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USE OF A GEOGRAPHIC INFORMATION SYSTEM TO FACILITATE ANALYSIS OF SPOT-MAPPING DATA

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Abstract.—Spot mapping is widely used in bird research, but the time required to compile species composite maps and the limited utility of paper maps are a drawback to its use. A Geographic Information System (GIS) was used to enter and analyze spot-mapping data. A new program (BIRDMAP) was written using the programming language of PC ARC/INFO to digitize data from field maps. Use of BIRDMAP greatly reduced the time required to produce species composite maps. Specific applications and benefits of using a GIS for analysis of spot-mapping data are presented.

LA UTILIZACIÓN DE SISTEMAS DE INFORMACIÓN GEOGRÁFICA PARA FACILITAR EL ANÁLISIS DE DATOS EN MAPAS DE PUNTOS

Sinopsis.—Los mapas de localización de puntos son ampliamente utilizados en investigaciones sobre aves. Sin embargo, el tiempo requerido para compilar los mapas por especie y la utilidad limitada de mapas de papel son aspectos limitantes de esta técnica. Se utilizó un sistema de información geográfica (SIG) para analizar mapas de localización de puntos. Se desarrolló un nuevo programa (BIRDMAP), utilizando el lenguaje de programación PC ARC/INFO para digitalizar los datos de mapas de campo. El uso de BIRDMAP redujó significativamente el tiempo requerido para producir dichos mapas. Se presentan en el trabajo aplicaciones y beneficios de la utilización de SIG para el análisis de mapas de localización de puntos.

Spot (bird territory) mapping has been used widely in bird research since the 1930s (Hall 1984, Kendeigh 1944, Williams 1936). It has been used primarily for estimating bird density and for evaluating habitat use (Bibby et al. 1992, Manuwal and Carey 1991), despite the labor-intensive nature of both field work and map analysis which is often cited as a major drawback (Bibby et al. 1992, Johnston 1990, Manuwal and Carey 1991, Oelke 1981, Verner 1985). In particular, the creation of species composite maps from the daily field maps requires a substantial amount of time and great attention to accuracy. Only after species composite maps are created and territories delineated can density be estimated. Further application, particularly spatial analysis, is difficult because of the paper format and the time-consuming nature of analysis. These constraints have led to the underutilization of the data by researchers.

Shaw and Atkinson (1990) emphasized the utility of a Geographic Information System (GIS) to facilitate analysis of spatial and temporal data in ornithological research. They described the purpose of a GIS as creating, organizing, and analyzing spatially oriented data and their associated attributes. One major advantage of a GIS is the capability for handling much larger data sets and more data layers (spatially related but distinct data) than would be possible with manual methods. These GIS features match the types of data sets associated with the analysis of bird spot maps.

Shaw and Atkinson (1990) outlined four components of a GIS: data entry, data management, data analysis and manipulation, and data display and product generation. Each of these components can be used by an application of a GIS to enter and analyze spot-mapping data. Data entry is done primarily with a digitizing tablet which transfers information from field maps to a computer. Because each data location is stored as a pair of X–Y coordinates with a unique identification number, it can be linked to its relevant information or attributes. Data management involves the storage of each map with its associated attributes and having both readily accessible to the GIS or other software packages. Data analysis and manipulation include transforming daily maps into species composite maps and then further analysis such as overlaying bird data with habitat information. Data display and product generation refer to using the GIS to create screen displays, to plot maps, and to produce other representations of analysis.

Frustrated by both the time burden and the limited utility of species composite maps prepared by hand, we decided to use a GIS to facilitate the process of compilation and analysis of spot-mapping data. The primary goals of this project were to: (1) automate the process of entering spot-mapping data, (2) automate the creation of species composite maps, and (3) create permanent digital records of the detections. In this paper we describe a program and other methods used to accomplish these goals and discuss some of the benefits of using a GIS for compiling, storing, analyzing, and displaying spot-mapping data.

