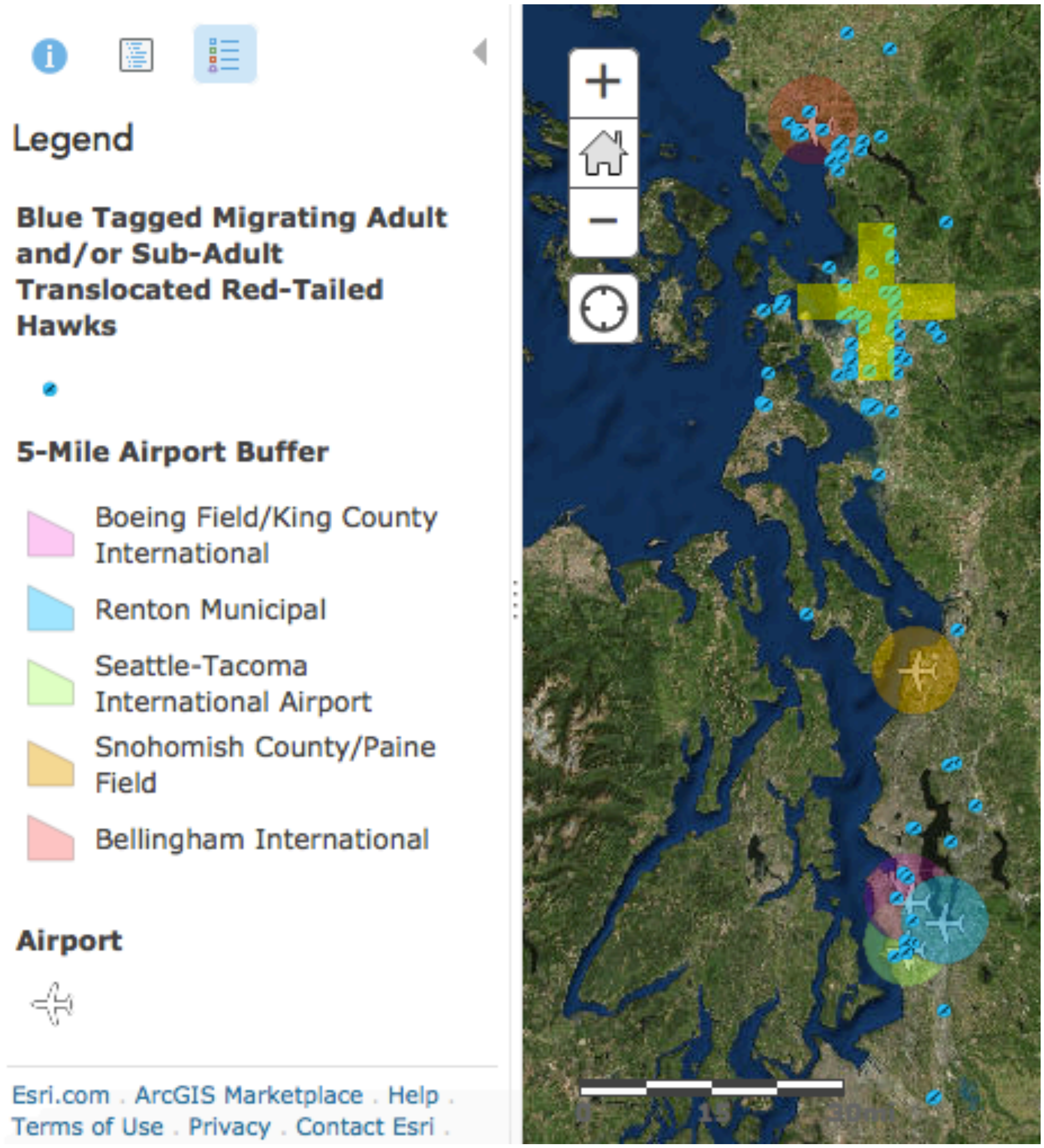


Figure 8. Blue Tagged Red-Tailed Hawk Resights, Five-Mile Airport Buffers, and Five-Mile Translocation Site Buffer.

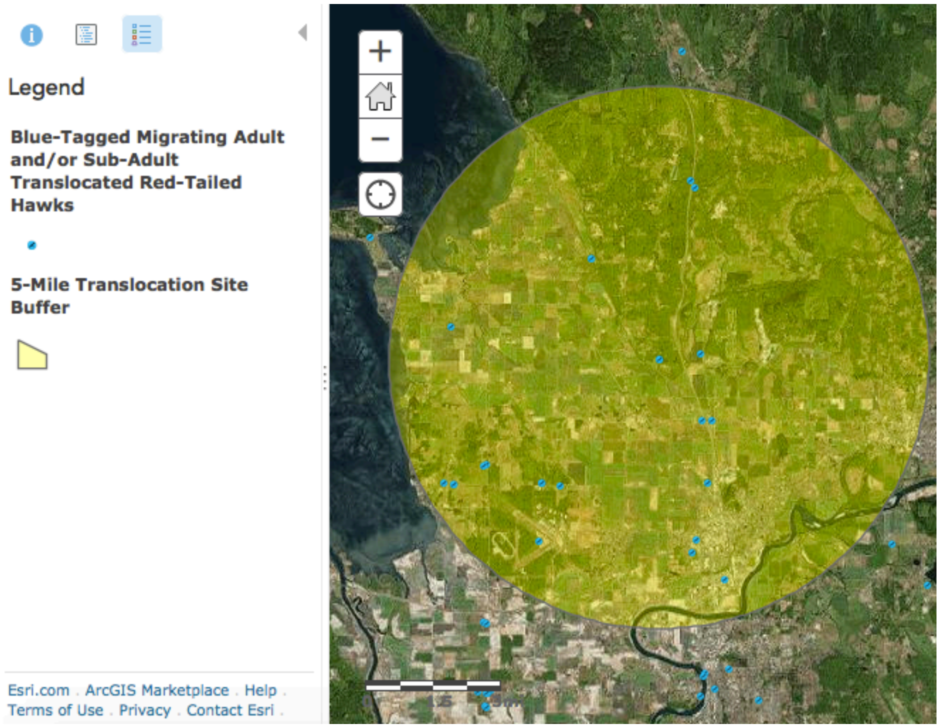


Figure 9. Blue-Tagged Red-Tailed Hawk Resights Within Translocation Site Five-Mile Buffer (n= 18).

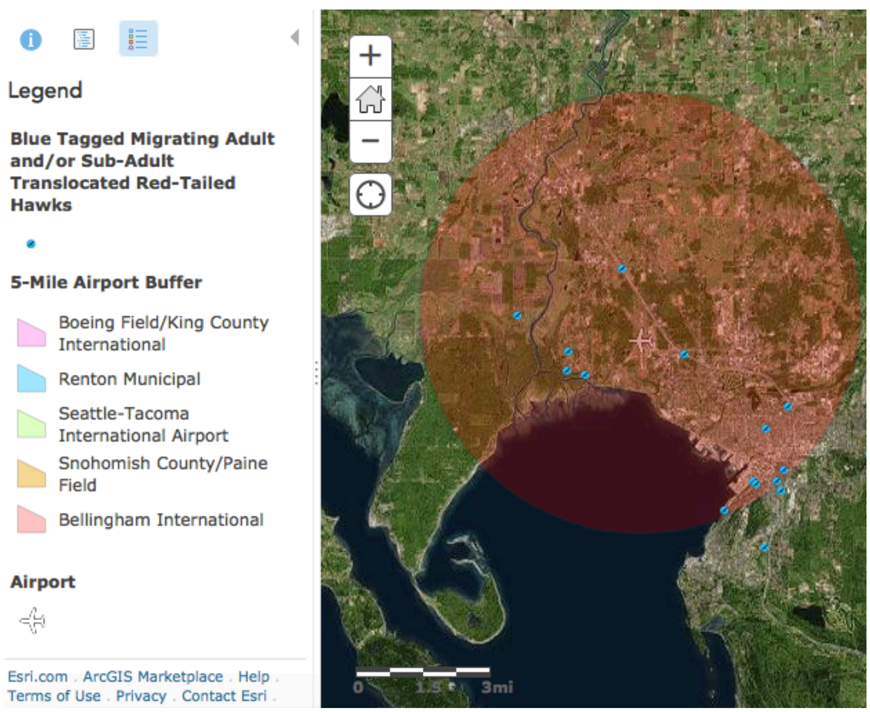


Figure 10. Blue-Tagged Red-Tailed Hawk Resights Within Bellingham International Airport Five-Mile Buffer (n=6).

