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Development of a Predictive Bird Avoidance Model For Low-Level Operations

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Twenty percent of all US Air Force bird strikes during 1978-1980 occurred while the aircraft was engaged in low-level operations. Modern military tactics stress that high speed low-level flight operations will significantly increase the chances for successful mission completion. Low-level operations also significantly increase the risk of encountering birds. Recent bird strike mishaps involving high airspeeds and low altitudes have underscored the fact that aircraft are still very vulnerable. This paper describes the USAF Bird/Aircraft Strike Hazard (BASH) Team's effort to reduce bird strike hazards on low-level routes and during range activities in the United States by developing a predictive bird avoidance model. The purpose of this model is to estimate bird strike risk on each low-level route by ranking the relative hazards of (1) all routes, (2) individual routes at specific times and (3) segments of each route.

Several solutions to the problem of low-level bird stikes have been considered. Removing birds from the aircraft's flight path with lasers or microwaves is a popular idea that is impractical at this time because of the large amounts of energy required to affect birds a sufficient distance ahead of the aircraft. This type of system would have significant environmental considerations such as the effect on other animal populations.

Designing aircraft to withstand all bird impact would sacrifice important performance characteristics for added safety. It is possible to develop bird strike resistant aircraft components, but this method does not reduce bird strikes. It is virtually impossible to protect jet engines from ingesting birds.

Avoiding bird concentrations or movements offers the most feasible method of reducing bird strikes. A predictive bird avoidance model is based on historical evidence of bird movements while a system based on radar provides a real time warning of bird hazards. Risk maps can help flight schedulers and planners avoid bird hazards, while radar advisories can identify significant bird concentrations for aircrews. The advantage of a predictive model are that flights scheduled several months in advance can consider expected bird hazards. Using a predictive model, new low-level training routes or ranges can be planned which will avoid seasonal bird hazards.

A predictive bird avoidance model must accommodate various aircraft types, schedules and missions. In addition, the model must consider chronology of bird movements as well as the intensity of migration. It must account for differences in behavior of birds and variances in regional availability of habitat. In short, a reliable bird avoidance model should consider both chan[illegible] in aircraft [illegible] bird populations within a [illegible].

[illegible] Routes

Military training flights [illegible] on several hundred low-level routes, ranges, and [illegible] areas throughout the US. Low-level operations occur over all terrain and under a variety of conditions. Low-level routes are usually located in remote regions where operations will not interfere with other air traffic, municipalities and farming. [illegible] regions of intense bird activity, particularly [illegible].

Geographical [illegible] of low-level routes are published in Department of Defense (DOD) Flight Information Publications (FLIP). Flight conditions for each route vary, i.e., some visual or instrument, and some flown at low airspeeds. New routes are periodically planned often using portions of existing routes. A wide assortment of aircraft and missions use these routes for training. Some missions are scheduled several months before the flight while others are flown spontaneously. Mission profiles are dependent on aircraft model, altitude, airspeed, time of day, seasons, date, and flight route entry and exit points.

Military operating areas and ranges may encompass thousands of square miles or relatively small areas [illegible]. Each low-level route or range has a certain degree of bird risk associated with flying a particular mission profile. We can calculate this risk to help plan and schedule flights to minimize the chance of a bird strike.

Waterfowl Populations

Information about waterfowl populations is basic to estimating the relative risk of low-level flight. Twelve to fifteen percent of all US Air Force bird strikes involve waterfowl; most occur during low-level operations.

In the US, waterfowl [illegible] birds. During the last century [illegible] were accumulated on waterfowl activities [illegible] estimates, per[illegible] an important source of [illegible] counts of water[illegible] nesting [illegible] of methods [illegible] data, nesting [illegible] determine waterfowl [illegible] compendium on waterfowl [illegible] (Bellrose, 197[illegible] Figure 1). Populations [illegible] fowl are con[illegible] location (geographic corridors, stopover sites, refuges) and chronology (seasonal passage, daily bird movements). The attractiveness of wetland areas to waterfowl and the intensity of migration through various corridors can be ranked according to relative usage. The behavior of ducks, geese and swans varies sufficiently to consider them separately.

