Locating waterfowl observations on aerial surveys

William I. Butler, Jr., John I. Hodges, and Robert A. Stehn

Abstract We modified standard aerial survey data collection to obtain the geographic location for each waterfowl observation on surveys in Alaska during 1987–1993. Using transect navigation with GPS (global positioning system), data recording on continuously running tapes, and a computer data input program, we located observations with an average deviation along transects of 214 m. The method provided flexibility in survey design and data analysis. Although developed for geese nesting near the coast of the Yukon-Kuskokwim Delta, the methods are widely applicable and were used on other waterfowl surveys in Alaska to map distribution and relative abundance of waterfowl. Accurate location data with GIS analysis and display may improve precision and usefulness of data from any aerial transect survey.

Key words aerial survey, Alaska, distribution, geographic information system, GIS, global positioning system, GPS, long-range navigation, LORAN, observations, sampling, transects, waterfowl

Aerial surveys are used to index the abundance of waterfowl in extensive, inaccessible arctic breeding areas (Martinson and Kaczynski 1967, Kaczynski and Chamberlain 1968, Gillespie and Wetmore 1974, Malecki et al. 1981, Malecki and Trost 1990). Beginning in 1957, the North American Breeding Pair Survey (NABPS) has provided primary population information for waterfowl in Alaska. However, the NABPS is continental in scope (Cowardin and Blohm 1992, Martin et al. 1979) and was not designed to index waterfowl populations in a specific refuge or state. Aerial survey observations are recorded by 26- or 29-km segments, and transects are widely spaced (Off. Migr. Bird Manage., Standard operating procedures for aerial waterfowl breeding ground population and habitat surveys in North America, U.S. Fish and Wildl. Serv., Washington, D.C., 1987), resulting in very coarse-grained waterfowl distribution information.

Improved aerial surveys were needed for monitoring local waterfowl populations and determining relative use by waterfowl of specific federal and private lands in Alaskan refuges. Managers were particularly concerned by population declines of geese (Raveling 1984) nesting in the coastal zone of the Yukon Delta National Wildlife Refuge (YDNWR). While initiating a goose survey on YDNWR in 1985, we developed a transect navigation and data recording technique using long-range navigation (LORAN-C) and later global positioning system (GPS) instruments, continuously running tape players, and a computer data input program. Our objectives here are to: (1) describe the technique for locating each aerial survey observation; (2) evaluate the location accuracy based on navigation with LORAN-C or GPS; and (3) suggest applications for aerial survey data collected in this way.

Methods

Survey transects and navigation

We randomly located the start of the first transect on the west coast of the YDNWR. Subsequent tran-

---

William I. Butler, Jr.: Migratory Bird Management Project, U.S. Fish and Wildlife Service, Anchorage, AK 99503, USA. John I. Hodges: Migratory Bird Management Project, U.S. Fish and Wildlife Service, Juneau, AK 99802, USA. Robert A. Stehn: Alaska Science Center, National Biological Service, Anchorage, AK 99503, USA. Present address for William I. Butler: 4401 North Fairfax Drive, Room 742, Arlington, VA 22203, USA.

Wildlife Society Bulletin 1995, 23(2):148–154

sects were placed along lines of latitude at systematic intervals that varied from 1.6 (high goose density) to 12.8 km (low goose density strata; Fig. 1). Transects started at the coast, extended 6.4-64.0 km inland, and were divided into 6.4 or 12.8 km segments. We flew transects in a Cessna 206 with amphibious floats at 35-45 m altitude and 145-160 km/hour. Survey timing was adjusted annually to begin at start of incubation by nesting geese; surveys were completed by mid-incubation. We flew transects once each year.