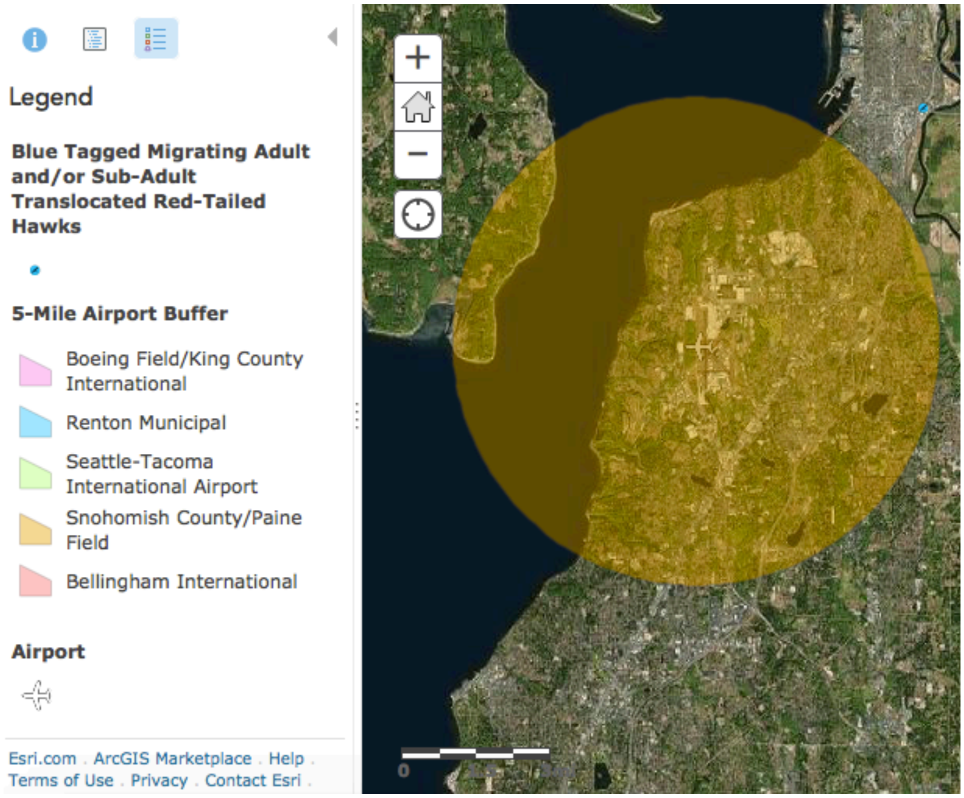


Figure 11. Blue Tagged Red-Tailed Hawk Resights Within Snohomish County/Paine Field Airport Five-Mile Buffer (n=0).

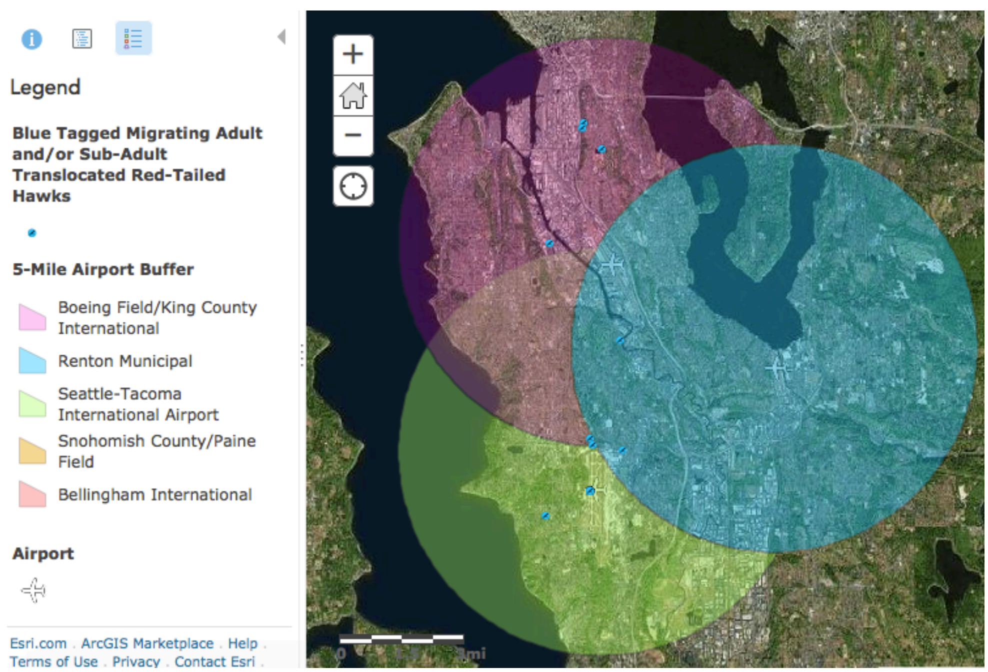


Figure 12. Blue-Tagged Red-Tailed Hawk Resights Within Seattle-Tacoma International Airport, King County International Airport/Boeing Field, and Renton Municipal Airport Five-Mile Buffers (Sea-Tac n=6, Renton n=5, Boeing n=7).

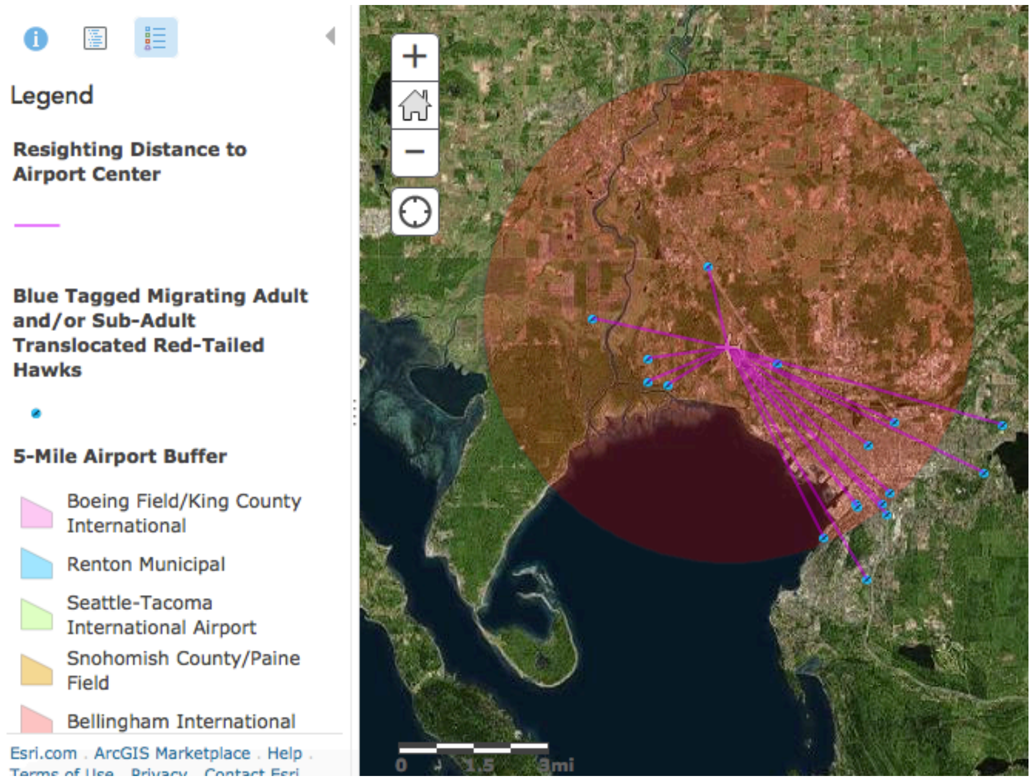


Figure 13. Distances of Red-Tailed Hawk Resights to Bellingham International Airport.

Figure 14. Distances of Red-Tailed Hawks Resights from Sea-Tac, Boeing Field, and Renton Municipal Airports.

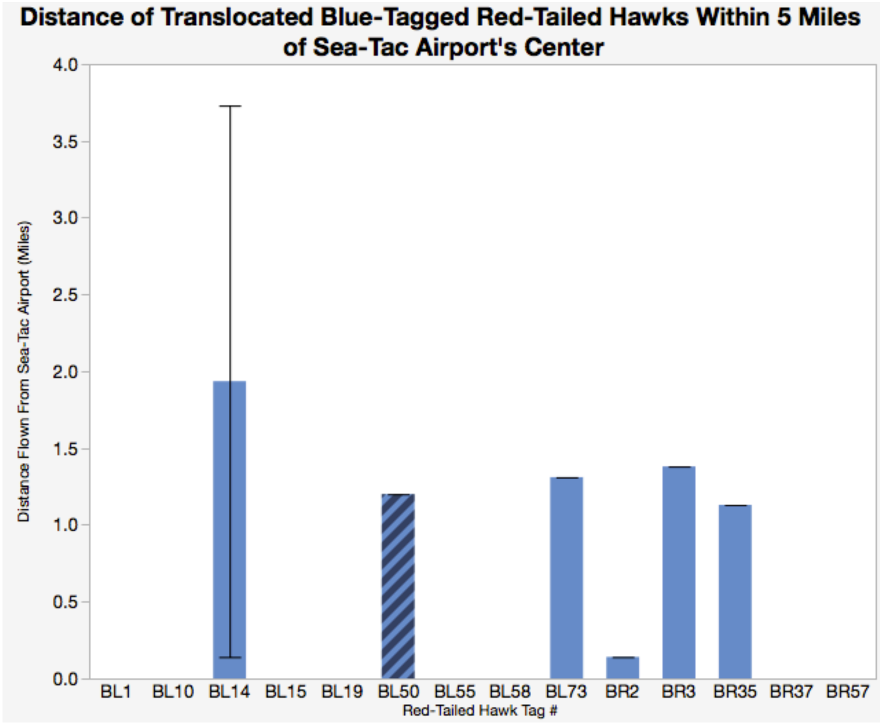


Figure 15. Distance of Translocated Blue-Tagged Red-Tailed Hawks Within 5 Miles of Sea-Tac Airport's Center (n=6).