Migration corridors are a convenient (and historically accurate) means of depicting routes of waterfowl passage. Figures 2, 3, and 4 show major migratory corridors for ducks, geese and swans, respectively. The corridors represent counts of the waterfowl migrating through a geographical region during the fall season. The birds overwinter in specific wetland habitat and usually return along the same routes in the spring. Hunting and other mortality factors reduce the spring migration population to approximately two-thirds of the fall count. Birds react to weather when migrating, often taking advantage of following winds. Weather changes from year-to-year affect the timing of waterfowl passage through various regions. This effect is evident from weekly waterfowl population surveys through each region conducted by ground and aircraft observations. These surveys show a gradual movement of waterfowl through North America each spring and fall. This chronological information is important when estimating the density of waterfowl in a region during a specific weeks in either season.

Waterfowl behavior between and at the stopover points was verified using radar and aircraft observations. Ninety percent of all ducks migrate at night, departing between 1600-2100 hours and stopping at daybreak to disperse to available wetland habitat to feed and rest. Geese and swans depart around the same time but often continue their flights well into the day since they fly longer distances between stops. The model assumes that non-migrating birds remain on the ground through the night and that birds make only feeding flights during the day. Waterfowl activity around refuges is determined by available wetland habitat and agriculture. Refuges (Figure 5) are considered relevant to bird hazard avoidance on low-level routes because waterfowl often make daily feeding flights as far as 30 miles at altitudes below 750 feet.

Bird Avoidance Model Formulation

Previous studies (Speelman 1979; Berens 1979; Berens et al, 1978) show that bird strike risk is characterized by a predictive model composed of two parts:

$$E(N) = E(n)P(D)$$

The first part, the expected number of bird strikes, is related to bird density along aircraft flight paths (D), the forward projected area of the aircraft or component (A), average aircraft

velocity ($\bar{V}$) and total tim[illegible]
The probability of striking [illegible]
total bird population in the [illegible]
Poisson and binominal distribution [illegible]:

$$E(N) = [illegible]$$

The probability of damage, the second part of the equation, depends on the kinetic energy of the bird strike and the ability of the aircraft to withstand it. P(D) is a function of the weight of bird, aircraft's velocity distribution, and structural strength (see Appendix I). To determine the probability of a damaging bird strike, it is necessary to calculate the relative bird strike susceptibility of critical aircraft components, e.g., engines, control surfaces, windscreens. A realistic estimate of structural integrity of aircraft is available by reviewing past bird strike reports for low-level operations to determine aircraft mission profiles and the extent of damage resulting from actual bird strikes.

Bird Avoidance Model

Bird strike risk quantification for the bird avoidance model is based on the ability to estimate annual total waterfowl populations as well as the historical distribution and movement of populations within broad geographic regions. Predicting bird strikes for low-level operations is possible with certain assumptions: (1) total density of birds at a particular time and location is known, (2) bird populations display random distribution with respect to time, altitude, and region, and (3) damage will result when the actual kinetic energy of the bird strike exceeds the critical level of damaging an aircraft component. Total kinetic energy of a bird strike is primarily a function of airspeed.

When comparing alternative low-level routes or mission flight times the effect of wrong assumptions on the model are slight. However, when predicting bird strike risks on a particular route or for a certain aircraft mission, the validity of the assumptions are more important. Clearly, these assumptions are difficult to abide by when faced with actual waterfowl data. For example, waterfowl are not distributed randomly during migration; they travel in flocks and prefer specific wetland areas. This information is well known but not readily quantifiable. The distribution of waterfowl throughout the airspace is better defined by imposing constraints on the altitude or timing of migration. Therefore, waterfowl airspace is defined on the basis of the time of day and whether the birds are involved in migration or feeding activities, i.e., whether bird strike risk is posed by migrating or non-migrating waterfowl. These constraints on the model greatly increase the number of location-time combinations required to describe aircraft-waterfowl interactions along a particular low-level route. It is important the methods to predict bird strikes do not overestimate the sensitivity of the available population data. Resolving this problem will require verification of predicted risk estimated by the model with actual bird strike statistics for that route or region.