METHODS

Study area and data collection.—The Holt Research Forest (HRF) in Arrowsic, Maine (43°52′N, 69°46′W) is a heterogenous mixture of forest cover types dominated by eastern white pine (*Pinus strobus* L.), red maple (*Acer rubrum* L.), and northern red oak (*Quercus rubra* L.). The 40-ha study area was divided into 20-ha managed and control areas and gridded at 50-m intervals. As part of a long-term forest ecosystem study, JWW collected spot-mapping data from 1983 to 1994 using a modified version of the standards suggested by Robbins (1970); see Witham et al. (1993) for details of the method. Sixteen visits were made each breeding season between 18 May and 22 July. Two maps (one for managed and one for control areas) were created during each visit. All field data were recorded on 216 × 356-mm paper at a scale of 1:2500 with a 50-m grid.

Data entry.—PC ARC/INFO, Version 3.4.1, a vector-based geographic information system produced by Environmental Systems Research Institute, Inc. (ESRI) was used for all entry and analysis. The programs were designed and tested on a 33 MHz 80386-based PC with 8 MB of RAM while the data were entered and analyzed on a 66 MHz 80486-based PC with 16 MB of RAM. A standard 30 × 45-cm digitizing tablet with a 16-button cursor was used for map and menu input.

A program (BIRDMAP) was written using the Simple Macro Language (SML) of PC ARC/INFO. Each SML file is a group of commands that

SPECIES										OBSERVATION TYPE and MOVEMENT				ARC/INFO COMMANDS and SML COMMANDS							
AMGO	AMRO	BAWW	BCCH	BHCO	BLBW	BLJA	BRCR	BTNW	BWHA	MOVE	X	♂	♀	SAME	END OBS			RESET	ERROR		NEW MAP
CAWA	COYE	CWAX	DOWO	EWPE	GCFL	GCKI	HAWO	HETH	MAGW	CCO	⊗	⊙♂	⊙♀	MULT IND	REPEAT	?MOVE		DEL LOC	NOTE		
MODO	NAWA	OVEN	PIWA	PUFI	RBNU	REVI	RUGR	SCJU	SCTA	NEST	E	○	⊙	AGE	DISP LOC	DRAW	ADD LINE	DEL LINE	SETUP DIG		
SOSP	SOVI	VEER	WBNU	WIWR	WTSP	YRWA	YSFL	OTHER SPEC	UNKN SPEC	OTHER BEH	e	•	FO	SHOW LAST INPUT	SHOW LAST LINE	ENTER	CMND KEYBD	CMND DIG	COORD DIG		EXIT

FIGURE 1. The digitizing menu used by the program BIRDMAP.

carry out a single task. SMLs can be used individually or organized into larger macros. SML macros can be used to accomplish a wide range of operations from simple (e.g., assigning a species number to a plotted detection) to complex tasks (e.g., controlling the entire input process of BIRDMAP). BIRDMAP was intended to be a time efficient and user-friendly program enabling a GIS novice to enter spot-mapping data with minimal training and supervision.

The primary attributes needed for each spot map detection are species, type of observation or behavior (e.g., male heard singing, female seen and heard calling), and location (X–Y coordinates). Additional information such as movements by an individual, presence of concurrently singing males, number of individuals (if >1), and age (if not an adult) may also be important. Each detection needs to be entered only once to be available for all further analyses.

BIRDMAP uses the custom digitizer menu feature of the ARCEDIT module in PC ARC/INFO. This feature enables a person to enter locations of detections, as well as all attributes, using primarily the digitizing cursor. The digitizing menu for BIRDMAP (see Fig. 1) is a 4 row, 22 column grid of cells placed and registered on the digitizing tablet. The menu serves as a template of commands and options. Each cell of the menu is linked to a command in an associated database file and selection of a cell with the cursor will run an SML macro or initiate a PC ARC/INFO command. Thirty-eight common species, all observation or behavior types, and many commands are found on the digitizing menu. Blank cells in the menu allow for the addition of other commands.

BIRDMAP includes pop-up menus (display windows on the computer screen with a selectable list of options) that are used to solicit information not available on the digitizer menu. For example, a user may select OTHER SPECIES on the menu to "pop up" a list of additional species to choose from. Information requests can be made to determine the status of the program (e.g., SHOW LAST INPUT, to display the most recently input data). Error messages and warnings are displayed on the screen if unexpected or incorrect information is entered.