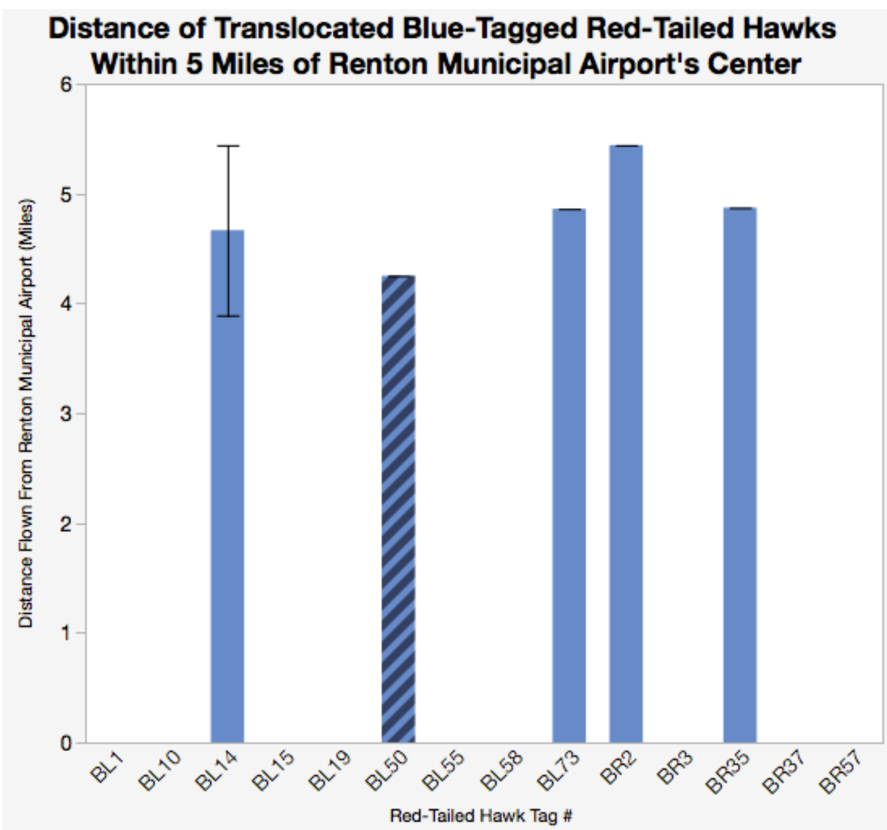


Figure 16. Distance of Translocated Blue-Tagged Red-Tailed Hawks Within 5 Miles of Renton Municipal Airport's Center (n=5).

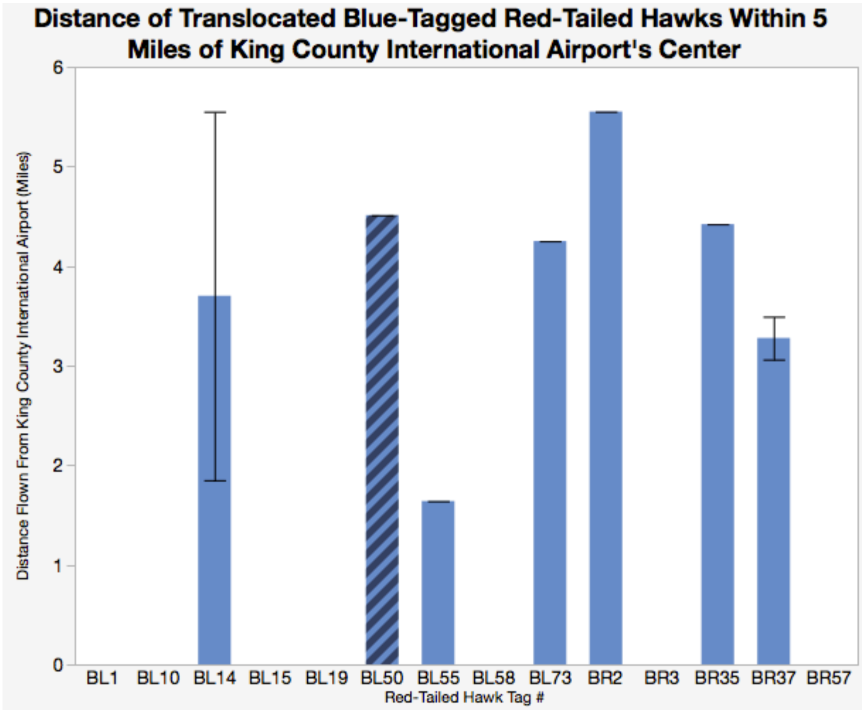


Figure 17. Distance of Translocated Blue-Tagged Red-Tailed Hawks Within 5 Miles of King County International Airport's Center (n=7).

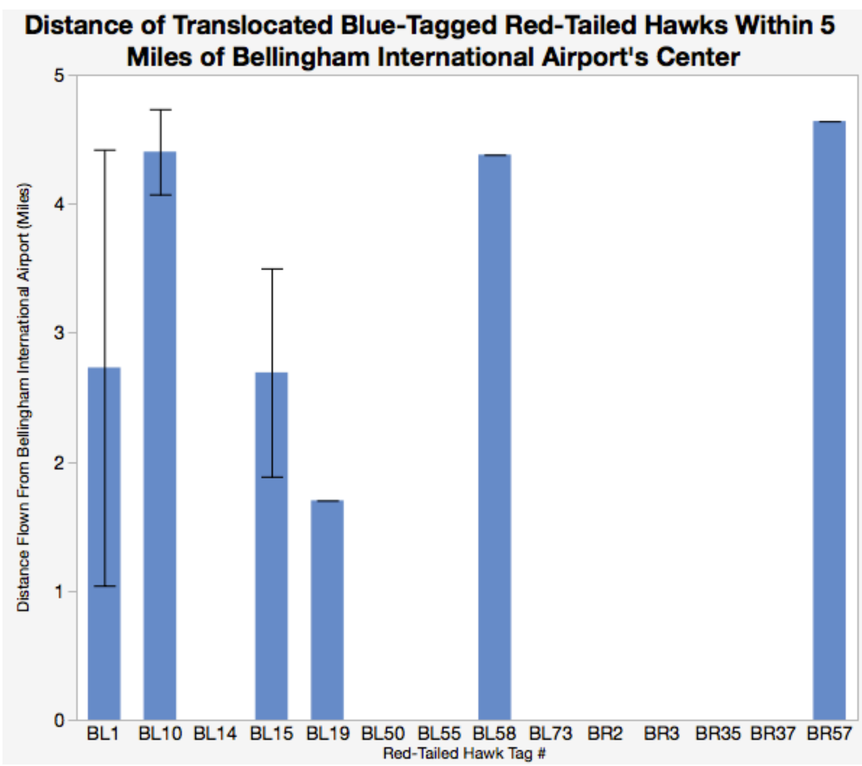


Figure 18. Distance of Translocated Blue-Tagged Red-Tailed Hawks Within 5 Miles of Bellingham International Airport's Center (n=6).

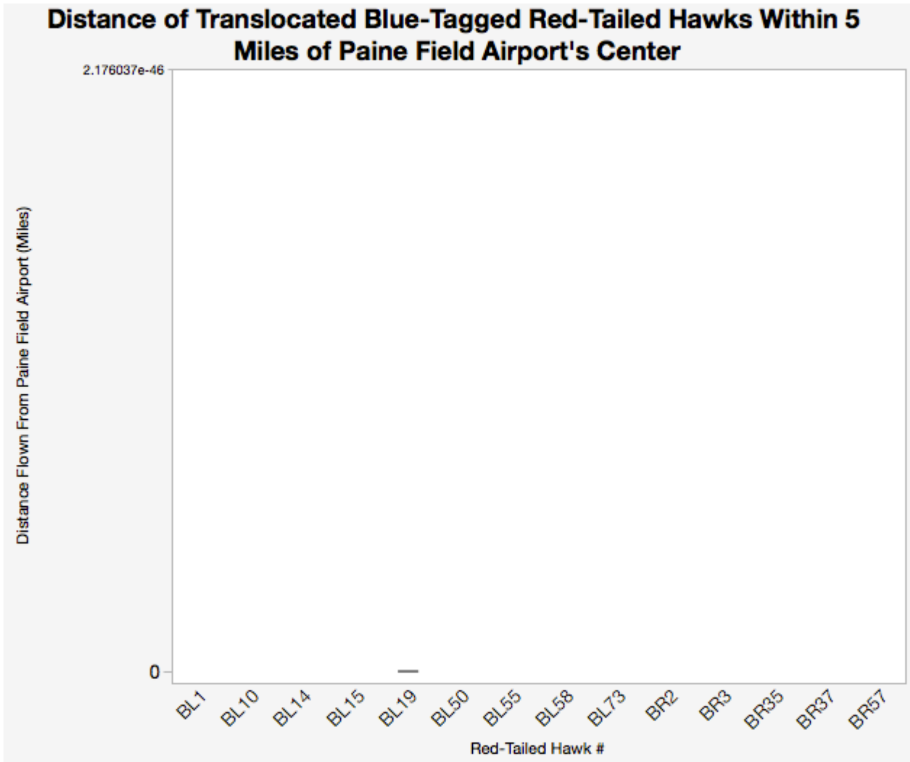


Figure 19. Distance of Translocated Blue-Tagged Red-Tailed Hawks Within 5 Miles of Paine Field Airport's Center (n=0).