Low-level routes are defined as a series of flight segments which are digitized as arrays of geographic coordinates. Numerous bird movements in the mission airspace present a greater risk to flight. Refuges and migratory corridor can be ranked according to relative waterfowl use. The geographic boundaries of the corridors are treated as distinct levels of waterfowl abundance. This insures relatively constant bird densities on each route subsegment. Calculation of the expected number of bird strikes for each route requires summing of bird density on various subsegments which are designated at the migratory corridor boundaries. Refuges are included in risk calculations when they lie within 30 miles of a low-level route.

Bird strike risk is related both to the density of birds in the airspace and the volume of airspace swept by an aircraft during a certain mission. Calculations of bird density is closely related to waterfowl behavior, i.e., the number and altitude of birds migrating through a region at any one time. To estimate these periods of bird density, the following categories of duck activity are modeled as follows: (1) each morning or afternoon flights from refuges to feeding areas (altitudes under 750 feet AGL); (2) minimized waterfowl flying activity at midday; and (3) nighttime migration (altitudes from 1500 to 3000 feet AGL). Geese and swans are considered a local flight problem at their major winter concentration and stopover points.

Calculation of the expected number of bird strikes assumes constant bird density over the entire route of flight. Actually, the bird density shows yearly changes among regions, corridors, refuges and seasons. These changes are brought about by loss of wetland habitat through urban encroachment and agriculture and affect birds both on breeding grounds and during migration.

The end result of the bird avoidance model is to provide a relative risk index for each low-level route and aircraft mission. Predictive bird strike avoidance models are useless unless applied to actual situations. Collation of large amounts of data on waterfowl populations and how they interact with a myriad of low-level aircraft missions throughout a geographic region as vast as the United States requires a complex system for storage and retrieval. Computerization allows construction of a permanent information base characterizing bird movements and behavior which is relatively constant but changing with weather, season, and region. The complexity of various aircraft missions and susceptibility of different aircraft to bird strikes also requires a stable yet flexible system for evaluation. New aircraft, hardware modifications, routes and mission profiles are continually developed, all of which carry varying degrees of bird strike risk.

The proposed bird avoidance model will allow updates as new information becomes available such as the formation of new waterfowl refuges or development of a new low-level route. Additional types of birds (raptors, gulls, shorebirds) will be included in the model as the necessary data about their population and chronology of movements becomes available. A centrally located system with multiple access via telephone lines will allow flight planners and schedulers to query the system about bird hazards expected at a particular time or location and a particular aircraft mission. Eventually, pilots can alter flight plans to fly routes with the lowest bird strike risks.

Radar is invaluable to further expanding the ability of the bird avoidance model to estimate bird strikes by documenting precise data on bird concentrations and movements. By closely monitoring bird populations it is possible to update knowledge of their abundances and habits. This information on birds is an integral part for predicting the risk of their movements on aircraft operations. Including information about other types of birds will greatly extend the ability of the bird avoidance models for planning and scheduling low-level routes. By developing methodology to distinguish concentrations of various birds and accurately predict their movements, aircrews can obtain adequate warning of bird hazards.

Summary

Low-level aircraft operations must consider bird populations along the route of flight to decrease the chance of serious bird strikes. Reduction of bird strikes along United States Department of Defense low-level routes is possible by predicting the density of birds expected at a specific location and time. A large amount of information is available concerning waterfowl concentrations and movements in North America. The interaction of waterfowl on United States Air Force low-level operations must consider the various types of aircraft and mission profiles flown as well as a variety of waterfowl behavior. A bird avoidance model is proposed which will calculate an index of relative waterfowl risk for USAF low-level operations in North America. The model is sensitive to seasonal, circadian, and operational mission changes.