We determined transect beginning and ending coordinates from 1:63,360 (1 inch = 1 mile) U.S. Geological Survey (USGS) maps and entered them as waypoints in a LORAN-C or GPS. With the development of LORAN-C and, more recently GPS, for airplanes, accurate navigation is possible for aerial surveys in remote arctic areas (Patric et al. 1988, Boer et al. 1989). The LORAN-C stations located at St. Paul Island, Port Clarence, and Narrow Cape provided excellent coverage for navigation on the YDNWR (Fig. 1). We drew transects on 1:250,000 USGS maps. The pilot used maps for general reference while flying transects and to obtain transect numbers and distances. The LORAN-C was calibrated daily in the air over the beginning or end of a transect with recognizable ground features, or on the ground at a location with known coordinates (e.g., a village airstrip). No calibration was required for GPS.

We intercepted the extended transect several kilometers before transect start point using the latitude readout from the LORAN-C or GPS and standard aircraft radio instrument procedures (Jeppesen Sanderson, Inc. 1981). We flew with the same precision required to complete instrument approaches. Ground reference features (e.g., coastline, lake shores, river banks) supplemented by LORAN-C or GPS distance readouts identified the transect start, segment transition, and transect endpoints. We used the course deviation indicator on the LORAN-C or GPS, set to 185- or 205-m increments respectively, to maintain transect centerline. When ground reference points indicated that the LORAN-C course deviated from the transects drawn on the map, we recalibrated the LORAN-C. No recalibration was needed for GPS navigation.

Data recording and entry

The pilot and observer recorded the following birds observed in a 200-m strip on each side of the aircraft: tundra swans (*Cygnus columbianus*), greater

