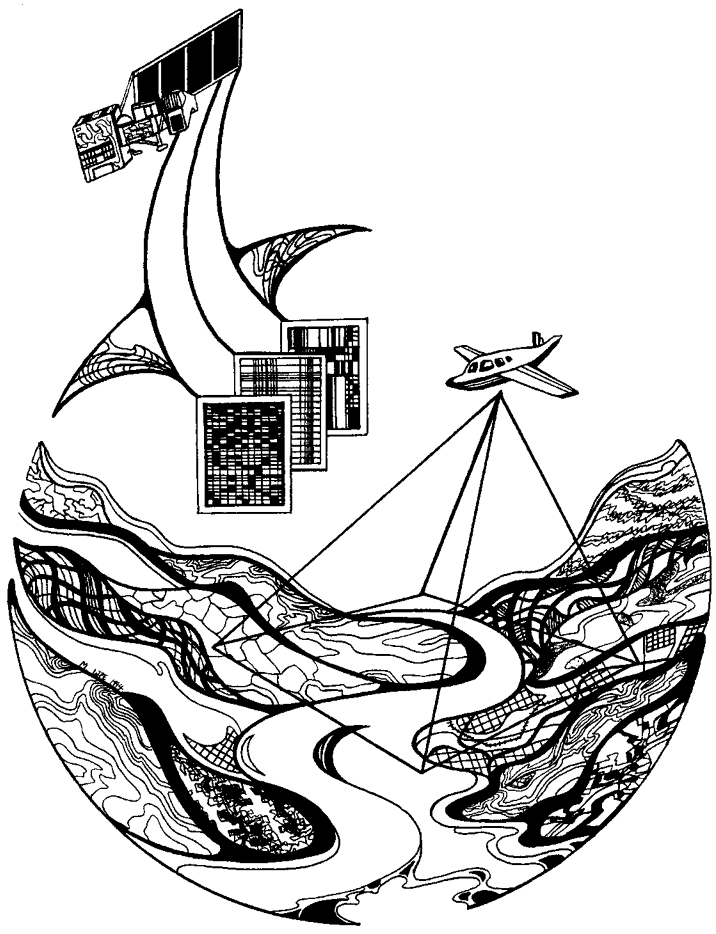
Long Term Resource Monitoring Program

Program Report

95-P001R

Geographic Information Systems and Remote Sensing Applications for Ecosystem Management



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Geographic Information Systems and Remote Sensing Applications for Ecosystem Management

by

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The Environmental Management Technical Center issues LTRMP Program Reports to provide Long Term Resource Monitoring Program partners with programmatic documentation, procedures manuals, and annual status reports.

Cover graphic by Mi Ae Lipe-Butterbrodt

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and sharing the biological information necessary to support the wise
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Preface

The Long Term Resource Monitoring Program (LTRMP) was authorized under the Water Resources Development Act of 1986 (Public Law 99-662) as an element of the U.S. Army Corps of Engineers' Environmental Management Program. The LTRMP is being implemented by the Environmental Management Technical Center, an office of the National Biological Service, in cooperation with the five Upper Mississippi River System (UMRS) States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin, with guidance and Program responsibility provided by the U.S. Army Corps of Engineers. The UMRS encompasses the commercially navigable reaches of the Upper Mississippi River, as well as the Illinois River and navigable portions of the Kaskaskia, Black, St. Croix, and Minnesota Rivers.

The mission of the LTRMP is to provide decision makers with information to maintain the UMRS as a sustainable large river ecosystem given its multiple-use character. The long-term goals of the Program are to understand the system, determine resource trends and impacts, develop management alternatives, manage information, and develop useful products.

This report will appear in the proceedings of the conference "Ecosystem Management: Applications for Sustainable Forest and Wildlife Resources" which was held at the University of Wisconsin-Stevens Point, March 3-4, 1994. The strategy to publish articles and make presentations as part of the information sharing process is included in the LTRMP Operating Plan (USFWS 1992) as Strategy 4.4.1, *Develop Information Sharing Process*.

Additional copies of this report may be obtained from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161 (1-800-553-6847 or 703-487-4650).

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By Frank D'Erchia

Abstract

Ecosystem management requires a more holistic approach than the focused practices of the past. Wildlife management traditionally concentrated on maintenance of specific habitat types used by a limited number of wildlife species. An ecosystem approach demands that managers take a broader view of the landscape, beyond political boundaries, and necessitates an understanding of the interrelationships among not only the wildlife and habitat components but also the human component of the ecosystem. Geographic information systems and remote sensing technologies provide tools for resource managers to use in analyzing ecosystems, allowing the manager to visualize and quantify the available information. Three case studies using these computer technologies are discussed: a landscape approach to resource management in the Upper Mississippi River System; a proactive approach to habitat modeling for migratory birds in the Upper Mississippi River corridor; and an overview of Gap Analysis, a national biodiversity effort, in the context of a tri-state project in the Upper Midwest.