BIRDMAP begins with screen prompts asking the user for the date of field work, map location or study area, and visit number. This information is entered on the keyboard and used to name any data files and the

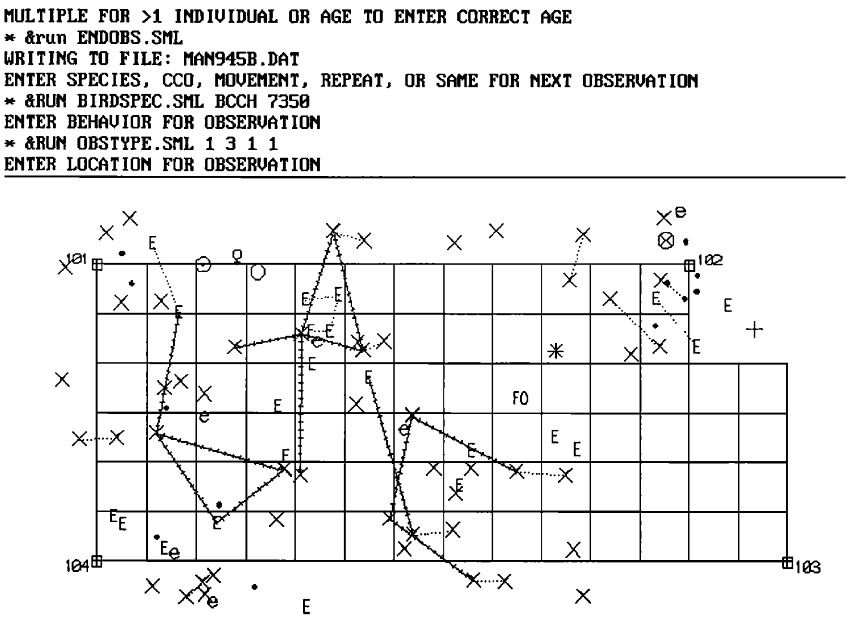

FIGURE 2. Screen capture of BIRDMAP in operation. Note commands on top eight lines, symbols to mark location of detections, numbered tics at the corners of the study grid, and cursor symbol (large plus) in upper right above grid.

graphical coverage (ARC/INFO term for a data layer) generated by the program. BIRDMAP then uses this information to select and copy a coverage of the study area grid to the screen (Fig. 2). The top eight lines of the screen are reserved to display the executed commands and program response. The remainder of the screen displays the coverage being created, which is initially a base map of the lines representing the study area grid.

A field map is placed on the digitizing tablet with the menu. The map is then registered (located and transformed) by digitizing a minimum of four predetermined control locations (tics). This links the field map to the line coverage viewed on the screen. The cursor is displayed on the screen as a large plus to facilitate the correct placement of detection locations.

Once the field map and digitizing menu have been set up, BIRDMAP prompts the user for all input. In general, BIRDMAP prompts for (1) a species, (2) an observation or behavior type, (3) the location of a detection on the field map and (4) an indication of the end of input for a detection. Most detections can be entered with four clicks of the digitizing cursor on the tablet. As each detection is entered, an "X" is displayed on the screen in the appropriate location and lines are displayed for any movements or to identify the location of concurrently singing males.

When a "DRAW" command is issued the screen is updated to reflect the correct observation-type and line-type symbols (Fig. 2). The final command selected from the digitizing menu for each detection is "END OBS," which readies the program for the next detection and outputs the attribute data to an ASCII file. When a spot map is completely entered, the coverage is saved and built (PC ARC/INFO term for constructing a topology). A new map can then be started without exiting BIRDMAP.

Data management.—Each field map is used to generate a coverage, so for each year of spot mapping at the HRF, 32 coverages (16 visits × two maps/visit) are generated. A completed coverage includes all X–Y locations of detections (points), lines (arcs) indicating movements or concurrent detections, and the attributes for each detection and its associated lines. Coverage data are stored by PC ARC/INFO in feature-attribute tables, which are compatible with dBASE file formats. At the HRF, the names of coverages are derived from the study area name, the year of data collection, and visit number. Coverages are stored in directories named by year (e.g., D:\BM89\MAN893B represents a coverage from data collected during visit 3B on the managed area in 1989).

