Satellite Telemetry, A Tool for Tracking and Monitoring Bird Movements from a Local to Global Scale

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Abstract

Bird strikes to aircraft can result in damage that is expensive to repair and as lost revenue due to equipment down-time. Bird strikes also poses a safety risk to commercial, private and military aviation because it has resulted in serious human injury and death. Biotelemetry has been used effectively to examine the behavior, range, and biology of avian species since the early 1960s (Samuel and Fuller 1984). Conventional biotelemetry has been used to support basic research on birds as well as the conservation of avifauna throughout the world. However, biotelemetry has limitations that do not easily allow for the continuous tracking and monitoring of bird species over long distances for long periods. In the early

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1980's satellite located Platform Transmitter Terminals (PTT), compatible with the French owned Argos System, were developed to track and monitor avian species on a local to global scale (Strikwerda et al. 1985 and 1986). We report here on aspects of the development of bird-borne PTTs and some of the past and present applications of satellite tracking to study avian species. The use of satellite tracking to locate and forecast bird movements and migration to aid in the bird strike problem has been proposed (Leshem 1990). A satellite tracking system used with other emerging technologies and capabilities to address the bird strike problem is discussed.

Conventional Telemetry System Technologies

Biotelemetry has dramatically influenced the direction of wildlife research since the first application by Southern (1964) to study the wintering behavior of bald eagles (Haliaeetus leucacephalus). The use of conventional telemetry has allowed for a more thorough capability to perform basic research and examine ecological and management issues related to animal behavior, survival, productivity, migration and habitat use. Biotelemetry has been especially helpful in the study of avian species because birds often are widely dispersed across the landscape and use large areas through which they can move quickly. Locally birds can make diurnal or nocturnal movements between forging areas and roosting sites while seasonally they can travel great distances between breeding, migratory and wintering habitats. Conventional telemetry is commonly employed to locate birds to observe behavior and gather information on their range and patterns of habitat use. This information can be collected by several methods, the most common by homing toward the radio signal or triangulation performed by deriving a directional bearing on the tagged animal from two or more receiver positions with a directional antenna. In nearly all applications of conventional biotelemetry, it is restricted to local use with animal positions being collected on foot, from automobiles or small fixed wing aircraft.

Applications of biotelemetry have been successful in developing management plans for the conservation of avian species. Bloom et. al (1993) determined by means of biotelemetry that red-shouldered hawks could easily be managed with human activity in areas in Southern California due to their home range of 1.2 square kilometer in selected woodland habitat. Haug and Olifant (1990) and Meretsky and Snyder (1992) conducting radio telemetry studies also were able to make conservation recommendations for burrowing owls (Athene canicalarga) and California condors (Gymnogyps californianus) in their own unique habitats. Condors posed more difficult study problems because they ranged over 200 kilometers during forging flights from their nest or roost. In this study conventional telemetry was used to supplement observations to assist in evaluating the birds behaviors and collect injured or dead individuals. Sherrod et. al (1981) similarly used biotelemetry to examine the release of captive bred peregrine falcons in order to re-establish the species in areas from which they were previously extirpated due to pesticide use. Small tail mounted transmitters were used to track peregrines to examine their behavior, adaptation to the wild state, and determine the causes and rate of mortality.

Biotelemetry also has been used to assess effects of land use activities on avian species. Buehler et. al (1991) and Anderson et. al (1990) used radio telemetry to evaluate raptor behavior in regard to material test and evaluation activities on military lands. Seegar and Fuller have co-managed a comprehensive program to study raptors in relation to military training in the Snake River Birds of Prey National Conservative Area (SRBOPNCA), (Marzluff et. al, 1993). Biotelemetry was used on 120 prairie falcons (Falco mexicanus) during four breeding seasons to examine their distribution and evaluate the effects of military training on their biology. Location estimates were collected and correlated to real-time military training, vegetation, ground cover, prey distribution and other geographically significant variables. Home range and falcon activity can be evaluated in regard to these parameters. Land use patterns of the local population of prairie falcons derived from the random telemetry sample also were examined using a splined subroutine in Arc/Info Software (Arc/Info, Environmental Systems Research Institute Inc., Redlands, California). This approach was used to produce a contour map of prairie falcon spatial use of the study area. The Geographic Information System (GIS) we developed enables us to identify areas of high and low use by falcons, and to relate them to land-use patterns and management options.