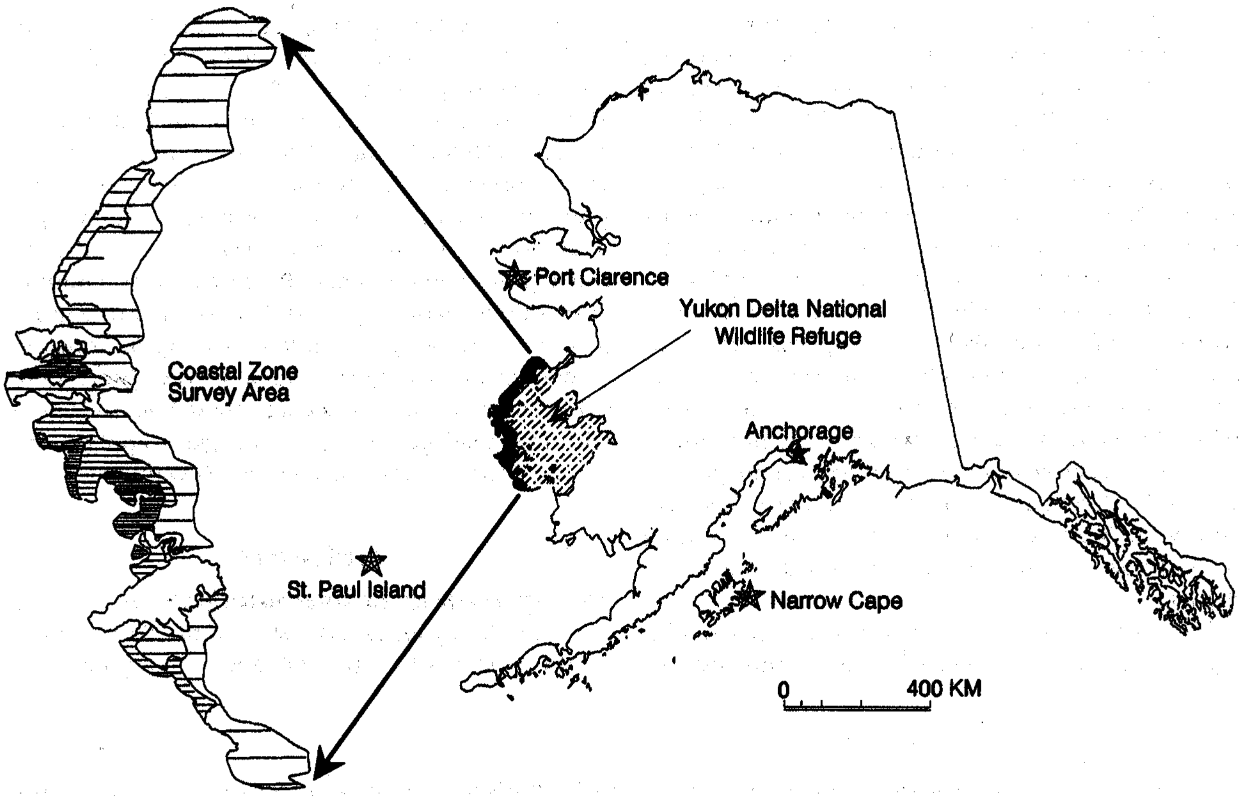

Fig. 1. Location of LORAN-C stations (3 large stars), Yukon Delta National Wildlife Refuge, Alaska, and the coastal survey area showing stratification boundaries and the east–west aerial survey transects for estimating populations of geese in 1992.

white-fronted geese (*Anser albifrons frontalis*), emperor geese (*Chen canagica*), black brant (*Branta bernicla nigricans*), cackling Canada geese (*Branta canadensis minima*), and sandhill cranes (*Grus canadensis*). Using a continuously running tape recorder, each observer voiced the start and end of each transect and segment and the species and group size for each waterfowl observation. We noted species name followed by group size (e.g., Canada goose single, swan pair, emperor goose flock of 3).

While running a customized data entry program on a personal computer, we replayed the tape for each transect. After initial entry of the necessary segment data (date, observer, transect number, segment number, flight direction, segment length), the tape was started. In synchrony with the recorded message of "begin segment", a keystroke stored the computer clock time and began a data input loop. Synchronous with each bird observation, species identification was quickly entered by a single keystroke on the species-labeled keyboard. The program simultaneously recorded the computer clock time at the moment of species key entry, and subsequent numeric key strokes entered the associated group size. At "end segment", a keystroke terminated the observation input loop, and for each observation, the program calculated the distance from the west end of the segment in proportion to time measured by the computer's clock according to the following formula:

$$d_{\mathrm{obs}} = d_{\mathrm{seg}} t_{\mathrm{obs}} / t_{\mathrm{seg}},$$

where d_{obs} is the distance from the segment start to the location of each observation, d_{seg} is the segment length, t_{obs} is the elapsed time between the start and the observation, and t_{seg} is the total time to replay the recorded segment. The data entry program attached segment information to each observation and allowed for corrections before saving the stored data to a file. The data were imported to a database for additional editing and sorting and exported in an ASCII format for use by geographic information system (GIS) and other analysis programs. Data entry while listening to tapes equaled flight time for the survey transects and was greater than the time required if data had been recorded on non-continuously running tapes. However, the increased time for replaying tapes was partially offset by concurrent error checking and standardization of the data file provided by the data entry program.

Observational efficiency of the pilot

We expected the pilot's efficiency as an observer to be reduced by the need to safely and accurately fly the aircraft along transects. We quantified the relative ability of the pilot and the right-seat observer to detect waterfowl. The front-seat observer called out all waterfowl observations over the aircraft intercom while the rear-seat observer recorded any additional observations. We used a 2 x 2 chi-square to test the null hypothesis that the pilot and observer missed the same proportion of observations.

Accuracy of locations

During the survey we recorded identifiable ground reference features such as riverbanks or lake shores. These reference observations were entered into the computer in the same manner as bird observations. Distances from the start of the segment to the ground reference points were measured on 1:250,000 scale USGS maps. We compared map-measured distances to calculated distances to determine the accuracy of locations. Accuracy was expressed as a positive or negative deviation from the measured distance and also as the absolute value of the difference between the 2 measures. We compared LORAN-C and GPS deviations from ground reference locations using t'-tests with unequal sample size and unequal variance.

