GIS for mapping waterfowl density and distribution from aerial surveys

William I. Butler, Jr., Robert A. Stehn, and Gregory R. Balogh

Abstract We describe a GIS (geographic information system) that combines a personal computer, a color printer, a color plotter, aerial survey data, software for programming, standard mapping, and 3-dimensional mapping. It allows us to display: (1) geographic locations of observations; (2) isopleths showing the distribution and relative density for each species or group of species; (3) changes in distribution; (4) changes in bird density; and (5) isopleth overlays on data layers such as land ownership. Our method of analyzing and graphically presenting waterfowl location data has increased the use, effectiveness, and application of multi-species aerial surveys in Alaska. These techniques should be equally useful outside Alaska.

Key words aerial survey, Alaska, density, distribution, geographic information system, GIS, global positioning system, GPS, mapping, waterfowl

Maps efficiently summarize extensive geographic data and can effectively indicate the range and relative density of wildlife populations. Several large data sets and computerized mapping techniques have recently been combined to provide previously impossible quantity and detail of information. Breeding Bird Atlas (BBA) data show the breeding range of avian species for many areas around the world (Robbins 1990). These data are based primarily upon presence or absence of species observed during visits to selected locations in 5-km^2 or larger grid cells (Robbins et al. 1989). Christmas Bird Count (CBC) data have been used to make 3-dimensional maps of bird distribution and relative density during winter (Root 1988). Many observations at scattered locations within a 24-km radius circle are summed in the CBC, and data need adjustment for differences in observer effort and expertise. The North American Breeding Bird Survey (BBS) data have been incorporated into a GIS (geographic information system) showing average relative density and trends in density of breeding birds counted along 40-km roadside routes across the continental United States and southern Canada (J. R. Sauer, Natl. Biol. Serv., Patuxent Wildl. Res. Cent., Laurel, Md., pers. commun., 1994). The North American Waterfowl Breeding Pair Survey (BPS) yields data on aerial survey observations of waterfowl summarized by 26- or 29-km segments along widely spaced transects.

None of the above methods, however, use the actual geographic location of individual birds as the foundation for maps. Our objective was to provide refuge managers with geographic waterfowl population data at high resolution by developing GIS techniques for mapping bird distribution, density, and changes in density based on aerial surveys that record the geographic location of individual observations. We describe a process to convert observation location data into 3-dimensional (3-D) density and distribution maps, and we discuss factors affecting map development and interpretation. Use of trade names does not imply endorsement of commercial products by the U.S. Fish and Wildlife Service or National Biological Service.

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Study area

Our survey areas included the Yukon Delta National Wildlife Refuge (YDNWR), the Yukon Flats National Wildlife Refuge (YFNWR), the Copper River Delta, Alaska's North Slope, Alaska's northwest coast, and Bristol Bay area wetlands in Alaska. The 6 surveyed areas encompass 226,600 km^2 and are inaccessible by road. Therefore, aerial surveys are the only practical way to survey waterfowl populations. The areas are highly dissected by river and stream channels and contain countless bodies of water. Vegetation includes coastal forests, shrub-dominated floodplains, wetlands surrounded by taiga, upland and lowland tundra, marsh, bog, open water, and sparsely vegetated mudflats (Bergman et al. 1977, Viereck et al. 1992). Low vegetation in wetlands increased the detectability of birds from the air.

Methods

Aerial survey

We followed aerial survey conventions established for surveys of waterfowl breeding pairs (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). Survey timing was adjusted each year to coincide with the first half of incubation for geese nesting in the area. We flew strip transects in high-winged aircraft at 35–45 m altitude and 145–160 km/hour. We maintained flight paths by referring to landmarks on 1:250,000 scale topographic maps with our transects plotted on them and by using a global positioning system (GPS) to navigate toward the longitude-latitude coordinates of transect endpoints. Systematic transects, spaced at 0.8–12.9 km intervals, originated from a random starting point and followed lines of latitude or longitude, or great circle routes.