Innovations in biotelemetry systems have led to the development of sensors and special-purpose transmitters to collect an array of information. The measurements of movement and temperature are the most commonly used sensors in wildlife studies (Kenward 1987:61). Motion sensors can be modified to log activity over time thus identifying periods of prolonged activity and inactivity or mortality (Kenward 1987). Sensors have been used to detect altitude (Bogel and Burchard 1992), humidity (Howey et al. 1977), gastric motility (Kuechle et al. 1987) and heart rate (Sawby and Gessaman 1974). Sladen and Cochran developed an automatic tracking station to detect the presence of telemetry signals from transmitters attached to tundra swans, (Cygnus columbianus columbianus) staging for spring migration from the Chesapeake Bay, Maryland and Virginia. The system was designed to alarm biologists when signals were detected from swans moving north from their wintering areas. Results from this work provided valuable information on the harness attachment of back-pack transmitters as well as temporal and spatial information on the swans' spring migration (Sladen et al 1969, Sladen and Cochran, 1969 and Sladen 1974). Individually coded transmitters have been developed in order to increase the number of transmitters that can be monitored in the field. Coded systems also can be used effectively with a computer based remote tracking systems that can run independently in the field (Howey et. al, 1989). Seegar, Howey and

Fuller (unpublished) used an automated coded tracking system to monitor for peregrine falcons tagged along a coastal barrier island autumn migration site in the eastern United States. The configuration of the coded system indicated the general direction of the presence of each coded transmitter on the 165/MHz receiver as it was received switching among four-element antennas pointing in different directions (north, east, south and west). This system allowed for the continuous collection of presence/absence data on an endangered species as it used critical coastal migratory habitat.

Aerial tracking can be very effective for locating wide-ranging birds on their breeding grounds, wintering areas (Buehler et. al, 1991) or migration routes (Hunt and Ward, 1988). However, the use of aircraft is expensive and not practical for tracking long distance migrants that travel thousands of miles, cross dozens of geopolitical boundaries and traverse remote regions of the globe. Limiting factors associated with conventional telemetry such as restricted geographic range and human operation required to obtain information on free ranging animals prompted the development of spaced base systems to track and monitor wildlife via satellite.

Space Based Satellite Tracking Technology

Satellite transmitters called Platform Transmitter Terminals (PTTs) were designed to interface with and be tracked and monitored by the French owned Argos system (Fancy et al. 1988). The PTTs operate on an Ultra High Frequency of 401.650 MHz, transmitting an identification code and data from up to eight sensors. The signals are digitally encoded on a pulse width of 0.36 second and a pulse interval of every 50-90 seconds. The frequency of the signal must be very stable (<2 Hz drift), and the radiated power must be relatively high (0.15 to 2.0 W). The signal is received by the satellites, then transmitted to processing equipment on the ground. Locations are estimated by the Doppler principle. Location estimates vary from ±150 m to many kilometers, depending on animal behavior, environmental variables, and data-processing options (Keating et. al, 1991). Satellites carrying the Argos system are located in 850 kilometer sun-synchronous orbits. Depending on the transmitter's latitude, it is possible to determine its location and collect information from the sensors between 6 and 20 times in a 24 hour period.

Early attempts to track wildlife by satellite involved elk that were tracked with PTTs weighing 11 kg (Craighead et. al, 1972). During the 1970's some reduction in size of the PTT was achieved and 5 kg units were used to track polar bears (Ursus arctos) (Kolz et. al, 1980, Schweingburg and Lee, 1982) and sea turtles (Caretta caretta) (Tiniko and Kolz, 1982). Toyo Communications Equipment Co., Ltd manufactured the smallest PTT available by the early 1980's, which weighed 1000 gms with the batteries included. The prototype PTT produced by the Johns Hopkins University, Applied Physics Laboratory was the first attempt to design and miniaturize a PTT for use on a bird (Strikwerda et al. 19894). Bird borne PTTs became a reality for tracking and monitoring activities of avian species in 1984 when this solar powered PTT was successfully fielded on the back of a wild mute swan (Cygnus olor) captured in the Chesapeake Bay of Maryland (Strikwerda et al. 1984). Since then the technology has continued to develop and provide a unique capability to track and monitor avian species weighing as little as 800 gms. The next field test conducted with the Johns Hopkins University PTT was in 1984 on a sub-adult bald eagle. This raptor was tracked for 270 days over a 2,400 kilometer range from Maryland to Florida. The results of this experiment led to a series of field tests of the technology with other avian species (Strickwerda et. al, 1986). Additional field tests were conducted on bald eagles, golden eagles and a gyrfalcon as the PTT was reduced in size from 185 gms to a 95 gm unit produced by Microwave Telemetry Inc. (Howey, 1989).