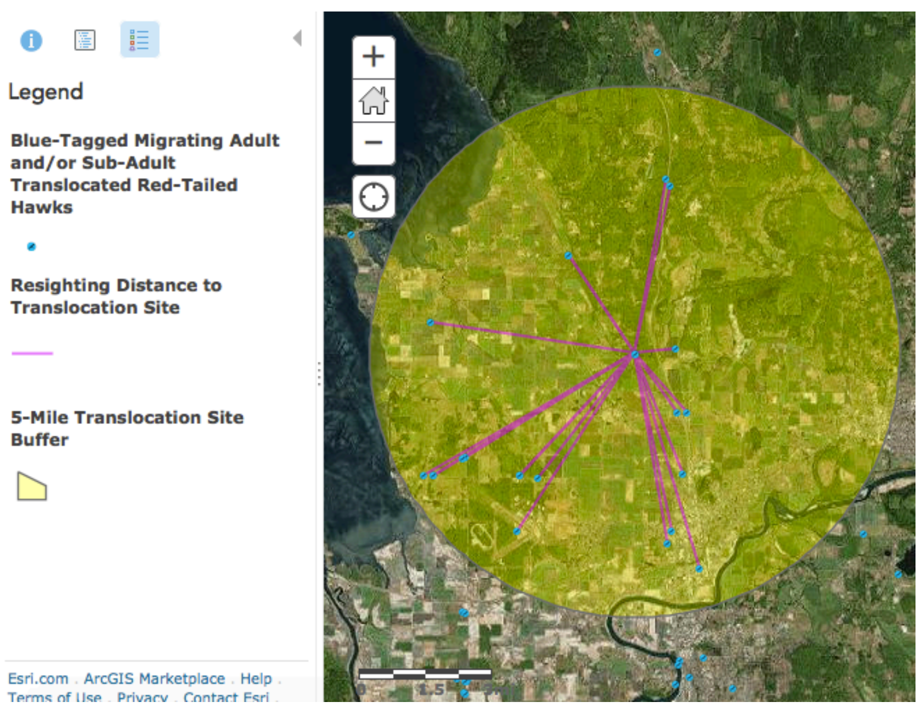


Figure 20. Distances of Red-Tailed Hawk Resights From Translocation Site in Bow, Washington.

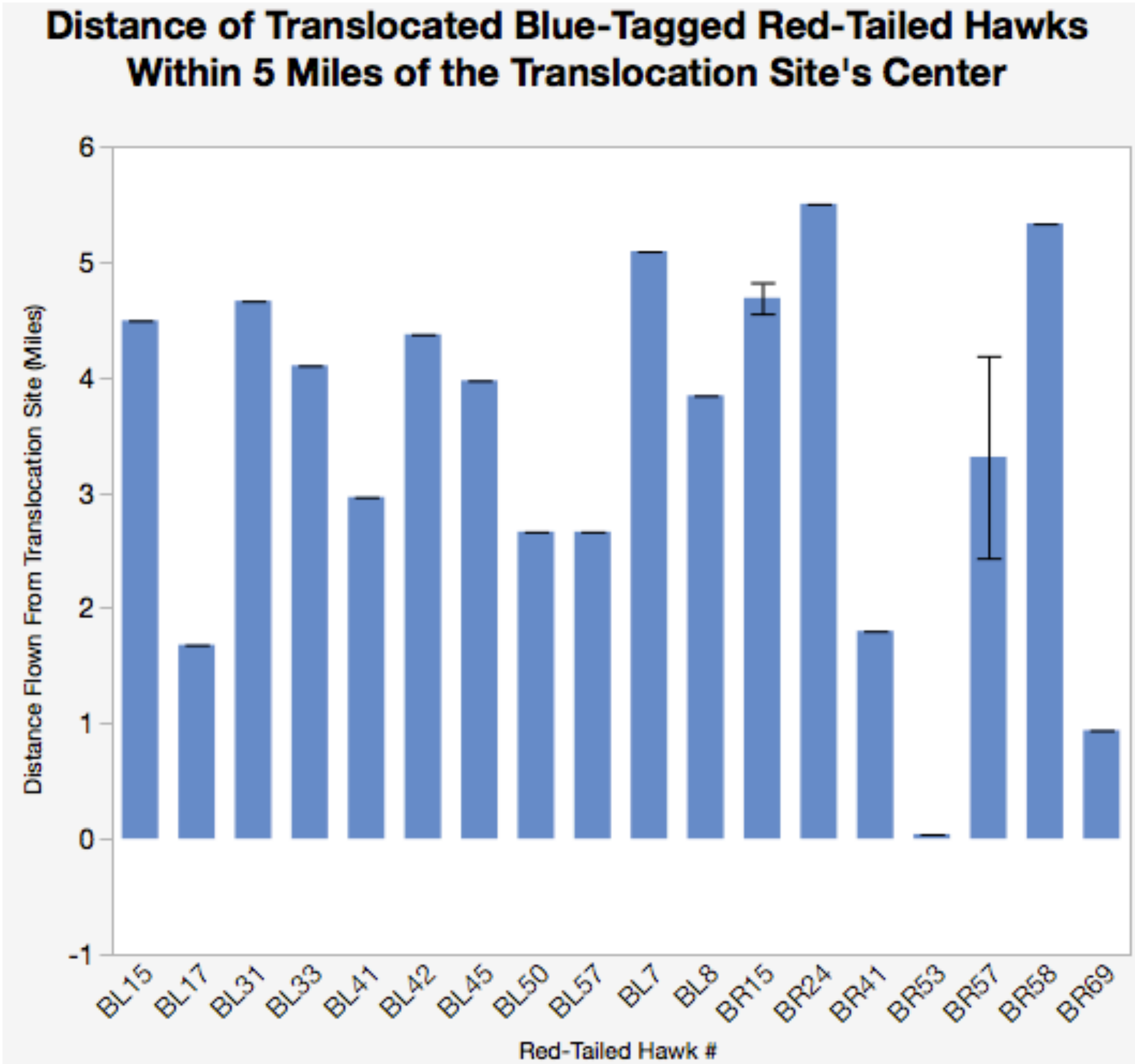


Figure 21. Distance of Translocated Blue-Tagged Red-Tailed Hawks Within 5 Miles of the Translocation Site's Center (n=18).

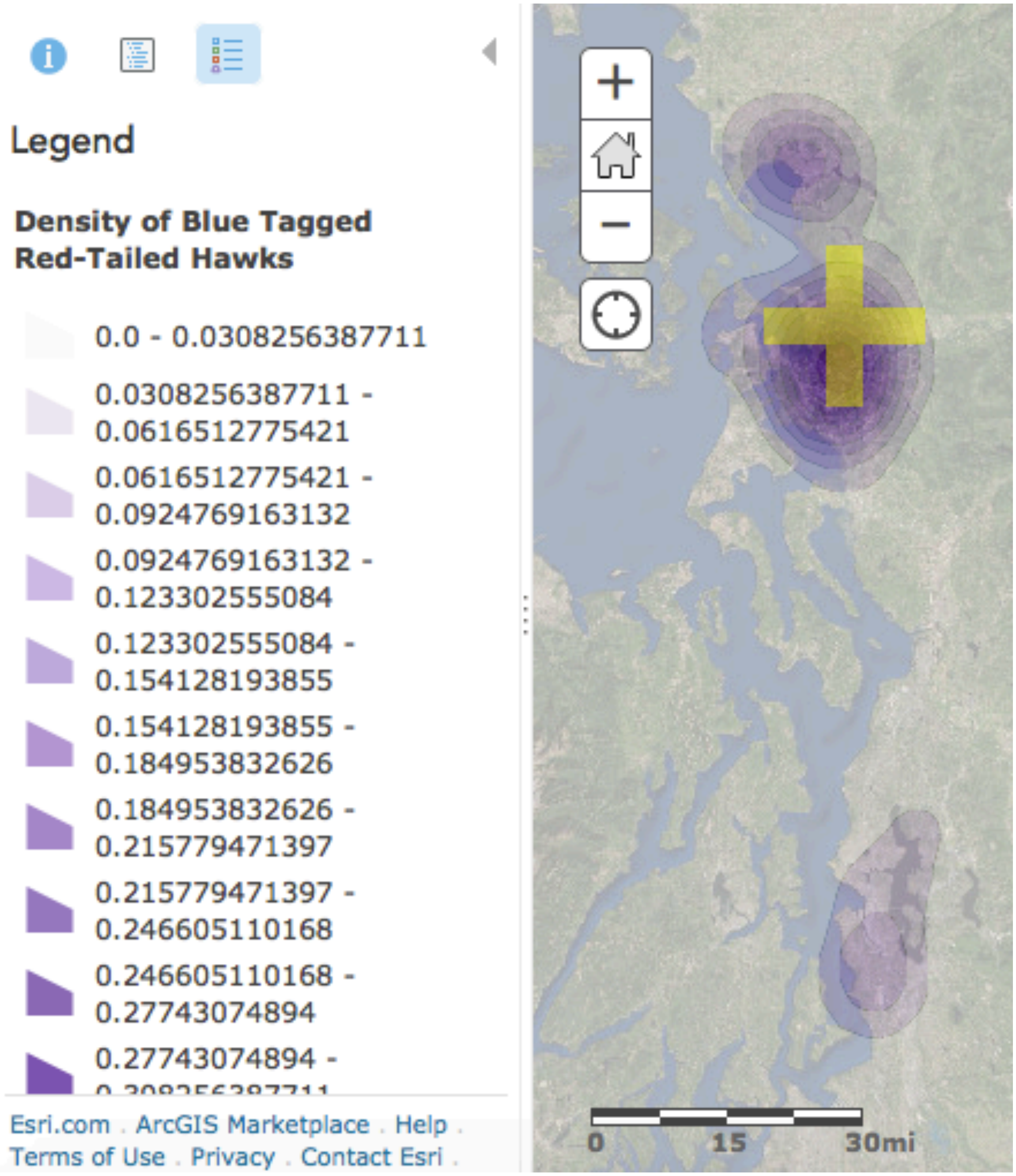


Figure 22. Blue Tagged Red-Tailed Hawk Resight Density.