We determined the geographic location of each observation along transect lines using GPS, cassette tape recorders, and a data input program that used elapsed time to calculate position of observations along transects (Butler et al. 1995). The input program created an observation data file with header information, species codes, group sizes, and position of observations along a transect.

Point-observation plots

A program written in True BASIC® (True BASIC, Inc., 39 South Main Street, Hanover, NH 03755; Kemeny and Kurtz 1990) read the observation data file and calculated geographic coordinates for each observation based on distance along a transect and transect start and end coordinates. From the data files, we generated point coverages with ARC/INFO® (Environmental Systems Research Institute, Inc., Redlands, Calif.; Environ. Sys. Res. Inst. 1989) to which we joined attribute information (species, group size, observer, and observation date). The resulting point coverages were used to make waterfowl location maps.

Creating three-dimensional plots

Although point coverages were useful, a continuous 3-D representation of the data allowed further analyses (e.g. overlays with other data, detection of change, delineation of critical habitat). The 3-D software could not be used directly on the waterfowl point data because the point coverages contained geographic coordinates only for discrete observations of a single, pair, or flock of birds and no data on locations where birds were not seen. To create suitable data for 3-D modeling, these location data were converted to units of density. We summed the number of birds observed in small sequential sections along transects. Three-dimensional processing of the aerial survey data was initiated by a True BASIC® program that read files of transect end coordinates and observation data and accumulated the number of observed birds within blocks of user-defined length at regular increments along each transect. The program converted block area (distance along the transect times the 400-m observation width) and discrete observation data to continuous bird density data.

We had the option of choosing the length of the block for the average density calculation. This smoothing of the data was analogous to an image processing smoothing filter (Estes et al. 1983:1,040), except that it only smoothed data along transects without regard for data on adjacent transects.

The resulting file summarized observations of individuals, pairs, and flocks of each species and diminished abrupt peaks and valleys in the data. The resulting output file of longitude, latitude, and relative density for each block was formatted for generating a coverage with PC TIN® (Environmental Systems Research Institute Canada Limited, 44 Upjohn Rd., Don Mills, Ont., Can., M3B 2W1; Environ. Syst. Res. Inst. 1991), the terrain modeling software written for PC ARC/INFO®. In PC TIN®, we used the GEN3D, BUILDTIN, and CONTOUR commands to produce waterfowl density isopleths (contours of equal value for some variable) at a base value and an interval specified by the user.

We extracted isopleths of equal value as separate coverages and attached the corresponding density values to the polygons in each coverage. We updated component isopleths to bring them together as a single coverage. This process allowed us to shade each isopleth level with a different color or pattern to create a waterfowl density "contour" map. The resulting polygon coverage was better suited to spatial analysis than the line topology output from the contour process. Our relative density polygons could be converted to absolute density by multiplying relative densities by a factor to correct for the proportion of birds not observed. Details of techniques are available from the authors.

Evaluation of the model

To determine if the 3-D modeling procedures accurately represented our data, we compared our statistical estimates of population with TIN (triangulated irregular network) volumes obtained from the same data. Systematic transect survey design and statistical procedures followed Caughley (1977) with variance estimated using ratio estimate procedures (Cochran 1977).

Results

Our GIS had >140,000 geographic locations of waterfowl observed along systematic transects flown from 1990–1993 on Alaska's north slope (*n* = 14,782 observations), 1988–1992 on the YFNWR (*n* = 16,506), 1988–1992 on the YDNWR (*n* = 17,826), 1986–1993 on the Copper River Delta (*n* = 7,992), and 1985–1993 on the coastal zone of the YDNWR (*n* = 80,011). In addition, we obtained 3,811 geographic locations for birds on Alaska's northwest coast in 1992 and 2,653 locations of birds in the Bristol Bay area in 1993.