Results

Survey effort

The YDNWR goose survey consisted of 93 transects (Fig. 1) totaling 2,800 km. Entering the coordinates of all transect start and endpoints in the LORAN-C was accomplished manually and required approximately 2 hours. Transect coordinates from a computer file were downloaded to the GPS with a data card. The survey required 8-10 days to complete. Total flight time was approximately 40 hours with 20 hours actually on the transects. Flying time required to complete the survey was similar to surveys using standard data recording procedures. Management of tape recorders and navigation instruments required practice and concentration when first learning the procedures.

The largest additional cost of including the location for each observation was the time necessary to listen to the recorded tapes and enter observations into the computer. However, this was not a major problem, as a 1993 error-free data file, containing over 9,000 observations with geographic locations, was ready for computer analysis within 1 week of flying the transects.

Pilot observations

On transects flown for efficiency testing, 817 waterfowl observations were made by front-seat observers; an additional 221 observations were made by the rear-seat observer, for a total of 1,038 observations. The proportion of total observations missed by front-seat observers was 0.213 (221/1,038). The proportions missed by the pilot and right-seat observer were 0.235 (134/569) and 0.185 (87/469), respectively. The difference in proportions was greater than would be expected by chance ($\chi^2 = 3.834$, 1 df, $P = 0.0502$).

Accuracy of locations

With LORAN-C navigation, differences between map-measured distance and calculated distance to reference points averaged −13 m (n = 109, SD = 489, range −1,244–1,833 m, Fig. 2); with GPS navigation, the average difference was −71 m (n = 83, SD = 259, range −676–482 m, Fig. 2). Average errors in direction were small in comparison to the large range of positive and negative differences in individual estimates of distance. The distances based on GPS had no differences over 700 m, and they were less variable ($F = 3.565$; 108, 81 df; $P < 0.001$) than differences obtained with LORAN-C. The absolute values of differences averaged 367 m (n = 109, SD = 323, range 0–1,833 m) with LORAN-C and 214 m (n = 83, SD = 162, range 0–676 m) with GPS. Calculated locations of observations were more accurate when navigating using GPS ($t' = 4.288$, 83 df, $P < 0.001$).

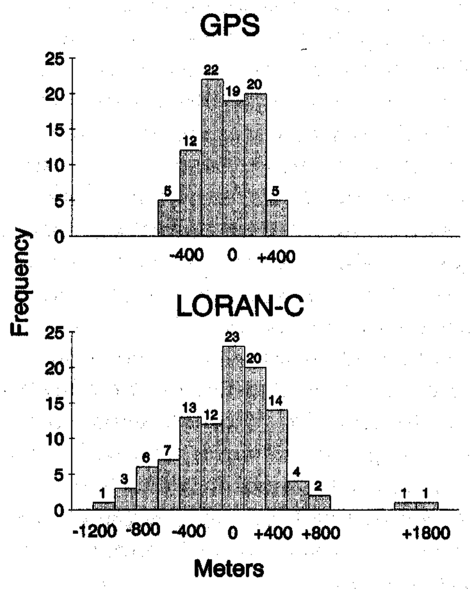

Fig. 2. Frequency distribution of deviations between the aerial observation computer-calculated locations and map-measured locations for test geographic reference points while navigating with LORAN-C in 1987 or GPS in 1993 on Yukon Delta National Wildlife Refuge, Alaska.

Discussion

Data recording and entry

A standard protocol for voice-recorded data was important to obtain accurate locations. In areas of high waterfowl density, the number of observations approached the maximum speed at which we could vocalize the data and, when transcribing tapes later, could enter species and group size on the computer. We were able to keep pace with recorded observations when consistent data recording protocols were followed.

Obtaining accurate locations also required that the computer program's data entry loop be started and stopped to match the time between segment start and end during the actual survey. Prompt and careful wording of transect number, flight direction, transect start, segment transition, and transect end provided the cues to correctly enter data on the computer. Because the proportion of time along each segment was used to calculate the proportion of segment distance for each observation, the aircraft flight speed, tape recording speed, and tape playback speed needed to be constant only for the 5 minutes required to fly each 12.8 km segment. Variation in flight speed, recording speed among segments, or between tape recording and playback speeds had no effect on the accuracy of locations.