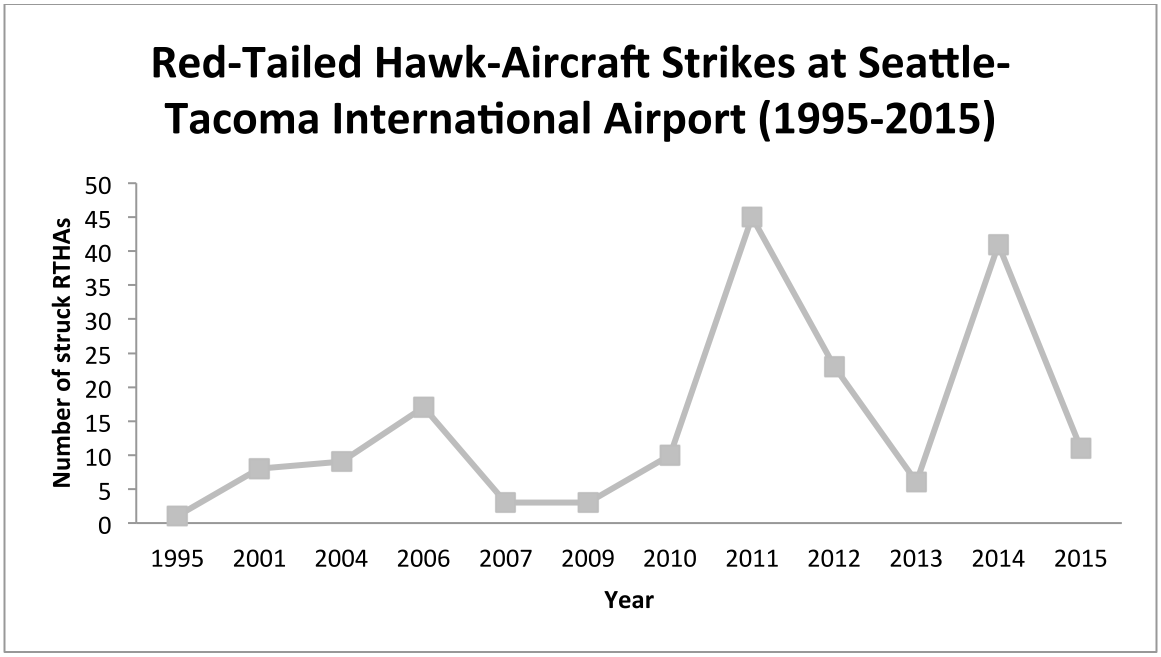


Figure 23. Red-Tailed Hawk Strikes With Aircraft at Seattle-Tacoma International Airport From 1995-2015 (FAA Wildlife Strike Database).

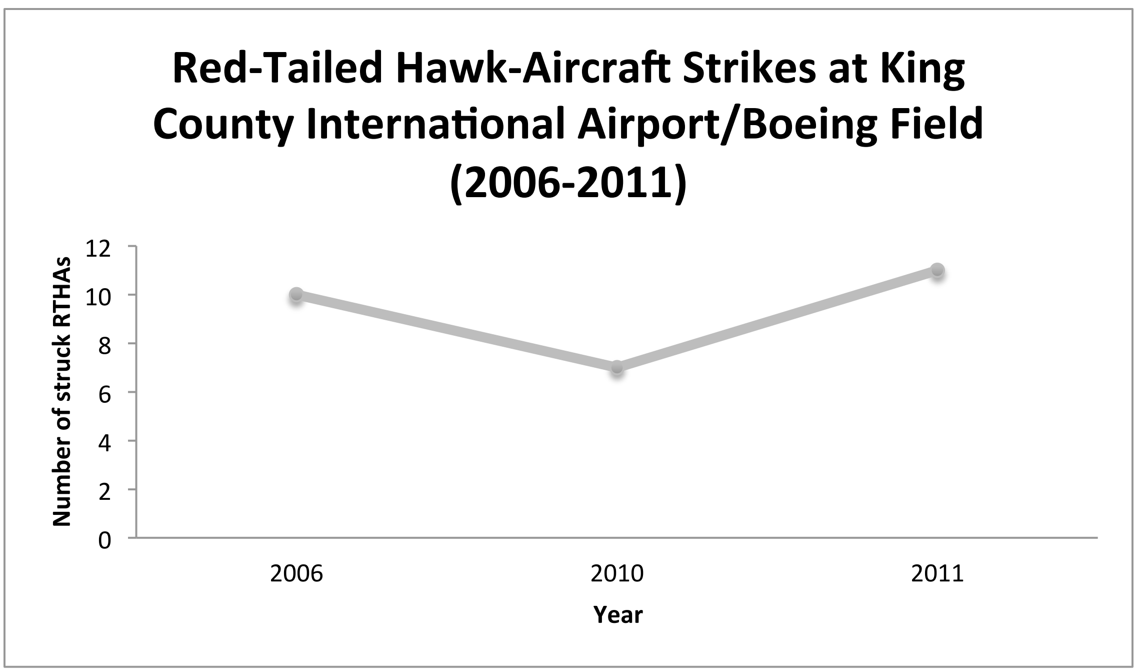


Figure 24. Red-Tailed Hawk Strikes With Aircraft at King County International Airport/Boeing Field From 2006, 2010 and 2011 (FAA Wildlife Strike Database).

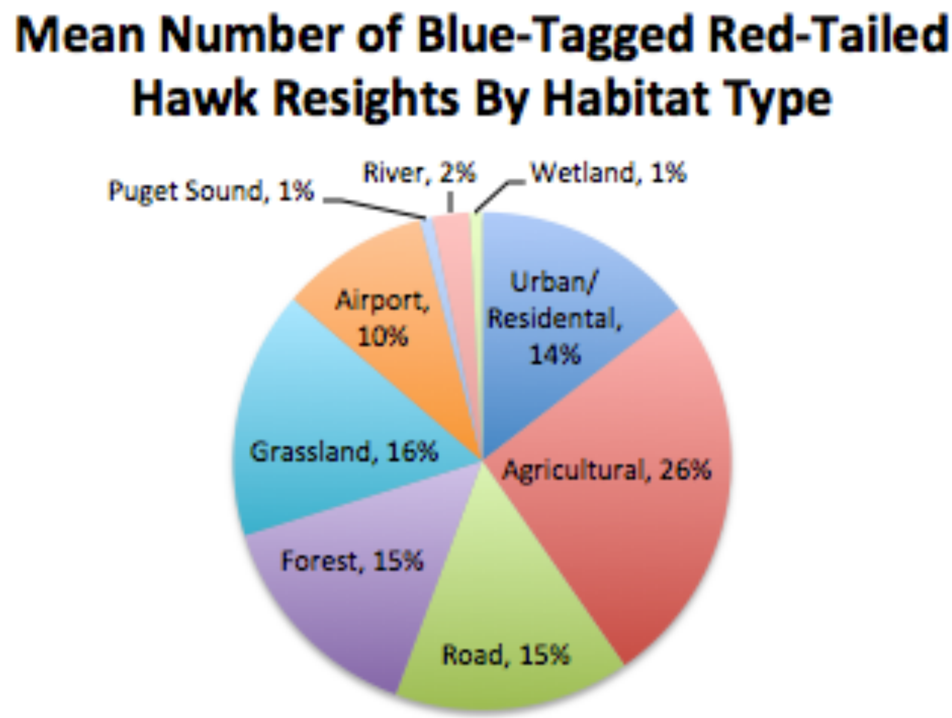


Figure 25. Mean Number of Blue Tagged Red-Tailed Hawk Resights By Habitat Type.