Our largely automated process using PC ARC/INFO® mapped bird observation locations (Fig. 1) for any species within 2 hours of completing data entry and error checking and automatically compiled and printed ≥50 waterfowl location maps overnight using macro programming. The automated process of creating polygon coverages and maps with relative density isopleths (Fig. 2) required 2 hours/species. GIS software allowed us to

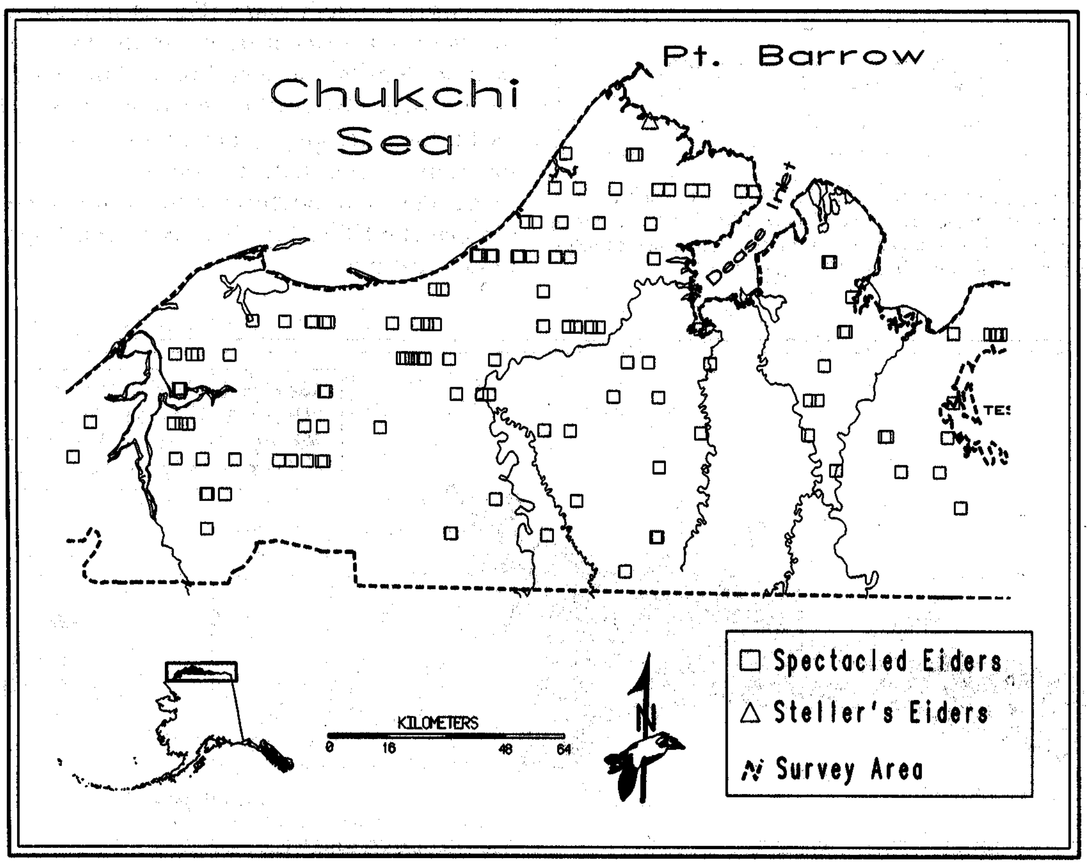

Fig. 1. Locations of spectacled eider (*Somateria fischeri*) and Steller's eider (*Polysticta stelleri*) breeding pairs within the northern portion of Alaska's north slope duck production area. Data are from aerial surveys flown 7–20 June 1993.

overlay density coverages with other data layers (Fig. 3). Overlays of relative density polygons from different years resulted in maps showing the geographic extent and relative amount of population change (Fig. 4).

Population estimates based on TIN volumes were within the 95% confidence interval of the statistical estimates for 5 of 6 species tested (Table 1). However, TIN volumes ranged from 1-18% lower than the statistical population estimates.