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APPENDIX 1

CALCULATING EXPECTED BIRD STRIKE RATE

(FROM SKINN AND BERENS, 1980)

In previous studies performed by the UDRI, the birdstrike risk was quantified by a probabilistic model composed of two elements. In the first element, the expected number of birdstrikes was calculated as a function of bird density, forward projected area, and average aircraft velocity and time in the bird environment. The second element calculated the percent of the total number of birdstrikes that would result in significant damage. (For the previous studies, significant damage was defined as the penetration of the transparency.) This percentage was calculated in terms of the kinetic energy of the impact and thus, depended on the velocity distribution of the aircraft, the birdweight distribution of impinging birds, and the transparency strength distribution. The mathematics of these calculations is relatively simple.

Consider first the problem of calculating the expected birdstrike rate. Assume that in a particular airspace of volume, V_a, there are a total of B birds and that the birds are randomly distributed in the airspace volume. Then, the probability, p, of an aircraft striking one bird in T hours in the airspace can be modeled as the volume of the airspace swept out by the airplane, v, divided by the total airspace volume.

$$p = \frac{v}{V_a} \qquad (1.1)$$

Since there are a total of B birds, the probability of striking k birds can be calculated from the binomial distribution. However, since p is small in comparison to B, the Poisson distribution can also be used to model the number of strikes. Thus, the probability of k strikes is given by

$$P(k) = \frac{e^{-pB} \cdot (pB)^k}{k!} \tag{1.2}$$

and the expected number of strikes in T hours is

$$\begin{aligned} E(n) &= p \cdot B \\ &= v \cdot \frac{B}{V_a} \\ &= v \cdot \rho \end{aligned} \tag{1.3}$$

where ρ is the density of birds. Letting A denote the airplane area (or any desired component) projected to a plane perpendicular to the direction of flight and $\overline{V}$ denote the average velocity in the birdspace, then it can be shown that

$$v = A \cdot \overline{V} \cdot T \tag{1.4}$$

and, hence,

$$E(n) = \rho \cdot A \cdot \overline{V} \cdot T \tag{1.5}$$

To calculate the probability that a birdstrike will damage an aircraft, it is necessary to consider the combination of bird weight and impact velocity (kinetic energy). The following analysis assume that the birdstrike threat can be characterized by the knetic energy of the impact and that airplane strength is characterized in terms of the probability of damage as a function of kinetic energy. This latter function is estimated from the ratio of the area which is susceptible to a given impact kinetic energy to the total projected area. (Note that this formulation would allow the possibility of any strike in a particular area causing damage.)

The unconditional probability that a random birdstrike will be damaging can be expressed as

$$P(D) = \int_0^{\infty} h(K) \cdot P(D|K)\, dK \qquad (1.6)$$

where h(K) represents the probability density function of impacting kinetic energies and P(D|K) is the airplane strength distribution of that percentage of the airplane which can be damaged by a kinetic energy of K. To determine h(K), the cumulative distribution of kinetic energy, H(K) is first calculated as

$$H(K) = P\left\{\frac{1}{2}\,\frac{W}{G}\,V^2 \leq k\right\}$$

$$= \int_0^{\infty} \left[\int_0^{\frac{2GW}{V2}} g(w)\, dw\right] f(V)\, dV \qquad (1.7)$$

where, g(w) = birdweight probability density function,
f(V) = aircraft velocity probability density function, and
G = gravitation constant.

Then, the density function of impacting kinetic energies is

$$h(K) = \frac{dH(K)}{dK}$$

$$= \int_{0}^{\infty} \frac{2G}{V^2}\, g\left(\frac{2GK}{V^2}\right) f(V)\, dV \qquad (1.8)$$

Thus, given the density functions which describe the distribution o aircraft velocity and impacting bird weights and the function which defines the percentage of the canopy susceptible to damage for each value of kinetic energy, Equations (1.3) and (1.6) yield the probability that a birdstrike will be of sufficient severity to cau damage. Note that Equations (1.5) and (1.6) can be combined to yie the expected number of damaging strikes.

FIGURE 1. Regional divisions of the timing (chronology) of waterfowl migration in the United States. The data for constructing these regions were obtained from weekly waterfowl censuses made by refuge personnel on wildlife refuges (Bellrose 1976).