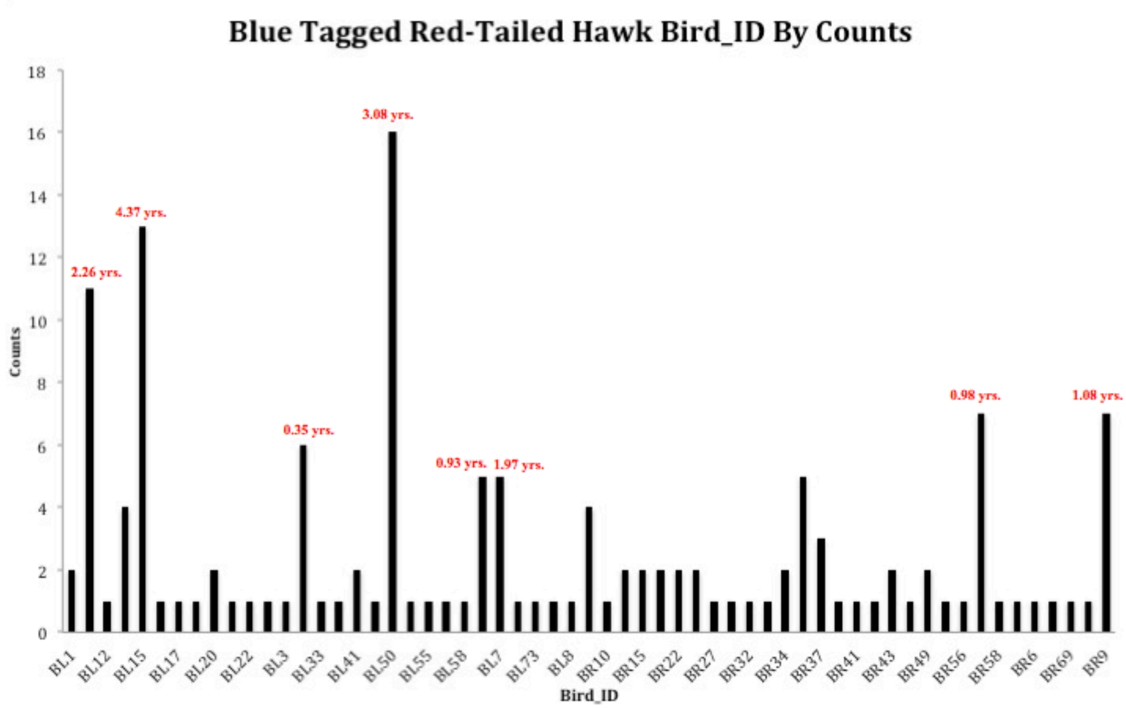
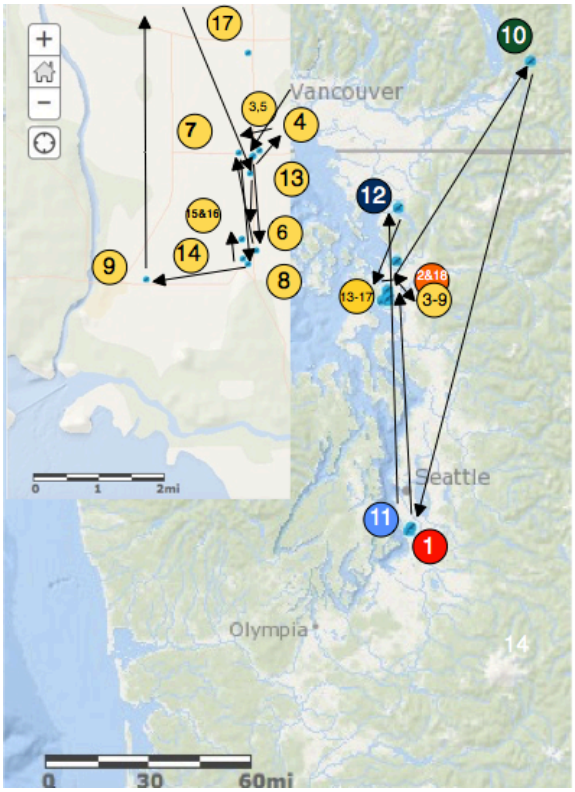


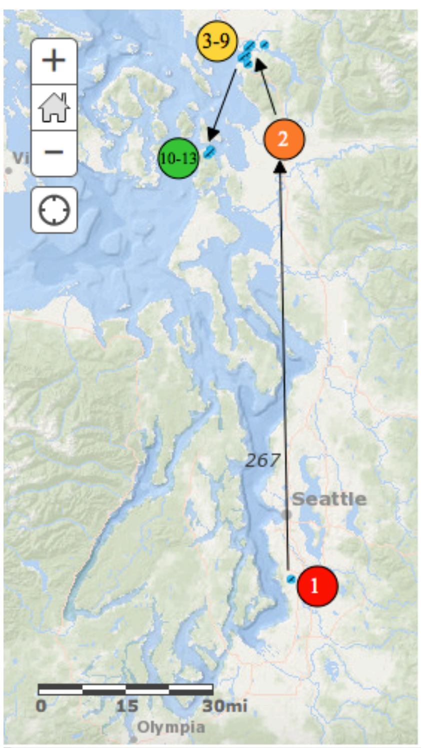
Figure 26. Repeatedly Sighted Translocated Blue-Tagged Red-Tailed Hawks in the Dataset.



BL50's Tale:

1 Trapped at Sea-Tac Airport (10/31/11)
2 Relocated to Bow, WA
3-9 Resighted near La Conner, WA (1/14/12, 1/31/12, 4/12/12, 6/12/12, 9/4/12, 12/31/12, 2/2/13)
10 Resighted in Hope, B.C., Canada (11/2/13)
11 Resighted near Sea-Tac Airport (12/4/13)
12 Resighted in Bellingham, WA (12/9/13)
13-17 Resighted in La Conner, WA (1/24/14, 2/14/14, 3/29/14, 8/17/14, 12/30/14)
18 Resighted in Bow, WA (2/14/15)

Figure 27. BL50's Flight Path Story Over Time.



BL10's Tale:

1 Trapped at Sea-Tac Airport (8/17/10)
2 Relocated to Bow, WA
3-9 Resighted in Bellingham, WA (11/27/10, 6/1/11, 8/13/11, 11/6/11, 11/12/11, 1/7/12, 2/10/12)
10-13 Resighted in Anacortes, WA (2/27/12, 4/1/12, 5/2/12, 2/19/13)

Figure 28. BL10's Flight Path Story Over Time.

Figure 29. BL82's Flight Path Story Over Time.

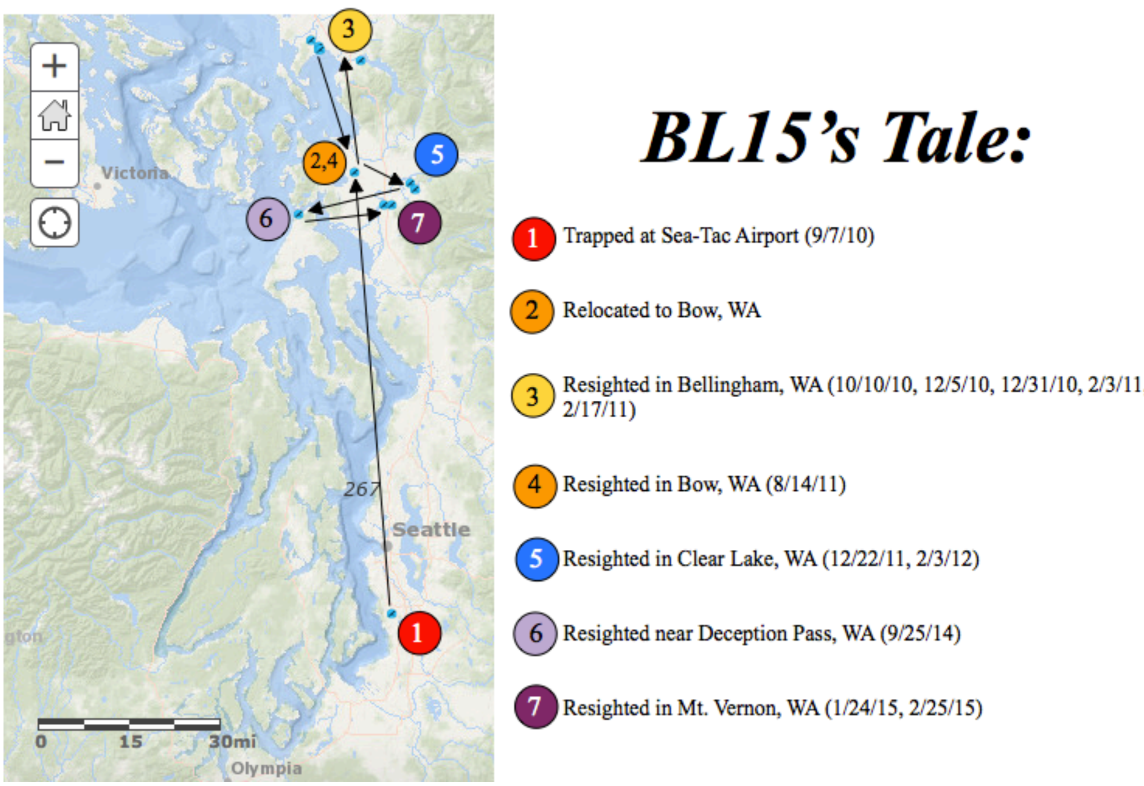
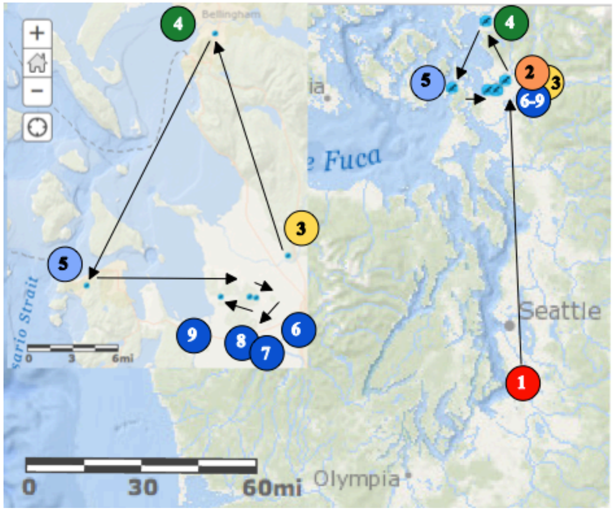


Figure 30. BL15's Flight Path Story Over Time.