Applications

Eagles

As the technology continued to develop and become available, others used PTTs to track and monitor the griffin vulture (Griesigner et. al, 1992), Lesser spotted eagles (Meyburg et. al, 1993) and a Steller's sea eagle (Meyburg and Lobkov, 1994). Satellite tracking is now being used to do basic research on many avian species for conservation and resource management planning. In Glacier Bay National Park, the seasonal movements of bald eagles, were examined by satellite tracking to study the eagles foraging relationship to streams and rivers that potentially could be affected by proposed copper mining activities (Kralovec 1994). In Canada, Brodeau and DeCarie (1993) studied golden eagles to evaluate the impact of a proposed hydroelectric damn to be constructed south of James Bay, Ontario. Eagles from the area to be flooded were tagged with PTTs and tracked south to their wintering grounds. The golden eagles tracked via satellite distributed themselves over the entire known eastern United States wintering range for the species, thereby establishing their natal origin south of James Bay as a critical area for the maintenance of the species in this part of North America.

In 1989 Seegar and Fuller initiated a 6-year comprehensive study on raptors for the Idaho Army National Guard (IDARNG), on the Orchard Training Area (OTA), the third largest National Guard training facility in the United States. On the OTA, centrally located within the Snake River Birds of Prey National Conservation Area , we examined the spatial relationships of military training to golden eagle movements. Satellite telemetry was used to collect location data from eagles that frequented military exclusion areas and to determine wintering ranges for adult and sub-adult eagles (Seegar et al. 1996, in press). Because golden eagles of unknown origin joined wintering eagles on the OTA, telemetry via satellite was also used to identify the breeding grounds. Initial results showed some wintering adult eagles used military areas extensively, having much smaller wintering ranges than wide ranging sub-adult eagles (Figure 1). Unique information on the breeding areas of adult eagles was obtained within the first year of the study. In the spring of 1993 all the adult birds migrated to breeding locations in central Alaska and Western Canada (Figure 1).

Peregrine Falcons

The application of tracking birds via satellite has expanded as a result of the continued development and miniaturization of PTTs. As the size and weight of the transmitters were reduced the number of species that could carry the PTT increased. Since the early 1990s Microwave Telemetry Inc. has supplied over 900 PTT that have been applied to more than 20 avian species on a global scale. The use of radio tagging should always be based on careful consideration of the effects of the transmitters on birds' behavior and flight (e.g., Obrecht et al. 1988, Samuel and Fuller 1994).

In the autumn of 1993 PTTs (NANO 100, Microwave Telemetry Inc.) weighing about 28 grams were attached to peregrine falcons (Falco peregrinus tundrius), an endangered species and a Neotropical migrant that breeds in the Arctic and winters as far south as Central and South America. Fifty-four PTTs were deployed on peregrines in five locations in North America and one location in the Western Russian Arctic. Results of this effort have described the range of this Arctic falcon and identified critical breeding, migratory and wintering habitats for the conservation of the species in North and South America.

We radio tagged peregrine falcons during the autumn migration on Assateague Island, Maryland and Virginia and Padre Island, Texas. Also, adults were tagged on Padre Island in the spring as they moved north out of Latin America to their Arctic breeding grounds. Padre Island is the only known staging area for the tundra peregrine in this hemisphere and provides critical migratory habitat for the species during their northward flight. The PTTs were programmed to operate for 12 months transmitting 8 hours every three days during migration then switching to a six day cycle of transmission during breeding and wintering periods when the birds were more sedentary. During the breeding season of 1994 we placed PTTs on adult females in Ungava Bay and Rankin Inlet, Canada; Sondrestromfjord, Greenland, and on the Kola Peninsula, Russia. During the past 24 months we have collected over 6,000 positions on these peregrines. These data have provided more information on the species distribution in the Northern and Southern Hemispheres of the Americas than 25 years of conventional field studies and banding returns. Satellite tracked peregrines from this sample in the New World wintered from Delaware to Argentina and returned to breeding grounds across the Northern Arctic from Alaska to Greenland.