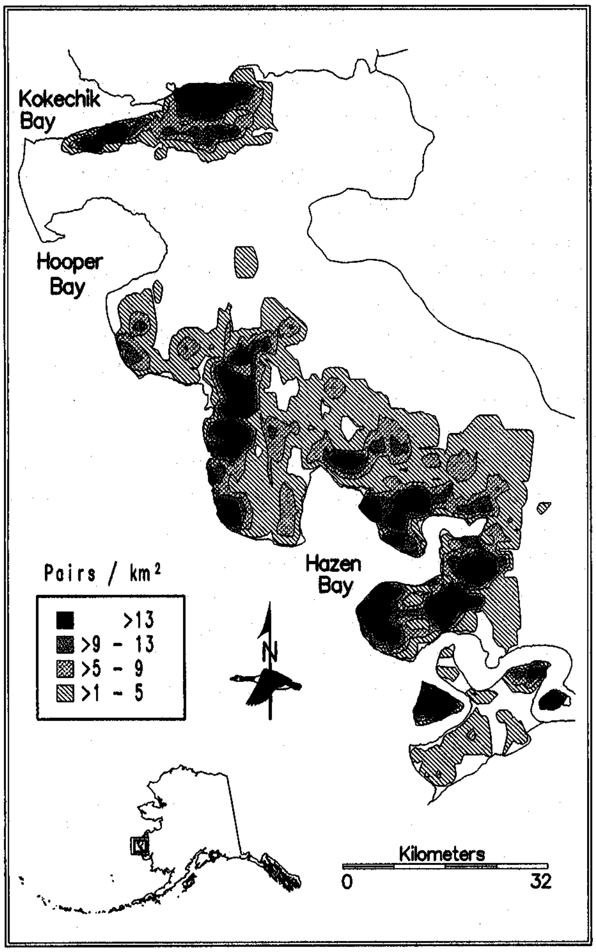

Fig. 2. Density polygons for cackling Canada geese (*Branta canadensis minima*) within the coastal zone of the Yukon–Kuskokwim Delta, Alaska. Shaded density polygons are defined by density isopleths. Data are from aerial surveys flown 10–19 June 1992.

Discussion

Use of maps

Observation location maps (Fig. 1) allow rapid identification of waterfowl concentration areas, display broad geographic patterns, and suggest associations of animals with terrain or cover-type. However, the usefulness of points to determine spatial relations is limited because densities along and between transects must be visually estimated. In addition, many animal locations often become superimposed on small scale maps and, when separate points are indiscernible in densely populated areas, location maps underrepresent actual density.

Density isopleth maps (Fig. 2) interpolate densities between adjacent transects and visually convey relative density and distribution information more clearly than observation location maps. They are useful for determining: (1) broad scale distribution patterns or population trends within a species' range, (2) strata boundaries for future surveys, and (3) spatial relationships between animal density and terrain features.