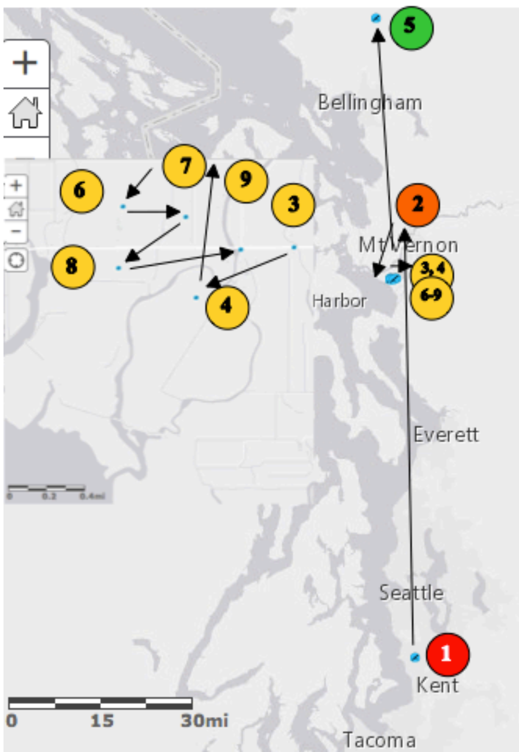


BR57's Tale:

1. Trapped at Sea-Tac Airport
2. Relocated to Bow, WA
3. Resighted near Bow, WA (3/9/14)
4. Resighted in Bellingham, WA (5/11/14)
5. Resighted in Anacortes, WA (11/16/14)

6-9. Resighted near Mount Vernon, WA (1/15/15, 2/17/15, 2/25/15, 3/2/15)

Figure 31. BR57's Flight Path Story Over Time.



BR9's Tale:

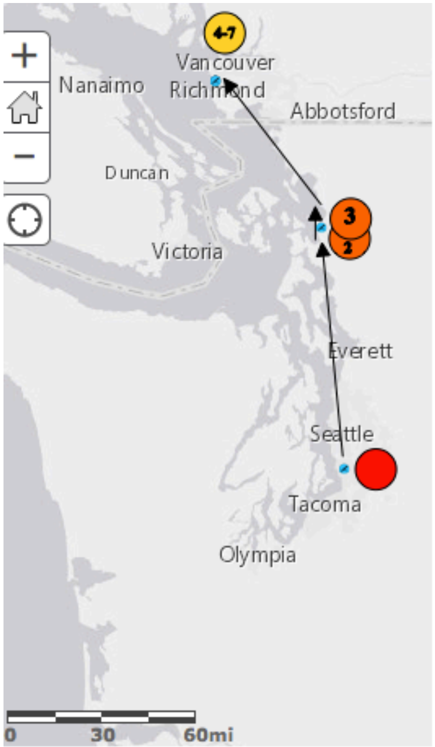
1. Trapped at Sea-Tac Airport (9/14/10)
2. Relocated to Bow, WA

3,4. Resighted near La Conner, WA (12/1/10, 12/10/10)

5. Resighted near Lynden, WA (4/11/11)

6-9. Resighted near La Conner, WA (8/12/11, 8/27/11, 10/9/11, 12/29/11)

Figure 32. BR9's Flight Path Story Over Time.



BL31's Tale:

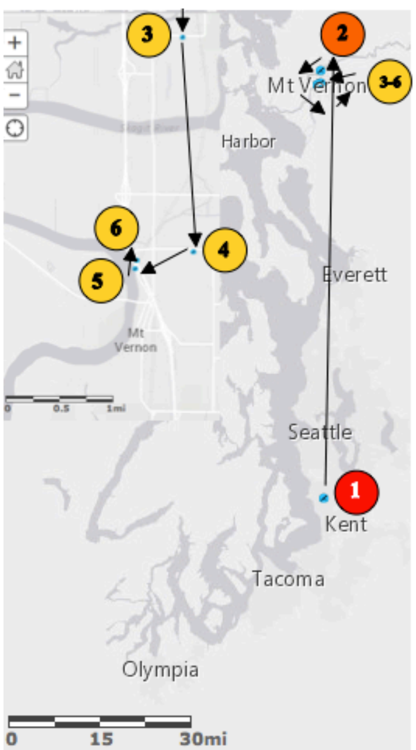
1 Trapped at Sea-Tac Airport (8/9/11)

2 Relocated to Bow, WA

3 Resighted in Bow, WA (12/7/12)

4-7 Resighted at Vancouver International Airport (12/24/12, 1/11/13, 1/29/13, 4/13/13)

Figure 33. BL31's Flight Path Story Over Time.



BL7's Tale:

1 Trapped at Sea-Tac Airport (1/19/10)

2 Relocated to Bow, WA

3-6 Resighted in Mount Vernon, WA (9/16/10, 10/14/10, 1/28/11, 8/19/11)

Figure 33. BL7's Flight Path Story Over Time.

Chapter 3 Tables

Rank	**Airport Name**	**Operations Count (Number of Airplane Takeoffs or Landings Per Year)**
1	Seattle-Tacoma International Airport	313,954
2	King County International Airport/Boeing Field	259,396
7	Snohomish County/Paine Field Airport	110,270
9	Renton Municipal Airport	80,059
17	Bellingham International Airport	62,783

Table 1. Washington State Department of Transportation Airport Names and Operations.

High Repeat	Trapped Date	First Observation	Last Observation	# Sightings	Sighting Duration	In Airport Buffer	In Bow Buffer	Last Observed Status	Return to Sea-Tac	Return 1 Date
BL10	8/17/10	11/27/10	2/19/13	11s.	2.26 yrs.	Yes (BLI)	No	Alive	No	
BL15	9/7/10	10/10/10	2/25/15	11s.	4.37 yrs	Yes (BLI)	Yes	Alive	No	
BL31	8/9/11	12/7/12	4/13/13	5s.	0.35 yrs.	No	Yes	Alive	No	
BL50	10/31/11	1/14/12	2/14/15	16s.	3.08 yrs.	Yes (SEA/BFI/RNT)	Yes	Alive	Yes	12/4/13
BL7	1/19/10	9/16/10	8/19/11	4s.	0.93 yrs.	No	Yes	Alive	No	
BL82	7/23/12	10/24/12	10/10/14	4s.	1.97 yrs.	No	No	Alive	No	
BR57	Unknown	3/9/14	3/21/15	7s.	0.98 yrs.	Yes (BLI)	Yes	Alive	No	
BR9	9/14/10	12/1/10	12/29/11	7s.	1.08 yrs.	No	No	Alive	No	

Table 2. Results Summary.

Chapter 4: Conclusions and Recommendations for Future Research

Conclusions

This study argues that the raptor program is working successfully and encourages a safer flight path for both air travel passengers and avifauna at Sea-Tac and Boeing Field based on the O'Hare and Toronto benchmark. Other airports beyond Sea-Tac could potentially benefit from adapting the Sea-Tac program for RTHA relocation and resighting to their own relocation and subsequent monitoring (resighting) needs.

Greater data standardization is needed to better answer my research question. There is certainly room for program improvement through more extensive public education, outreach opportunities, and bird identification training classes. Further study of aircraft strike reports could help to relate the relocation/return evidence to aircraft operations and flight safety, but would require more systematic protocols for both strike reporting and resighting data collection.

Recommendations for Future Research

A better method of determining elevation preferences would be useful for future research. For example, using a contouring method for the elevation preference data and enhanced quantitative analysis in GIS could have been more effective for elevation spatial analysis. Contouring analysis may be a better way of looking at elevation data than using the slope data that was used in this thesis.

Additionally, data management for the RTHA resight data could be significantly improved and more efficient. An area for improvement that Sea-Tac Aviation Operations wildlife staff might consider could be creating a mobile collector application where staff and public participants can submit hawk resight data from their smartphone device (which automatically tags bird locations and generates a map of all resights), rather than wildlife biologists receiving an abundance of resight location emails. Improvements in data organization are also needed. Improving methods for data collection and reporting could lead to more precise understanding of program effectiveness and areas where funding could help to fill in gaps in knowledge.

More substantial research needs to be done on the resident RTHA airport population to fully understand the role of resident birds at Sea-Tac. For example, Sea-Tac biologists do not have enough evidence to support the role of resident RTHAs at the airport. Anecdotally, biologists' observations have reported that resident birds have learned aircraft avoidance and scare off other non-resident birds. To fill these information gaps, Sea-Tac's future research plans include recapturing resident airport RTHAs and tracking resident movement using radio telemetry. This future research has the potential to monitor residents and determine if residents are crossing runways and/or defending the runway from other avian migrants and juveniles. Additionally, more resident data and grant funding for radio tags has the potential for more research questions to be answered.

Improving the program may require targeted funding for improved data collection methods, relating strike data to raptor presence and quantifying the benefit of relocation of raptors (like RTHA) to areas far away from airfields in this study, to enable more widespread outreach and observer training over a larger region, and to capture metrics on observer effort in areas where birds are not observed.

References

Anderson, C. and Osmek, S. (2005). Raptor strike avoidance at seattle-tacoma international airport: a biological approach. *2005 Bird Strike Committee-USA/Canada 7th Annual Meeting, Vancouver, BC.* Paper 1.

Barras, Scott C. and Seamans, Thomas W., "Habitat Management Approaches for Reducing Wildlife Use of Airfields" (2002). *USDA National Wildlife Research Center - Staff Publications.* Paper 463.

Blackwell, B.,Wright, S. (2006). Collisions of red-tailed hawks (buteo jamaicensis), turkey vultures (cathartes aura), and black vultures (coragyps atratus) with aircraft: implications for bird strike reduction. *Journal of Raptor Research* 40(1):76-80.