The following peregrines were all captured in the spring on Padre Island

and tracked to their wintering and breeding grounds (Figure 2: 5709, 5695 & 5707). The track of 5709 shows a bird that bred in the Eastern Canadian Arctic then moved south to a wintering area on the Yucatan Peninsula in the autumn. The track of 5695 shows a western migrant that bred in Alaska north of the Yukon river and wintered in Northern Argentina. Falcon 5707 shows the unique track of a wandering non-breeding adult (Seegar et al. in press) (Figure 3). This falcon flew to the Rankin Inlet study area where non-breeding peregrines commonly are seen by biologists. She then left the western shore of Hudson Bay, traveled to southern Baffin Island and went north to the Arctic Ocean. From northern Baffin Island she traveled south by way of the Eastern Coastal flyway to a wintering area along the Northern Coast of Venezuela. Satellite based tracking data demonstrate the importance of Padre Island as critical habitat for the tundra peregrine falcon. During the spring migration birds staging on Padre Island migrated to breeding areas representing the entire range of the species on the North American continent. This information was collected and mapped with minimal field time and expense. The space based tracking system provided regular data from birds flying through remote areas that could not be accessed or effectively covered by conventional wildlife tracking methods.

During the past 15 years the electronics in the PTTs have been miniaturized and have provided new capabilities through the integration of microprocessors. The transmitters can interface with a variety of sensors to index activity and collect data from the environment surrounding the organism. An experimental bird borne transmitter produced by Microwave Telemetry Inc. weighs 20 grams which includes only 3.5 grams of electronics is being field tested on the Texas Gulf Coast to track the migration of the adult male peregrine falcon (600 gms.). This further reduction in size and weight of the PTT will allow for the application of satellite tracking to a wider variety of smaller avian species. Generally, tracking via satellite is being used to gather data addressing issues that were previously too costly or impossible to consider with conventional methods. We are combining satellite tracking with other technology and with proven procedures for innovative approaches to research and management of natural resources (Fuller et al. 1995b). Furthermore, we are continuing the development of more advanced PTTs and new sensors which will expand the present capabilities.

Advanced Bird Borne Satellite Telemetry Development

The present configuration of the bird borne PTT allows for the interface of a variety of sensors. The most commonly used on the satellite transmitters are temperature, motion, altitude and battery voltage. Absolute vapor pressure sensors are available for limited use with a temperature thermistor to monitor for humidity (Howey et al. 1977). Howey (pers. comm.) is currently developing a bird borne transmitter design that will incorporate a Global Positioning System

(GPS) receiver and will interface with an acoustical sensor to monitor animal behavior and a miniature camera (Seegar et al. 1996)

Global Positioning System Qualified ARGOS PTT

The Argos system maximum accuracy is location estimate of $\pm$150m but locations obtained from low power (100mW) bird borne PTTs often are in the range of $\pm$2 km of the bird's true locations. To achieve the highest grade ARGOS location at least 4 messages have to be received by the satellite over a period exceeding 420 seconds. A single Argos message can relay up to 256 bits of information from sensors on the transmitter to the user via the satellite.

The availability of small commercial GPS receivers make it possible to combine such a receiver with an Argos transmitter and field a package small enough to be carried by a goose size bird. By scheduling the collection of GPS locations throughout the day and storing these positions for later transmission via Argos as many as 20 more accurate GPS positions ($\pm$20 m) can be transmitted to the user in a single Argos message. The present Argos/GPS package under development by Microwave Telemetry Inc. incorporates a commercially available GPS receiver, a microcontroller based data logger and a Microwave Telemetry NANO PTT. The data logger controls the GPS receiver and the collection of GPS data, which is dependent on power availability from the solar charged power source. The data logger then sequences data transfer to the NANO PTT at times favorable to satellite availability. The prototype unit (200 gms) is undergoing laboratory testing.