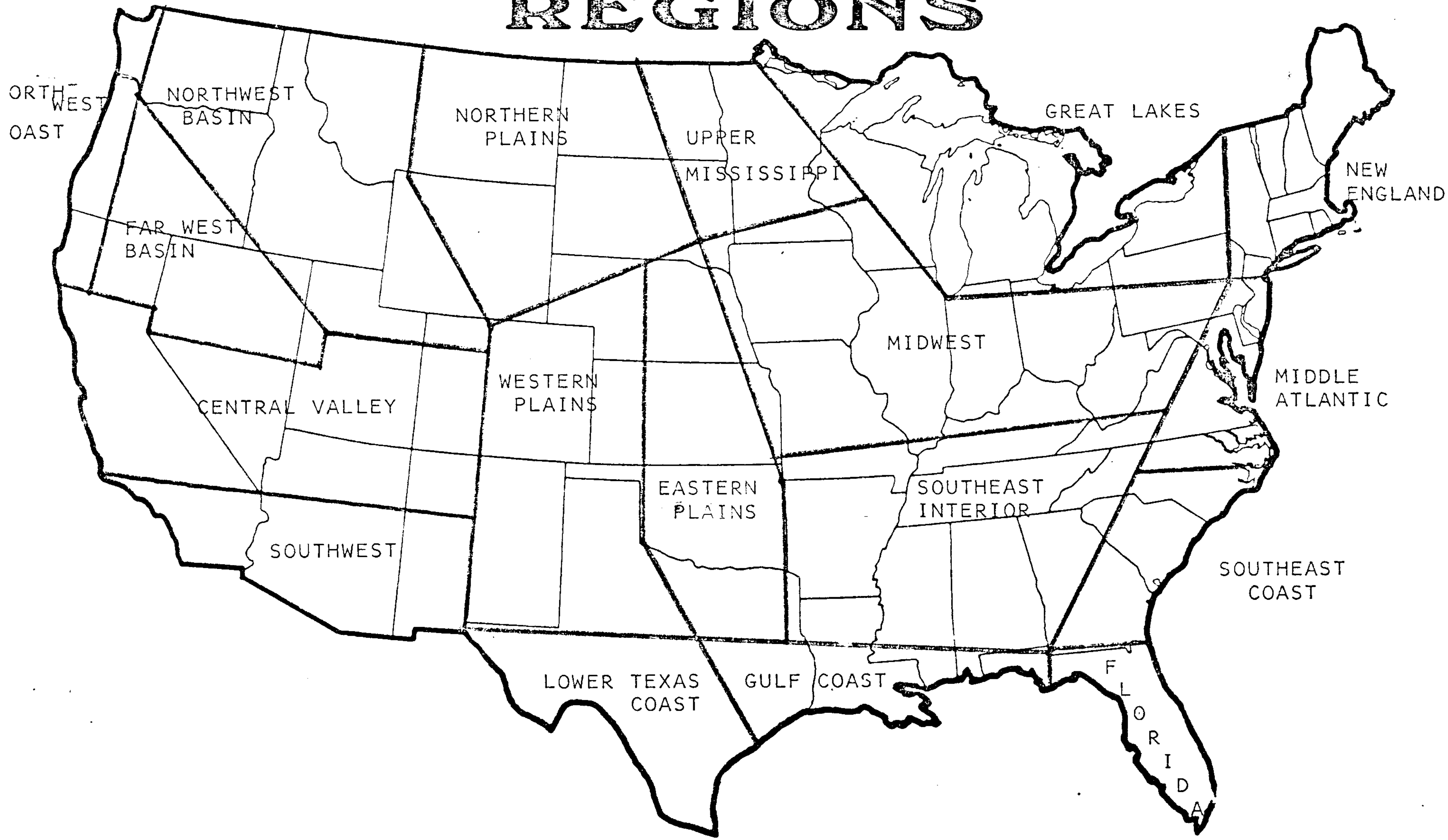
FIGURE 2. Duck migration corridors through the continental United States. Corridors were delineated using aircraft observation, refuge population counts, radar tracking, banding returns, and hunting records (Bellrose 1976).

FIGURE 3. Goose migration corridors through the continental United States. Corridors were delineated using aircraft observation, refuge population counts, radar tracking, banding returns, and hunting records (Bellrose 1976).