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

Baker, J., Brooks, R. (1981). Raptor and vole populations at an airport. *The Journal of Wildlife Management* 45(2):390-396.

Clay, W. (2016). Biologists to test impact of auxiliary markings on snowy owl. *USDA National Wildlife Research Center.*

Coccon, F. Zucchetta, M. Bossi, G. Borrotti, M. Torricelli, P. Franzoi, T. (2015). A landuse perspective for bird strike risk assessment: the attraction risk index. *PLoS ONE* 10(6):1-16.

Craven, S., Barnes, T., Kania G. (1998). Toward a professional position on the translocation of problem wildlife. *Wildlife Society Bulletin* 26:171-177.

Belant, J.L., B.E. Washburn, and T.L. DeVault. 2013. Understanding animal movements at and near airports. In T.L. DeVault, B.F. Blackwell, and J.L. Belant, editors. Wildlife in Airport Environments: Preventing Animal-Aircraft Collisions through Science-Based Management. The Johns Hopkins University Press, Baltimore, Maryland, in association with The Wildlife Society. 128-138.

Belant, J.L., B.E. Washburn, and T.L. DeVault. 2013. Wildlife translocation as a management alternative at airports. In T.L. DeVault, B.F. Blackwell, and J.L. Belant, editors. Wildlife in Airport Environments: Preventing Animal-Aircraft Collisions through Science-Based Management. The Johns Hopkins University Press, Baltimore, Maryland, in association with The Wildlife Society. 128-138.

Dolbeer, R., Wright, S., Cleary E. (2000). Ranking the hazard level of wildlife species to aviation. *Wildlife Society Bulletin* 28(2):372-378.

Donohue, K., Dufty, A. (2006). Sex determination of red-tailed hawks (buteo jamaicensis calurus) using DNA analysis and morphometrics. *Journal of Field Ornithology* 77(1):74-79.

Dunn et al. (2005). Enhancing the scientific value of the Christmas bird count. *The Auk* 122(1):338-346.

Wildlife Strikes to Civil Aircraft in the United States, 1990-2014. U.S. Department of Transportation, Federal Aviation Administration, Washington D.C., USA. < http://wildlife.faa.gov/database.aspx >Accessed 2015 Jan 17.

Guerrant, T., Pullins, C., Beckerman, S., Washburn, B. (2013). Managing raptors to reduce wildlife strikes at chicago's o'hare international airport. *Wildlife Damage Management Conferences – Proceedings.* Paper 159.

Guinn, J. (2013). Generational habituation and current bald eagle populations. *Human-Wildlife Interactions* 7(1):69-76.

Griffith, B., Scott, J., Carpenter, J., Reed, C. (1989). Translocation as a species conservation tool: status and strategy. *Science* 245:477-480.

Henkes, G. (2009). Migratory canada geese cause crash of us airways flight 1549. *Frontiers in Ecology and the Environment* 7:297-301.

Hull, J., Hull, A., Sacks, B., Smith., J., Ernest., H. (2008). Landscape characteristics influence morphological and genetic differentiation in a widespread raptor (buteo jamaicensis). *Molecular Ecology* 17(3):810-824.

Janes, S. (1984). Fidelity to breeding territory in a population of red-tailed hawks. *Condor* 86:200-203.

Janes, S. (1984). Influences of territory composition and interspecific competition on red-tailed hawk reproductive success. *Ecology* 65(3):862-870.

Kelly, T. (1999). Seasonal variation in bird strike rate for two north American raptors: turkey vulture (cathartes aura) and red-tailed hawk (buteo jamaicensis). *Journal of Raptor Research* 33: 59-62.

Martin, James A.; Belant, Jerrold L.; DeVault, Travis L.; Blackwelll, Bradley F.; Berger, Loren W.; Riffell, Samuel K.; and Wang, Guiming, "Wildlife risk to aviation: a multi-scale issue requires a multi-scale solution" (2011). *USDA National Wildlife Research Center - Staff Publications.* Paper 1311.

Stout, W., Temple, S., Papp, J. (2009). Landscape correlates of reproductive success for an urban-suburban red-tailed hawk population. *The Journal of Wildlife Management* 70(4):989-997.

Schafer, L., Cummings, J., Yunger, J., Gustad, K. (2002). Evaluation of raptor translocation at o'hare international airport, Chicago, Illinois final report. *USDA National Wildlife Research Center – Staff Publications.*

Sullivan, B. et al. (2014). The ebird enterprise: an integrated approach to development and application of citizen science. *Biological Conservation* 169:31-40.

Tulloch, A., Possingham, H., Joseph, L., Szabo, J., and Martin, T. (2013). Realizing the full potential of citizen science monitoring programs. *Biological Conservation* 165:128-138

Washington State Department of Transportation Statewide Airports Report 2015.

Wernaart, M., Groh, T., Roberts, P (1999). Evaluation of controlling red-tailed hawks (buteo jamaicensis) through live trapping and relocation to minimize aircraft strikes at canadian airports. *1999 Bird Strike Committee-USA/Canada First Joint Annual Meeting Vancouver, BC.* Paper 37.

Witmer, G. (2011). Rodent population management at kansas city international airport. *Human-Wildlife Interactions* 5(2):269-275.

Port of Seattle Wildlife Management Plan 2004.

Appendix

Variables

The variables of interest for this research include elevation preferences, habitat preferences, hawk distance from the five chosen airports, and return rates. Independent variables include elevation, habitat type, and distance to nearest airport. Dependent variables include time, return rates, and hawk sightings. Elevation will be measured in meters, return rates will be measured in percentages, hawk distance from the chosen airports will be measured in miles, and habitat types will be documented categorically. To evaluate the success of the RSAP, Sea-Tac's RTHA resight data in GIS will be used calculate the return rates of relocated RTHA.

Detailed GIS Methods

GIS Data Management

The RTHA resighting dataset came from Sea-Tac Airport in an Excel (xlsx) spreadsheet file. The xlsx file was converted into a comma separated value (CSV) file because CSV files are compatible for ArcCatalog and ArcMap. The RTHA CSV file consisted of Object ID, Bird ID, Date, Action, Location, Latitude, Longitude, Comments, and Originating Airport attributes. The western Washington airport operations data table was generated from page thirty-nine of Washington Department of Transportation's (WSDOT) Statewide Airports Profile Report Based on Information Recorded in 2015 Top Twenty Airports By Operations within WSDOT's Airport Information System PDF document. This PDF file supplemented with data from its associated pop-ups for airports in WSDOT's Airport Map Application was first converted into an xlsx file and then saved as a CSV file. The western Washington airport operations CSV file consisted of Rank, Civil Airport Name, Latitude, Longitude, Operations Count, Location, Ownership, and FAA Class attributes. Initially, ArcCatalog was used to manage a geodatabase for preliminary data management. In ArcCatalog, the RTHA resighting data table and the western Washington airport operations table were both imported into the geodatabase. A feature class for the RTHA resighting data and a feature class for the western Washington airport operations data were created by right clicking on each of the data table icons (within the geodatabase) and selecting create feature class in ArcCatalog and then clicking from xy table (one at a time). This allowed the feature classes to become depicted as points and have associated spatial coordinates in its preview interface. The two feature layers were then dragged and added into ArcMap and the coordinate system was set to WGS 1984 for both feature classes (now called layers in ArcMap language). Next, the ArcMap mxd file was shared as service map package (mpk) file into ArcGIS Online. From ArcGIS Online, a basemap was added to the map and the legend became more clearly defined and specialized for the project. The United States Geological Survey (USGS) layer called 'Terrain: Slope Map' was added to ArcGIS Online as a layer for elevation spatial analysis. Raptor resightings were added as a feature class to the map with a raptor icon in circular blue circle symbology. Airport operations were added as a feature class to map with airplane symbology.

GIS Spatial Analysis

A six-mile airport buffer was made around each airport. A yellow buffer was used for Snohomish County/Paine Field, pink buffer was used for Boeing Field, blue buffer for Renton Municipal and a green buffer for Sea-Tac. The ArcGIS Online

Analysis tool was used to gather distances of RTHAs to the nearest airports within the six-mile airport buffers. After clicking the Analysis tool, 'Proximity' was chosen, then 'Find Nearest' was clicked. Next, the Red-Tailed Hawk Resightings feature class was chosen for the '(1) Choose the layer from which the nearest locations are found' option. The Airport Operations in Western Washington feature class was chosen for the (2) Find the nearest location' option. A line distance was used for '(3) Measure'. Under '(4) for each location in the input layer' three was the 'limit the number of nearest locations' and five miles was the 'limit the search range'. The density tool was used to show concentrations of RTHA population densities and depicts where RTHA resight clusters occur, but does not indicate statistical significance for clustering. In ArcGIS Online, 'Analyze patterns' was chosen to calculate density for the dataset. For option (1), 'Choose point or line layer from which to calculated density: Red-Tailed Hawk Resightings' was chosen. For option (2), Use a count field: no count was chosen. A 50-mile search distance was generated and classified by equal intervals for the dataset. Ten classes were created for the data and square miles were the output units. The drawing style of the map was changed using the counts and amounts option. In ArcGIS Online, each RTHA resighting was given a habitat preference. The categories of habitat preferences were as follows: urban/residential, agricultural, road, forest, grassland, airport, Puget Sound, river, and wetland. Additionally, mean elevation preferences (in meters) were documented.