Digital Audio Capture Sensor System

The digital audio capture sensor is being developed at the Johns Hopkins University, Applied Physics Laboratory (JHU,APL) for interface with an Argos compatible PTT (Seegar et al, 1996). It is anticipated that the entire digital portion of the audio capture system including the microphone could be built on a 2 cm by 2 cm circuit board weighing about 16 grams. All components used in the design are available in surface mount packages. The software for the system was all written in 6800 series assembly language. Acoustical information stored in the microprocessor will be processed to determine the specific nature of the animal vocalization. The information will be processed and evaluated by means of pattern recognition. This information along with the time and location will be stored for transmission.

Camera Qualified Satellite PTT

The camera packaged chip measures .66 cm square x 0.105 cm high and weighs less than 2 grams. The camera can be mounted on a circular circuit board with diameter 1.25 cm and requires a regulated 5 volt, 20 mA power supply. The camera's exposure can be set to either automatic or manual mode. The camera's frame rate (i.e., exposure time) is variable between 0.5 and 24 frames per second. The camera's image format can be configured to one of 160 x 160, 160 x 120, 120x 160 or 120 x 120 pixels. This allows the user to trade coarser image detail for greater image storage. Twice as many 120 x 120 pixel images can be stored in a given amount of memory as 160 x 160 pixel images. For the satellite transmitter application the camera will be operated remotely from its central control, using the camera in its digital mode. In this mode the image data can be stored indefinitely aboard the sensor package, and transmitted at a pre-arranged time (Seegar et al. in press).

Discussion

The use of PTTs for repeatedly sampling the movements of birds continentally and locally has been well demonstrated. With the integration of GPS and new sensors with the PTT, more accurate locations of free ranging birds, as well as environmental and behavioral data, can be collected on a regular basis. We have collected and evaluated geographic, demographic, and ecological information. Our capabilities are being expanded to include information pertinent to bird flight, such as weather, migration, and avian biology on a global scale. One of our goals is to provide information for maintaining and conserving biodiversity.

One of our objectives is to monitor and forecast bird migration on a continental to transcontinental scale. The system to accomplish this will incorporate emerging technologies in remote sensing, tracking via satellite, radar, and advanced data processing to support a model to provide near-real time forecast function of bird movements.

The system we are developing includes a GIS, remote sensing, GPS and Argos satellites. We are using the system for natural resource management data for U.S. military installations, research of endangered species and transcontinental tracking including monitoring of Neotropical migrants. This basic research supports multiple land use management for the conservation of biodiversity. The system is Unix-based ARC/INFO running on a SPARC station 10 Model 41. Grass 4.1 is being used on the SPARC station for image processing and Arc View is being used for desktop mapping and data exchange among collaborators

In Idaho we used remote sensing and GIS to develop spatial databases on vegetation, landscape characteristics, and animal distribution in the Snake River Birds of Prey National Conservation Area. The system includes a ground truthed vegetation map from Landsat Thematic Mapper satellite imagery. Temporal sequences of Landsat Multi-spectral Scanner imagery are used to detect changes in land cover related to wildfire, military training, and climate change. Data from field research including conventional and satellite telemetry are incorporated into a spatially-explicit model of habitats, prey and raptors to project outcomes of different disturbance and climate scenarios and to generate management alternatives for the Bureau of Land Management, Idaho Army National Guard and Department of the Army.

The application of bird tracking via satellites to bird strike to aircraft has been proposed (Leshem 1991). In Israel a bird strike program has been successfully developed for the Israel Air Force (IAF), which integrates the use of gliders, drones, ground observations and ground based radar. This program has contributed significantly to the reduction of bird strikes by military aircraft and was adopted by civil aviation in Israel in 1990. The program in Israel has saved the IAF 300 million dollars in damage as well as the lives of pilots during the past ten years. Geographic information on satellite monitored sentinel birds moving in migratory flocks that pose a threat to aircraft can be integrated with the other elements of Israel's system and enhance the forecast and monitoring of birds there.