FIGURE 4. Swan migration corridors through the continental United States. Corridors were delineated using aircraft observation, refuge population counts, radar tracking, banding returns, and hunting records (Bellrose 1976).

FIGURE 5. Major state and federal waterfowl refuges over 1000 acres in size. Refuges are usually located in areas of prime waterfowl habitat for that region (Bellrose 1976).

REGIONS



After Bellrose (1976)

REGIONS

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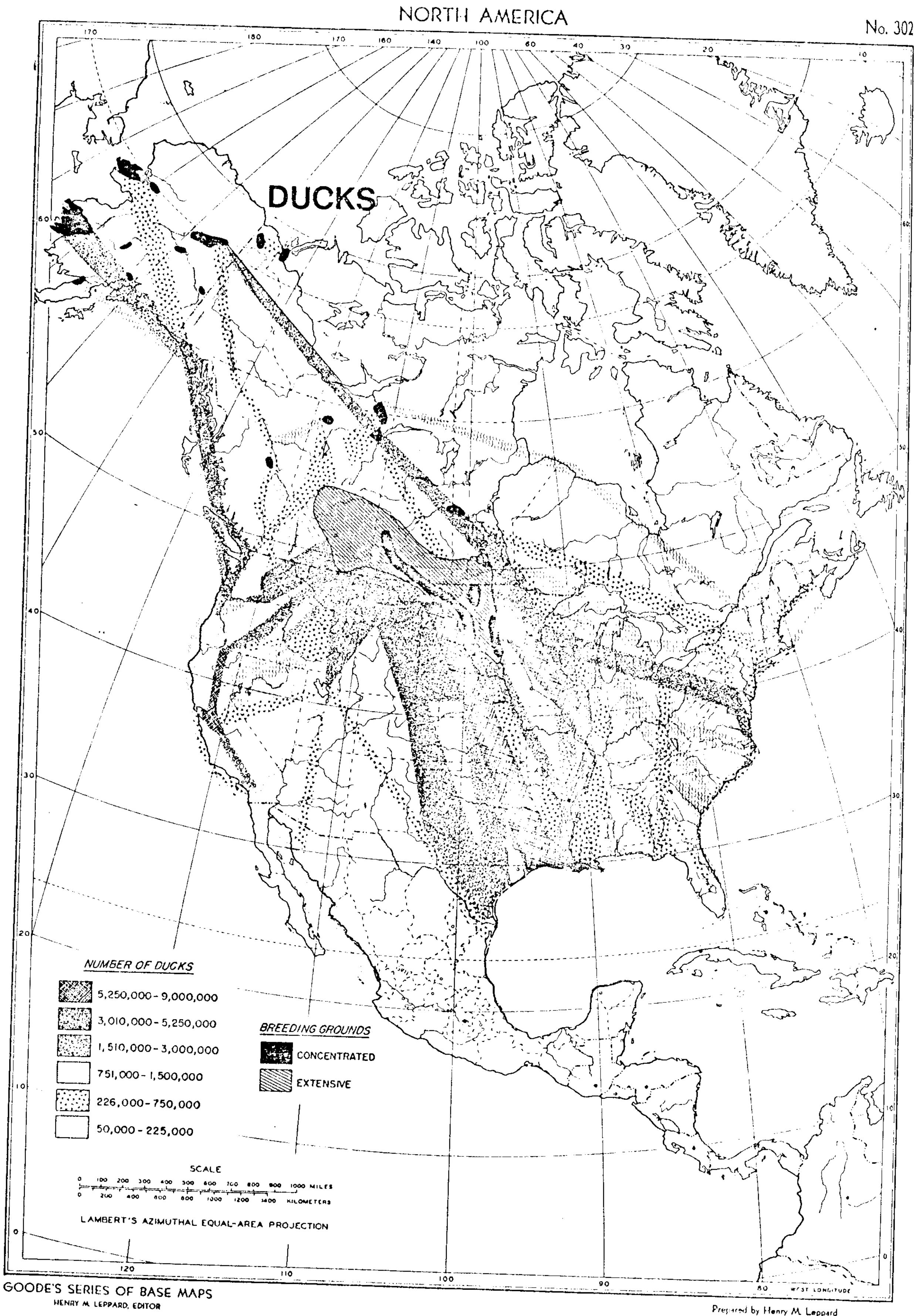