Data analysis and manipulation.—When all detections have been digitized using BIRDMAP, another series of SML macros are used to generate the yearly species composite coverages. The 32 daily coverages are combined to create a yearly coverage of all detections. A computer-generated species composite coverage is created by extracting all detections for a species and placing them in a new single species coverage. This entire procedure, simplified as FIELD MAPS → DAILY COVERAGES → YEARLY COVERAGE → SPECIES COVERAGE, is repeated for each year of data collection and/or study area. Further analysis and manipulation of the species composite maps can include overlaying the bird data with other spatial data layers. At the HRF, we are using pre-existing spatial data sets and coverages such as forest stands, timber inventory data, soil and drainage types, forest canopy gaps, and topographic relief.

RESULTS

For the HRF, a total of 384 coverages were created (16 visits per year × two maps per visit × 12 years). All field data collected from 1983 to 1994 were entered by one person, initially unfamiliar with any GIS, in 280 h. The time required per map varied from 20 to more than 60 min. This was primarily dependent on the number of detections on a field map, but also decreased as the skill level of the user increased. The average number of detections per map was around 120 with a range of 53–243. The 384 coverages contained over 45,000 total detections and occupied over 40 MB of disk space. The species composite maps occupied additional disk space nearly equivalent to the original coverages. The SMLs to create species composite maps required additional time to run. No time estimates are provided because the SMLs were tested and run as they were written.

DISCUSSION

The benefits of this GIS application are numerous. First, the input time was considerably less than the estimated 2–3 wk per year (estimated total 1000–1400 h) to create species composite maps by hand at the HRF. Second, greater accuracy was achieved by searching a map only once and marking each location as it was digitized. With the manual method each map is searched separately for each species. Third, the ASCII data sets created by BIRDMAP can be used for further analysis. Finally, the data are now in a spatial and digital format which allows great flexibility in use. For example, copies of the maps can be produced at any scale at any time, maps can be overlaid with other data sets in the GIS, data can be converted to other GIS formats and data can be output to other software packages for spatial data analysis.

At the Holt Research Forest, we are exploring temporal changes in bird populations and relationships between birds and forest cover types, timber harvesting, forest canopy gaps, vegetation density, and other data sets we have collected as part of our long-term forest ecosystem study. Topics that have been explored using PC ARC/INFO include the temporal change in the distribution of Nashville Warblers (*Vermivora ruficapilla*), the relationship of forest harvesting and canopy gaps to occurrence of Common Yellowthroats (*Geothlypis trichas*), and the relationship between the distribution of Golden-crowned Kinglets (*Regulus satrapa*) and red spruce (*Picea rubens* Sarg.) density. The latter is shown in Figure 3 and is an example of Shaw and Atkinson's (1990) fourth GIS component: data display and product generation. This relatively simple application demonstrates the benefit of a GIS for the visual exploration and analysis of data.

Data sets created by BIRDMAP can also be used in other programs. One possibility is to use TERRIT, a FORTRAN program written by Scheffer (1987) to automate the process of estimating the number of bird territories. TERRIT is designed to use ASCII data sets with a clustering routine to select the detections belonging to a territory. Although not a simple matter, the program holds promise for reducing analyst inconsistencies in the interpretation of territories, which several authors cite as a significant problem with mapping data (Best 1975, O'Connor 1981).

We agree with Shaw and Atkinson's (1990) premise that a GIS offers a powerful tool for use in ornithology. Our experience developing BIRDMAP argues strongly for its use with spot-mapping data. We must also offer several caveats, however, for both implementing a GIS and for its use with spot-mapping data. The implementation of a GIS can have significant software, hardware, and personnel costs. One cost aspect requiring careful consideration is the selection of software. GIS packages vary considerably in purchase price and functionality. Ultimately, the software should meet all the needs of a project, have an acceptable user learning curve, and have accessible technical support either through the company or other users. Another cost consideration is access to other spatial data