The position of a bird relative to the aircraft when the observation was recorded could affect the geographic location. Most observations were recorded within 45° ahead to 45° behind a line perpendicular to the flight path at the observer's position. With a 200-m width, the actual position of birds observed could be as much as 200 m ahead or behind the observer. In areas of very high bird density, voice recording the last in a series of rapid observations sometimes was delayed until the aircraft had moved beyond the point the bird was actually observed. The time required to catch up in recording in this situation was ≤5 seconds. With the aircraft moving at approximately 45 m/second, the error in position associated with delay in voice recording was ≤225 m.

Flying the aircraft

Proper flying technique, use of instruments, and orientation of transects were important in maintaining accuracy of waterfowl locations. In addition to the LORAN-C or GPS, a gyro-stabilized heading indicator and a radar altimeter were the most important instruments required to fly transects safely and accurately. The pilot also needed a map that clearly showed transect number, latitude and longitude of transect start and endpoints, and distance from the start and from each segment transition to the transect end.

Transects oriented along lines of latitude simplified flying the initial sections of transects with accuracy. The present position readout from the LORAN-C or GPS allowed the pilot to intercept the extended transect several kilometers before the start of the transect. After establishing a course along the correct latitude, the pilot set the GPS readout to display the distance to the transect end waypoint. Start of the transect or segment was indicated when the distance to the waypoint matched the distance noted on the flight map. This procedure ensured accuracy even when we approached at low altitude over water or over tundra with few recognizable ground features. Use of navigation instruments and standard procedures enabled the pilot to stabilize the aircraft at the correct altitude, airspeed, and heading needed to maintain centerline prior to beginning the transect and to voice-record information into the tape recorder before passing over the transect start point.

With each mark on the course deviation indicator equal to 185-205 m, we believe use of LORAN-C or GPS enabled the pilot to keep the left-right flight deviation from centerline to within the distance reported for average accuracy (367 m for LORAN-C and 214 m for GPS) of observations along the transect. The course deviation indicator provided the pilot with a single reference for maintaining the transect. This helped the pilot maximize time spent looking for waterfowl and minimize time needed to fly the aircraft with precision. Flying the aircraft reduced the observational efficiency of the pilot by 5% relative to the observer (78% vs. 83%). This decrease was small compared to other factors known to affect observability of wildlife from aircraft (Caughley 1974, Caughley et al. 1976).

LORAN versus GPS positioning

The accuracy of position information from LORAN-C is affected by the distance from LORAN ground stations, the geometry between ground stations and the receiver, and the type of terrain over which signals must pass (Boer et al. 1989). In coastal Rhode Island, Patric et al. (1988) found that LORAN-C could determine position within 200 m and return to previously stored locations within 60 m. The YDNWR study area is optimally located for LORAN-C position information because it is near the center of a triangle connecting the LORAN-C ground stations (Fig. 1). Because of differences in terrain features and the changing geographic relationship between the aircraft LORAN-C receiver and LORAN-C ground stations, the error in position using LORAN-C varied within the YDNWR study area. With daily calibration of the LORAN-C, we corrected for variations in positioning information and located ground reference positions with an average absolute deviation of 367 m using our method of data recording and transect navigation.

In 1992 we replaced the LORAN-C with a GPS instrument for transect navigation. The GPS receives signals from satellites and can determine position to within 15 m (Trimble Navigation 1990), although selective availability of the satellite signal reduces the positional accuracy to 100 m or more at times. The GPS is not subject to the terrain-induced signal propagation error of the LORAN-C and provides consistent positioning data anywhere on the earth's surface as long as satellite information can be received. Replacement of LORAN-C with GPS improved the average accuracy of locating ground reference positions by 42% (367 m to 214 m). We attribute improved accuracy to the inherent accuracy of position information from GPS and the lack of change in positional error depending on location that was associated with LORAN-C.