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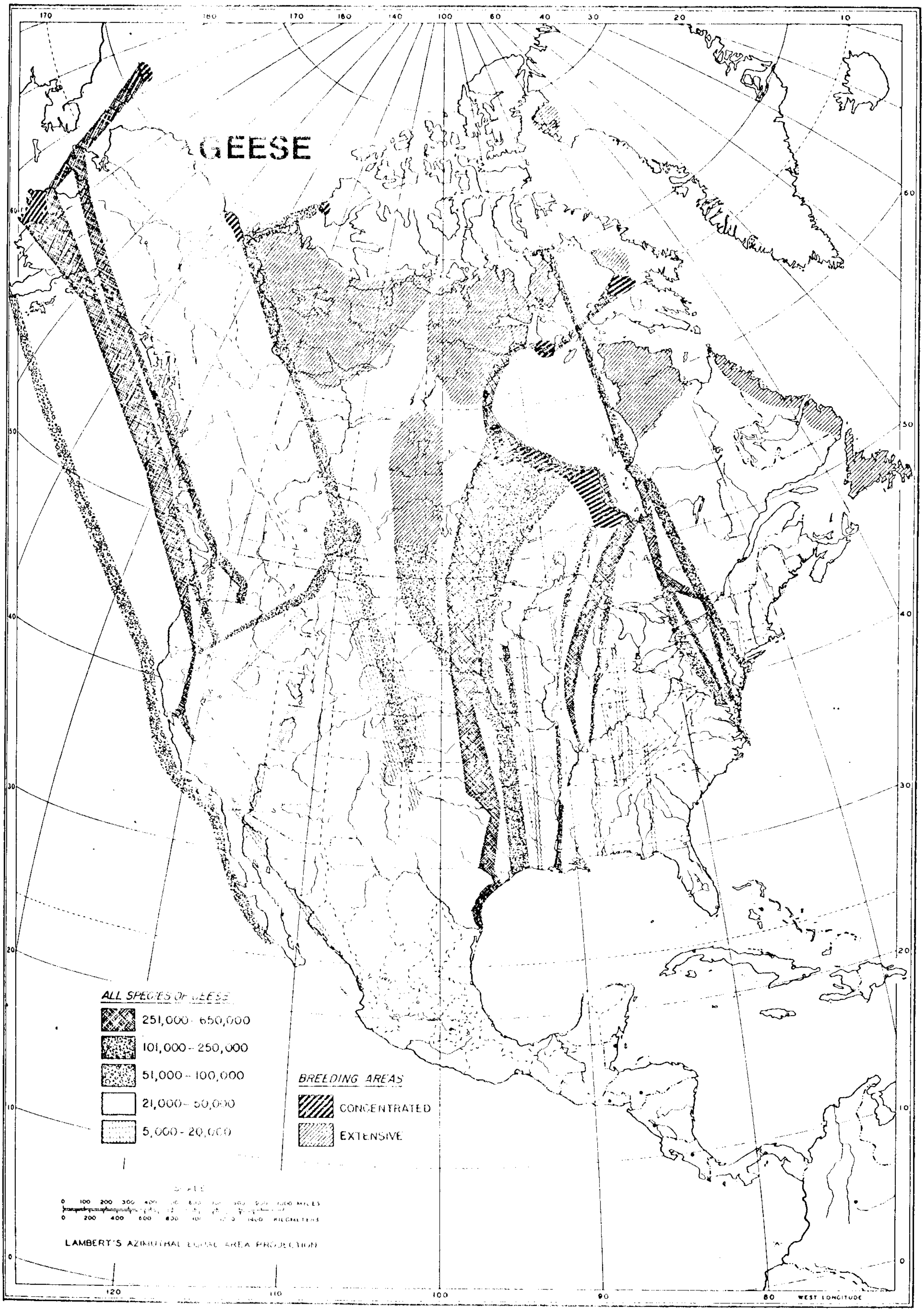