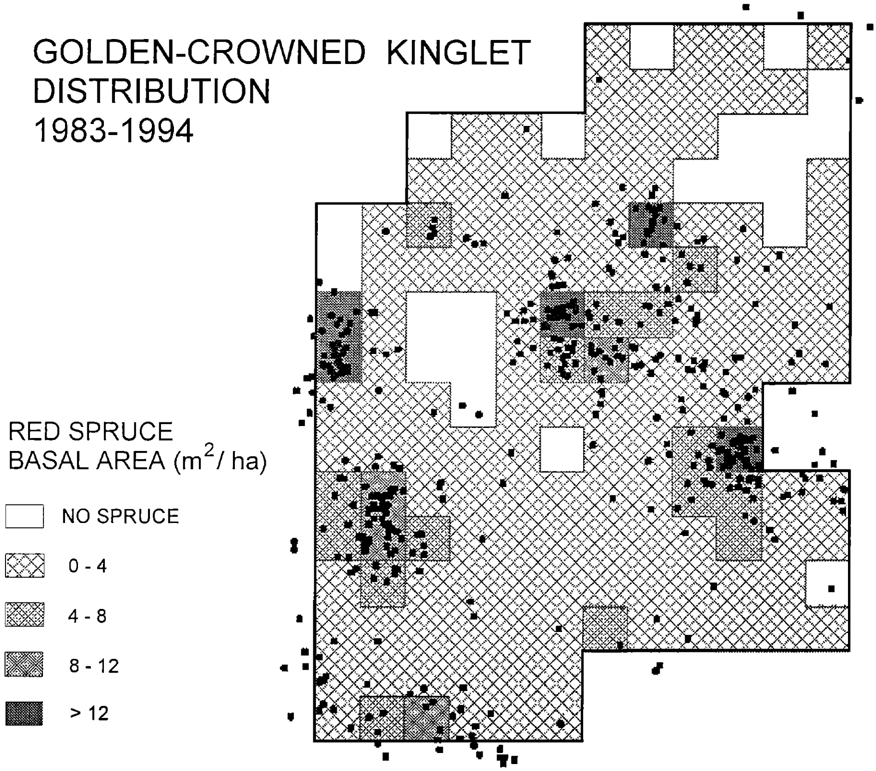

FIGURE 3. Sample output of a GIS overlay, comparing Golden-crowned Kinglet distribution to red spruce density.

either self-created or available through sources such as those discussed by Shaw and Atkinson (1990). Decisions about software are critical to the successful implementation of a GIS and consultations with GIS professionals or other users can provide insightful information. BIRDMAP was written specifically for PC ARC/INFO for several reasons: the software was already in use at the HRF, a significant data base was established, and the programming language offered many features. No attempt was made to test other GIS software, although others may have similar capabilities.

When contemplating the use of a GIS for spot mapping, the end use of the mapping data may be the most important consideration. In this regard, the significance of the spatial aspects of the bird-territory data, the size and number of study areas, the longevity of the study, the availability of other spatial data sets, and the availability of GIS for use are all key considerations. We found that the potential time savings from employing a GIS increases as the size of the data set increases. For example, the costs of beginning a GIS from scratch for one season of data from a single location would be difficult to justify, but as the number of years and/or study locations increases, so does the potential cost savings.

Some estimates for software and hardware costs are included to provide a rough idea of the expenses involved in establishing a GIS. PC ARC/INFO (now version 3.4.2) retails for US $2995. The hardware recommendations given for PC ARC/INFO by ESRI (1990) are a 80386-based PC with 2 MB of RAM, DOS version 3.3 or above, 70 or more MB of hard disk space, an 80387 math coprocessor, and one parallel and two serial communication ports. A mouse, graphics card, and monitor are also recommended. The above configuration is not recommended, in our experience, because the program will run very slowly. A large hard-drive (>540 MB) should be considered a necessity for most users. Most computers available today exceed these minimums, and a 80486-based PC with the above configuration can be purchased for less than US $1500. A digitizing tablet (minimum of 30 × 30 cm depending on the size of field maps, estimated US $300) will be needed. A hard copy device (graphics printer or plotter) will be needed to produce output of coverages; costs for such devices cover a wide range starting at about US $300.

The use of a GIS has unquestionably benefited our study. A considerable time savings has already been realized through the use of BIRDMAP and other SMLs. Application of a GIS has enabled us to conduct analyses, which because of time constraints, we could not have done otherwise. We recommend that ornithologists seriously consider integrating a GIS into research initiatives where similar benefits can be achieved (Liu et al. 1995).

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The program BIRDMAP and instructions are available for PC ARC/INFO users. For more information, contact the first author by mail (Holt Research Forest, Old Stage Road, Box 309, Arrowsic, ME 04530) or at the Univ. of Maine, Dept. of Wildlife Ecology Home Page (http://wlm13.umenfa.maine.edu/w4vl.html).

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