Maintaining location accuracy

Accuracy of geographic locations depended on the type of navigation instrument (LORAN-C or GPS), frequency and accuracy of calibration when using LORAN-C, accurate identification of transect start and endpoints, accurate identification of segment transition points, use of standardized voice recording procedures, and ability of the pilot to stay on transect using a map and navigation instruments. All the above factors need to be considered in achieving the accuracy reported.

Our measure of accuracy for ground reference locations with LORAN-C and GPS compared distances only along the transect; deviations to the side were not measured. Because some reference points (river banks and lake shores) crossed transect lines at an angle, left-right error in flying the transects contributed to some of our estimates of error. With GPS, the error along the transect in position of an observed geographic feature averaged 214 m with a maximum absolute difference of 676 m. In addition, a bird observation could be up to 200 m to either side of the aircraft, as much as 200 m ahead or behind the present location, and the aircraft could be as much 205 m from centerline even before response by the course deviation indicator. We have no measure of the average values of these additional potential errors in locations.

Several software programs are available that download coordinate information from LORAN-C or GPS to a computer at regular intervals and whenever a key is pressed (R. H. Pollard, Caribou distribution in the Prudhoe Bay Oil Field, Summer 1990 final report, BP Exploration Alaska Inc., Anchorage, 1992; Anthony and Stehn 1994). Such programs that record geographic position, number of birds, and species at each observation (real-time geo-referencing) are useful for surveys from slowly moving survey vehicles or for species occurring at low density because the observer must enter each observation directly to the keyboard. The rapid rate of observations and number of species recorded on our surveys precluded direct keyboard entry by the pilot or observer. Computer voice recognition technology has the potential to allow direct coding of aerial survey observations. Applying this technology would eliminate continuously running tapes and improve the accuracy of geographic locations by eliminating the error associated with the pilots ability to maintain the transect centerline.

Applications

Geographic locations for all observations provide the following benefits for waterfowl aerial transect surveys:

- Existing aerial surveys can be flown to obtain more detailed information with no additional flight time using our data recording methods.
- Location data can be used to improve survey design, analysis, and precision of population indices. Data can be post-classified to determine a stratified survey design that yields the most precise population estimates. Such strata, perhaps with reallocation of sampling intensity, provide statistically valid variance estimates with the next year's data. Provided that stratification boundaries of differing sampling intensity are maintained, post-classification can be different for each species or species group.
- Location data increase the ability to integrate ground-based or other sampling with aerial observation data to improve our understanding of aerial surveys. Methods of determining visibility correction factors (Cook and Jacobson 1979, Pollock and Kendall 1987) could be enhanced with accurate location data. Independent estimates of nest, egg, or brood density from ground plots can be correlated with aerial observations either by direct pairwise comparison with plots or by comparison of mean densities within a specified geographic areas.
- The location of observations along transects can be converted to geographic coordinates and entered into GIS for display on maps and various spatial or overlay analyses. We use location data from aerial transect surveys to map distribution of waterfowl on remote nesting areas throughout Alaska (Butler et al. 1995).
- Accurate locations increase the use of data to answer biological and management questions related to the distribution of populations. Waterfowl density may be influenced by proximity to brood rearing areas, coastlines, human disturbances, or other factors. Location data can be used to correlate density to habitat features measured on aerial photographs, video imagery, or satellite data. Impact assessment on areas selected for potential development or evaluation of specific land parcels considered for purchase, exchange, or easement can be examined objectively based on relative number of waterfowl observed.

Acknowledgments. We appreciate the reviews of this manuscript by G. R. Balogh and J. R. Morgart. Wildlife biologists W. B. Eldridge, R. A. Malecki, C. J. Lensink, and K. S. Bollinger served as observers. We thank the staff of YDNWR for their support and assistance during the project.

Literature cited

Anthony, R. M., and R. A. Stehn. 1994. Navigating aerial transects with a laptop computer map. Wildl. Soc. Bull. 22:674-676.