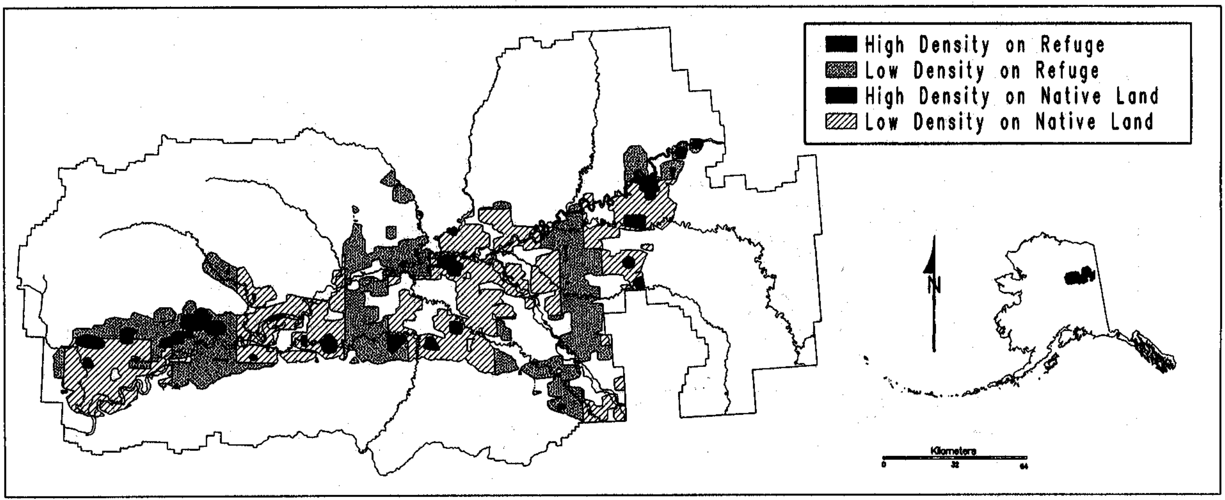

Fig. 3. Density polygons for lesser scaup (*Aythya affinis*) overlayed upon land ownership information within Yukon Flats National Wildlife Refuge, Alaska. Scaup data are from aerial surveys flown 4–7 June 1992.

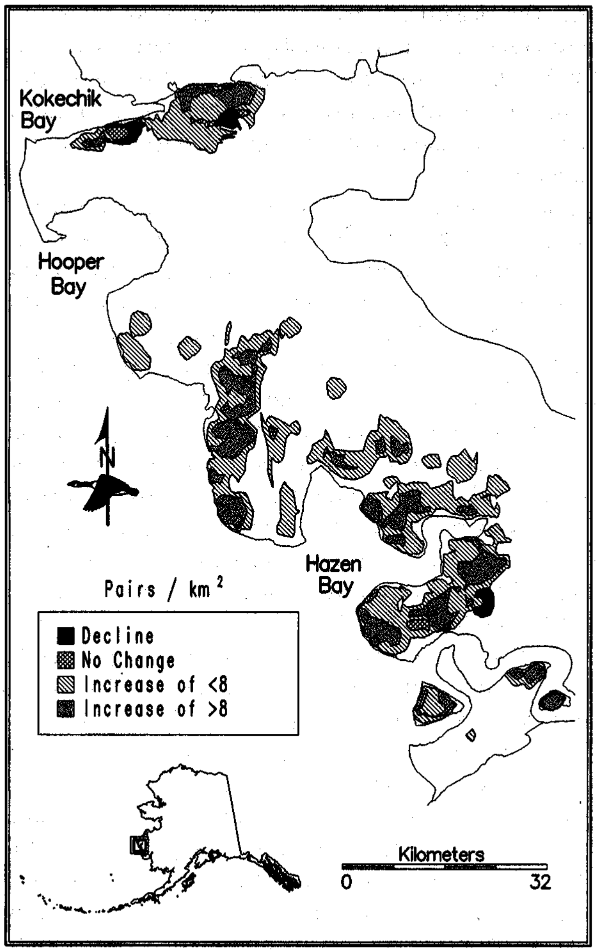

Fig. 4. Density change polygons for cackling Canada geese in the coastal zone of the Yukon–Kuskokwim Delta, Alaska, 1985 versus 1992. Data are from aerial surveys flown during early June of both years.

Accuracy of surveys and maps

Factors affecting aerial surveys of waterfowl are well understood (Cowardin and Blohm 1992). Surveyors must understand waterfowl behavior at the time of the survey to identify whether singles, pairs, or flocks best index the breeding population for each species (Sauder et al. 1971, Malecki et al. 1981, Schneider et al. 1994). They also must understand visibility bias related to differences among species, habitat, survey timing, weather conditions, observer, and aircraft (Malecki et al. 1981, Broome 1985). We minimized variability in our surveys by using experienced pilot biologists and observers, timing the surveys in each area to the appropriate seasonal phenology and using the same type aircraft in all areas.