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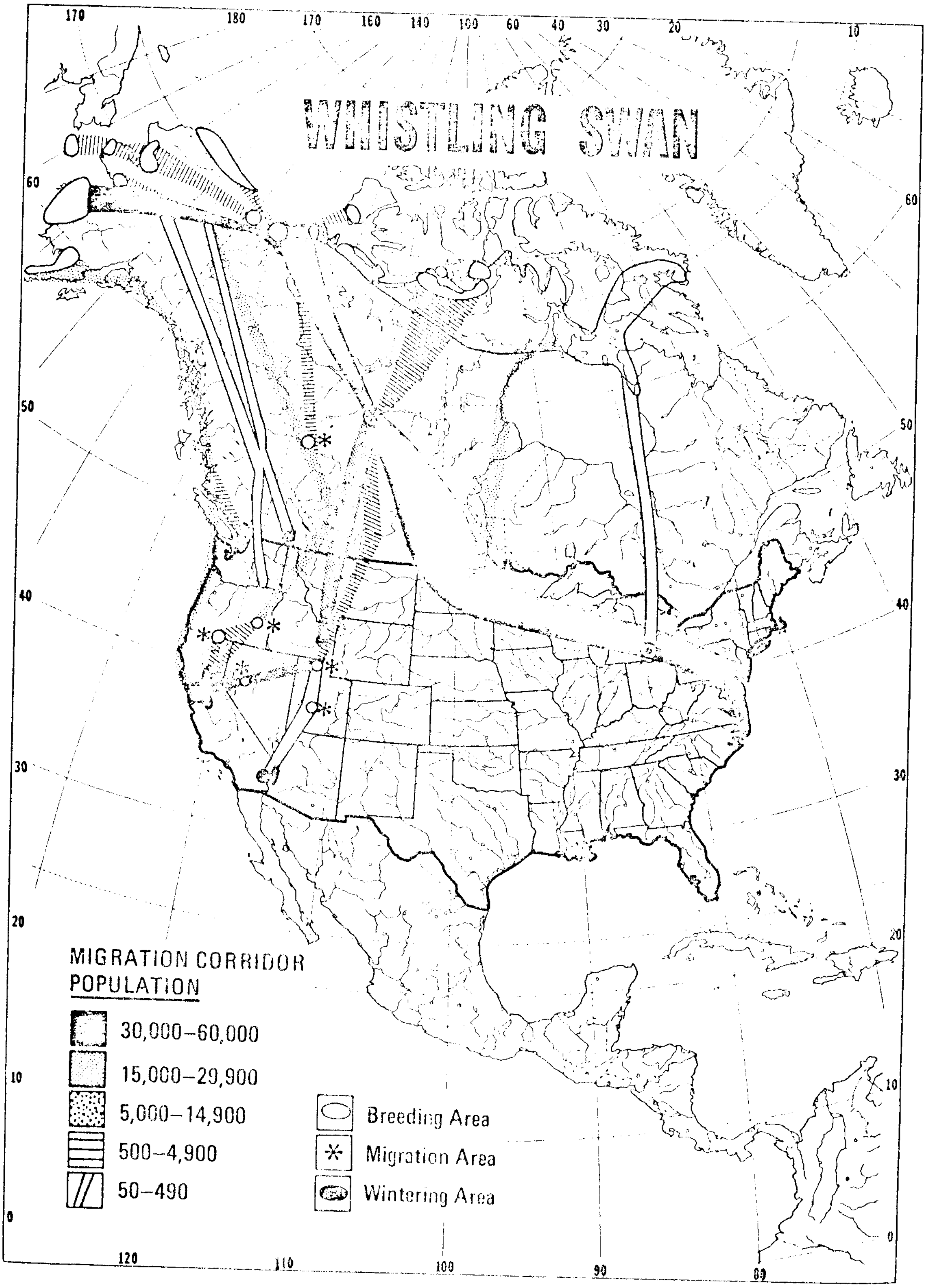

From Bellrose(1976)

REFUGES