Boer, A. H., G. Redmond, and T. J. Pettigrew. 1989. LORAN-C: a navigation aid for aerial surveys. J. Wildl. Manage. 53:228-230.

Butler, W. I., R. A. Stehn, and G. R. Balogh. 1995. GIS for mapping waterfowl density and distribution from aerial surveys. Wildl. Soc. Bull. 23:140-147.

Caughley, G. 1974. Bias in aerial survey. J. Wildl. Manage. 38:921-933.

Caughley, G., R. Sinclair, and D. Scott-Kemmis. 1976. Experiments in aerial survey. J. Wildl. Manage. 40:290-300.

Cook, R. D., and J. O. Jacobson. 1979. A design for estimating visibility bias in aerial surveys. Biometrics 35:735-742.

Cowardin, L. M., and R. J. Blohm. 1992. Breeding population inventories and measures of recruitment. Pages 423-445 *in* B. D. J. Batt, A. D. Afton, M. G. Anderson, C. D. Ankney, D. H. Johnson, J. A. Kadlec, and G. L. Krapu, eds. Ecology and management of breeding waterfowl. Univ. of Minnesota Press, Minneapolis.

Gillespie, D. I., and S. P. Wetmore. 1974. Waterfowl surveys in Labrador-Ungava, 1970, 1971, 1972. Pages 8-18 *in* H. Boyd, ed. Waterfowl studies in eastern Canada. Can. Wildl. Serv. Rep. Ser. No. 29.

JEPPESEN SANDERSON, INC. 1981. Advanced pilot manual. Jeppesen Sanderson, Inc., Inglewood, Colo. 466pp.

KACZYNSKI, C. F., AND E. B. CHAMBERLAIN. 1968. Aerial surveys of Canada geese and black ducks in eastern Canada. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. No. 118. 29pp.

MALECKI, R. A., F. D. CASWELL, R. A. BISHOP, K. M. BABCOCK, AND M. M. GILLESPIE. 1981. A breeding ground survey of EPP Canada geese in northern Manitoba. J. Wildl. Manage. 45:46-53.

MALECKI, R. A., AND R. E. TROST. 1990. A breeding ground survey of Atlantic Flyway Canada Geese, *Branta canadensis*, in northern Quebec. Can. Field-Nat. 104:575-578.

MARTIN, F. W., R. S. POSPAHALA, AND J. D. NICHOLS. 1979. Assessment and population management of North American migratory birds. Pages 187-239 *in* J. Cairns, Jr., G. P. Patil, and W. E. Waters, eds. Environmental biomonitoring, assessment, prediction, and managementæcertain case studies and related quantitative issues. Stat. Ecol. Ser. Vol. 11. Int. Coop. Publ. House, Fairland, Md.

MARTINSON, R. K., AND C. F. KACZYNSKI. 1967. Factors influencing waterfowl counts on aerial surveys, 1961-66. U.S. Fish Wildl. Serv. Spec. Sci. Rep. Wildl. No. 105. 78pp.

PATRIC, E. F., T. P. HUSBAND, C. G. MCKIEL, AND W. M. SULLIVAN. 1988. Potential of LORAN-C for wildlife research along coastal landscapes. J. Wildl. Manage. 52:162-164.

POLLOCK, K. H., AND W. L. KENDALL. 1987. Visibility bias in aerial surveys: a review of estimation procedures. J. Wildl. Manage. 51:502-510.

RAVELING D. G. 1984. Geese and hunters of Alaska's Yukon Delta: management problems and political dilemmas. Trans. North Am. Wildl. and Nat. Resour. Conf. 49:555-575.

TRIMBLE NAVIGATION. 1990. TNL-2000 GPS and TNL-3000 GPS/LORAN navigators. Operators Manual. Trimble Navigation, Sunnyvale, Calif. 270pp.

Received 2 April 1993.
Accepted 11 October 1994.
Associate Editor: Rotella.