The accuracy and precision of our waterfowl distribution and abundance maps depend upon: (1) accuracy of geographic locations along transects, (2) intertransect spacing, and (3) the manner in which the 3-D modeling software represents the data. Positional accuracy is an important component of map quality. Aronoff (1989) defined positional accuracy as the expected deviation in geographic location of an object on a map from its true ground location. Accuracy also involves a probability. The aerial survey techniques used to gather our waterfowl location data resulted in an average positional error for a single observation of 214 m (SD = 162 m, range = 0–676 m; Butler et al. 1995). Average positional error accounts for error along a transect line but does not account for left–right error in flying the transect. It also assumes observed birds were along the centerline of a transect, when they could be up to 200 m to either side. This distance is comparable to national map accuracy standards for 1:250,000 maps which states that <10% of the map points tested shall err by >135 m (Thompson 1988). Few U.S. Geological Survey 1:250,000 scale maps in Alaska are tested for conformance to national map accuracy standards. Greater positional accuracy is superfluous for our applications.

Table 1. Population estimates[a] of waterfowl breeding in Alaska in 1992 obtained by standard statistical analysis of a stratified systematic aerial transect survey and, based on the same data set, the volume of a triangulated irregular network (TIN), a 3-dimensional draped surface of bird density calculated from summary blocks along each transect.

Survey area	Species	TIN volume	Statistical estimate $\bar{x}$	Statistical estimate 1.96 SE
Yukon Delta coastal zone	Cackling Canada goose (*Branta canadensis minima*)	12,521	12,630	1,599
	Emperor goose (*Chen canagica*)	3,806	4,042	527
	White-fronted goose (*Anser albifrons frontalis*)	5,496	6,401	960
Arctic coastal plain	Northern pintail (*Anas acuta acuta*)	21,497[b]	26,380	7,404
	Oldsquaw (*Clangula hyemalis*)	21,754	25,470	2,914
	Spectacled eider (*Somateria fischeri*)	1,255	1,376	886

[a] Not corrected for visibility.

[b] TIN volume is not within 1.96 SE of $\bar{x}$.

The close comparison between TIN population estimates and statistical estimates (Table 1) lends credibility to our method of mapping waterfowl abundance and distribution. TIN estimates were slightly lower than the statistical estimates of population for unknown reasons, but the reason is perhaps analogous to negative bias observed when estimating home range by the minimum convex polygon method (Boulanger and White 1990). TIN's and minimum convex polygons consist of straight lines connecting the observed points into 2- or 3-D area or volumes based on sampling data. Boulanger and White (1990) reported that the bias for the minimum convex polygon estimate of home range area was variable but was large and negative for small sample sizes. Despite the possible negative bias in the TIN volumes, the close comparability of these volumes to the statistical estimates showed that density polygons are useful for representing survey data. The TIN volumes and statistical estimates are both derived from the same data. The comparison only serves to illustrate that the 3-D model of our data is consistent with the more standard statistical method of obtaining population estimates from transect samples.

Influences on density polygons

Length of the block for density calculation should approximate the distance between transects. Likewise, the distance increment along transects for each block center must be the same size or smaller than the distance between transects. As block distance increases, density polygons in areas of few or patchy observations become elongated along the axis of the transect. Similarly, short block lengths cause polygons to elongate perpendicular to the axis of the transects (Fig. 5).

Placement and spacing of transects within the study area influenced the size and shape of bird density isopleths. Within randomly-spaced transects, the inter-transect distance would vary as would the slopes of the 3-D surface from a given density value on 1 transect to another value on an adjacent line. Where transects were widely separated, the slopes were more gradual and the polygons averaged larger than those resulting from equivalent density data on more closely spaced transects. By controlling the effect of variable transect spacing on density polygon size and shape, systematic transects are more appropriate than random transects for mapping distribution (Caughley 1977).