Aircraft movements are projected to go up substantially in the near future (Garber 1995) and bird populations that increase the risk of bird strikes (e.g. non-migratory canada geese, seasonal gull flocks near airports) are increasing in North America (Rusch et al. 1995, Hestbeck 1995). Information from world-wide sources show a marked increase in strike rates during the migratory months in spring and fall when the numbers of birds in proximity to airports increase dramatically(Dolbeer et. al. 1995). Factors influencing the timing and routes of migration are little understood but new technologies can enhance our ability to follow migrating birds and track their locations relative to airports and aircraft flight paths. Much effort has been expended to understand bird strike on a local level. Studies include: local bird movements; nesting and feeding habits; crop management practices that attract or deter wildlife species; relocation of landfills that attract gulls to the proximity of aircraft; and, different techniques for scaring birds from runways. The implementation of airport wildlife management plans and the development of active bird strike teams have had a positive effect on bird strike rates but important research is yet to be done (Garber, 1995)

Reduction of the probability of bird strike to aircraft in the U.S. is a cost effective approach to human safety and the financial problem. Regulations stipulate the development of aircraft and aircraft engines capable of withstanding the impact of birds that weigh .7 kg.. This is expensive and adds additional weight to aircraft. These new modifications will be incorporated in future generations of aircraft but not in older equipment currently in use. Over the past decade Israel developed a program designed to reduce the probability of bird strikes that resulted in reduced damage and loss of life. This was done through the organized education and training of personnel within the aircraft community. The system also provided information on the presence of migratory birds within aircraft operating areas. The addition of a space based system to track avian species of concern to the aircraft industry using Geographic

Information Systems and ground based radar as well as other bird tracking techniques can provide critical information to assist in reducing the probability of bird strikes with aircraft.

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Figure 1

Wintering and Breeding Areas
And
Migration Tracks Of

Two Adults and One Sub-Adult Golden Eagles
Radio Marked At The Orchard Training Area, Idaho

Adults ....

Sub-Adults - - - - - - - - - - -

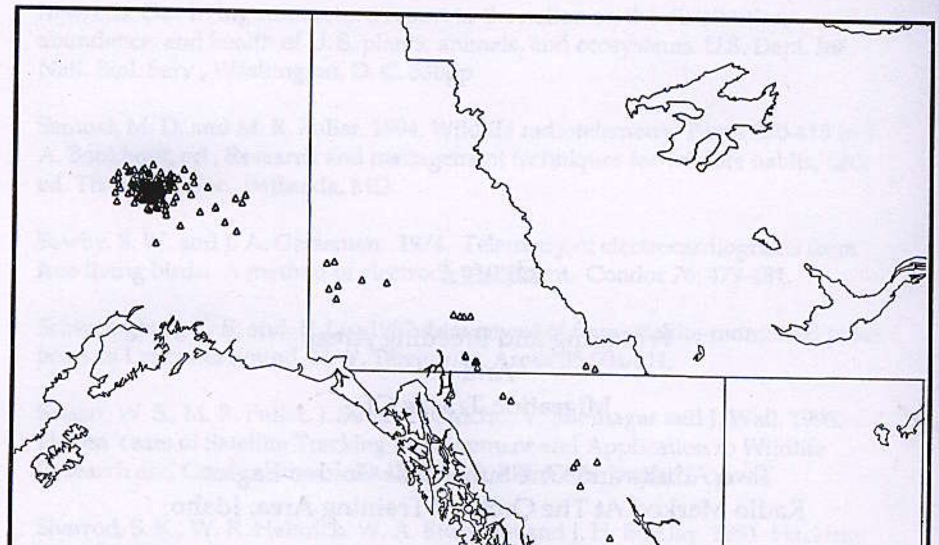
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Figure 2