The PC TIN® terrain modeling software produced a more meaningful product when the density values were set to zero at and beyond a defined boundary. When the data surface was unconstrained, the TIN process extrapolated from the density values on the edge of the survey area across unsampled areas and produced misleadingly large density polygons. This edge-constraint of the data surface only affected the shape of density polygons near the edge of the study area. Creating a zero-density boundary is appropriate

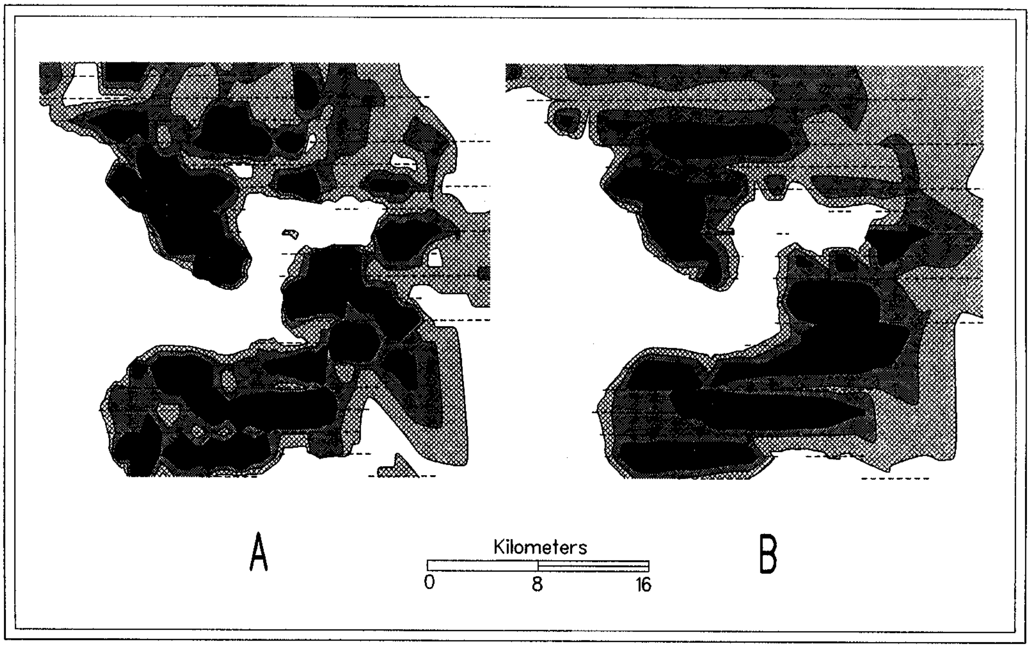

Fig. 5. Density polygons for the same set of sample data illustrating the effect of short block length (A) versus long block length (B) for calculating average density of birds

when the edge of the study area represents a biological boundary beyond which bird density actually is zero (e.g., a coastline) rather than an arbitrary limit relating to breeding bird density (e.g. a refuge boundary). Our transect surveys extended to the edge of wetland breeding habitat.

Comparison to other methods

Robbins (1990) mapped bird distribution based on presence-absence data in grid format, and Root (1988) used 3-D software to map isopleths of relative number of birds observed/unit effort. However, we are unaware of any GIS that routinely processes large numbers of individual animal locations from aerial surveys and produces isopleths of animal density or change in density using 3-D terrain modeling software.

GIS models have been developed for predicting animal abundance based on land-cover data and habitat preference (Miller et al. 1989, Walker 1990, Yonzon et al. 1991). GIS also is used with image-processing systems or aerial photographs to identify habitat and habitat changes (Williams and Lyon 1991, Kempka et al. 1992). Our methods allow GIS analysis of animal observations independent of habitat data and portray distribution and abundance data simultaneously.

Our method of conducting aerial surveys and use of PC-based GIS allowed us to rapidly and effectively display animal distribution, abundance, and population change on maps at low cost. Our technique of gathering and displaying geographic location data offers higher spatial resolution than traditional atlas grid methods of mapping bird abundance (Robbins et al. 1989). Also, our 3-D data processing allows us to display animal abundance and changes in abundance with more precision than atlas maps based only on presence-absence data (Bart and Klosiewski 1989).

The standard North American waterfowl breeding pair survey summarizes data by 26- or 29 km-long transects. Our method of data collection and display represents at least a 100-fold increase in mapping resolution over standard waterfowl survey methods and approaches the national map accuracy standards for 1:250,000 scale maps. Individual users must decide if these data collection, processing, and mapping methods meet their accuracy needs.

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