Breeding, Wintering, and Migration Tracks
of
Three Peregrine Falcons

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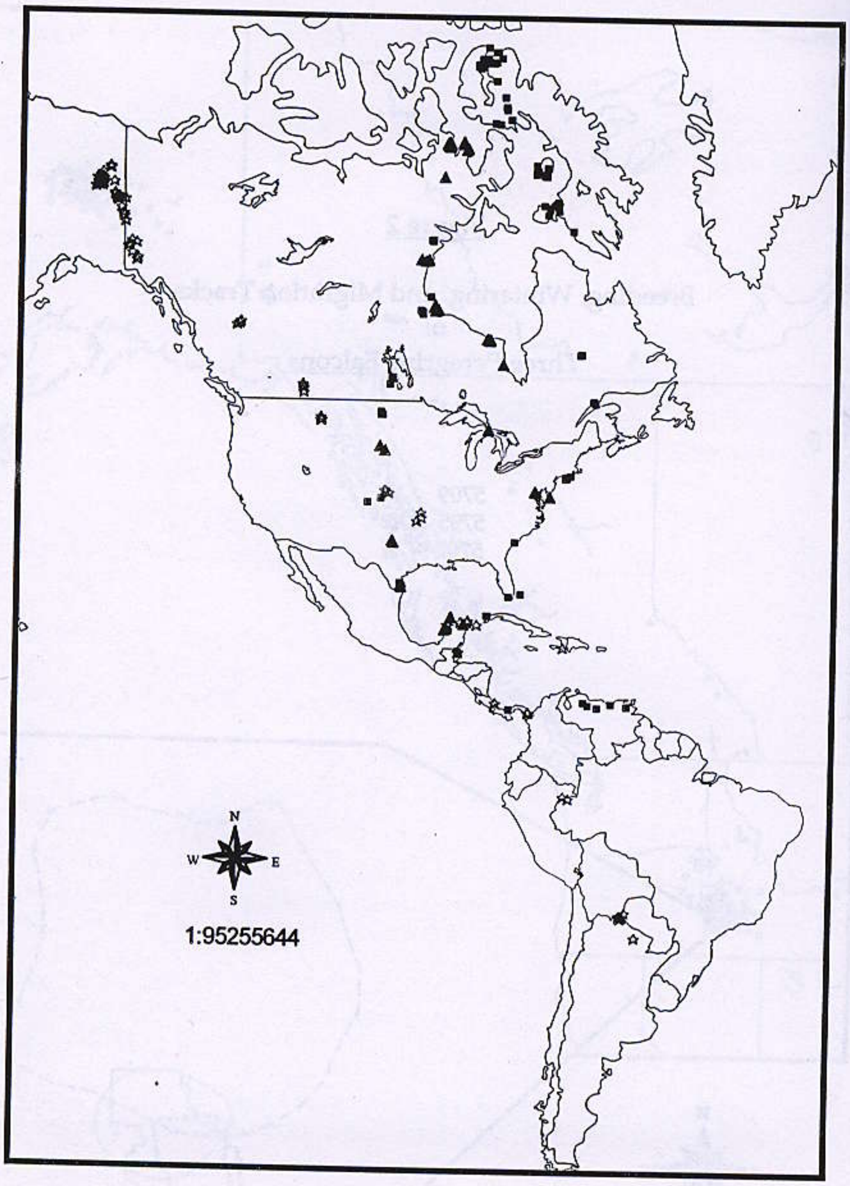
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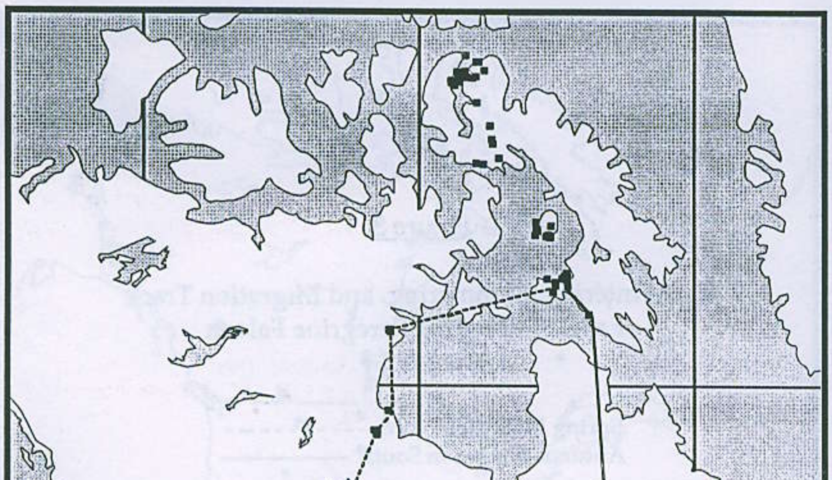
Figure 3

The Wintering, Summering, and Migration Track
of a Non-Breeding Peregrine Falcon
5707

Spring Migration North - - - - - - - - - - -
Autumn Migration South ——————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