Introduction

As resource managers recognize the importance of adopting an ecosystem approach in managing natural resources, the use of geographic information systems (GIS) and remote sensing technologies is increasing. These technologies provide tools for resource managers to use in analyzing and understanding an ecosystem, allowing decision makers to better visualize, integrate, and quantify available resource data.

The role of GIS in ecosystem studies is expanding as researchers exploit the increasingly sophisticated capabilities of GIS technology. Recent advances include the ability to store and manage large datasets and to perform spatial and statistical analyses. GIS can also provide input to both static and dynamic ecosystem models. For example, a static model may be used to make erosion estimates based on soil type and terrain characteristics, whereas a dynamic GIS model could be used to represent a spatial landscape at different time periods (Stow 1993). I will present three case studies demonstrating applications of GIS and remote sensing technologies.

The first case study discusses GIS applications in the Long Term Resource Monitoring Program for the Upper Mississippi River System. The long-term goals of the Monitoring Program are to understand the ecosystem, determine resource trends and impacts, develop management alternatives, and provide information and technology transfer (USFWS 1992). The Monitoring Program is responsible for collection of data on parameters including water quality, fisheries, vegetation, and invertebrates. Land cover/use spatial databases are developed, stored, and managed in a GIS for analysis and dissemination to river resource managers.

The second case study is a pilot project that uses GIS to analyze migratory bird habitats within the Upper Mississippi River corridor. This pilot project evaluated GIS technology as a tool to assist national wildlife refuge staff and other resource managers in making management decisions. Detailed land cover/use spatial data were used to predict habitat ranges for migratory birds by associating land cover classes with life cycle habitat preferences (Lowenberg, in review).

The final case study discusses Gap Analysis, a nationally instituted GIS effort to identify "gaps" in biodiversity protection, in the context of a tri-state effort in the Upper Midwest. Gap Analysis uses GIS to combine the distribution of natural vegetation, mapped from satellite imagery and other data sources, with distributions of vertebrate and other taxa as indicators of biodiversity (Scott et al. 1993). Maps of species-rich areas, individual species of concern, and overall vegetation types are generated and compared with land ownership and protection status.

Case Study 1: Long Term Resource Monitoring Program

Background

From 1930 to 1950, the U.S. Army Corps of Engineers constructed 29 locks and dams on the Upper Mississippi River System (UMRS) to maintain a 2.7-m channel for commercial navigation during periods of low flow. The locks and dams created a series of impounded pools, resulting in an initial boom in biological productivity. However, because natural alluvial river ecosystems are characterized by a floodplain and an annual flood pulse, this increase in aquatic habitat consequently brought loss of riparian habitat and reduced biological diversity, resulting in a net reduction in resource productivity. Floodplain encroachment and development, wetlands drainage, and channelization of the river have accelerated water velocities. Wave action resuspends lake bottom sediment and erodes islands and shorelines. Loss of islands creates greater wind fetches, resulting in greater wave action. The UMRS now experiences higher and more erratic river stages which disrupt the natural functions of the floodplain ecosystem (Sparks et al. 1990).

Congress recognized the importance and uniqueness of the ecology of the area but also acknowledged the national economic significance of the navigation system. Therefore, the Water Resources Development Act of 1986 (Public Law 99-662) authorized the Upper Mississippi River System Long Term Resource Monitoring Program to provide decision makers with the information needed to maintain the UMRS as a viable multiple-use large river ecosystem.

The Monitoring Program is being implemented by the Environmental Management Technical Center, a National Biological Service facility, in cooperation with field stations staffed by the five UMRS states (Illinois, Iowa, Minnesota, Missouri, and Wisconsin). Guidance is provided by the U.S. Army Corps of Engineers, which has overall responsibility for the Monitoring Program (USFWS 1992).

The Environmental Management Technical Center is responsible for inventory and monitoring, research, analysis, and application of GIS and remote sensing technologies. Spatial data (including land cover/use, bathymetry, transportation, wetlands, and other spatial features) are processed and managed in a GIS at the Center.

Study Region

The study area for the Monitoring Program encompasses the commercially navigable portions of the Mississippi River north of Cairo, Illinois, plus the entire Illinois River and Waterway and four other Midwestern rivers (Fig. 1). Current research efforts focus on the floodplain of the UMRS.

Methods

Land cover/use databases are developed through photointerpretation of aerial photography (Owens and Hop 1995). These databases are stored in a GIS at the Center. Color-infrared photographs (1:15,000-scale) are taken annually of specific pools or reaches of the UMRS (a pool is defined as the impounded section of the river between locks and dams; e.g., Pool 8 is the impounded reach above Lock and Dam 8 to Lock and Dam 7). Detailed land cover/use spatial data coverages have been created for several pools within the study area from 1989 color-infrared aerial photography

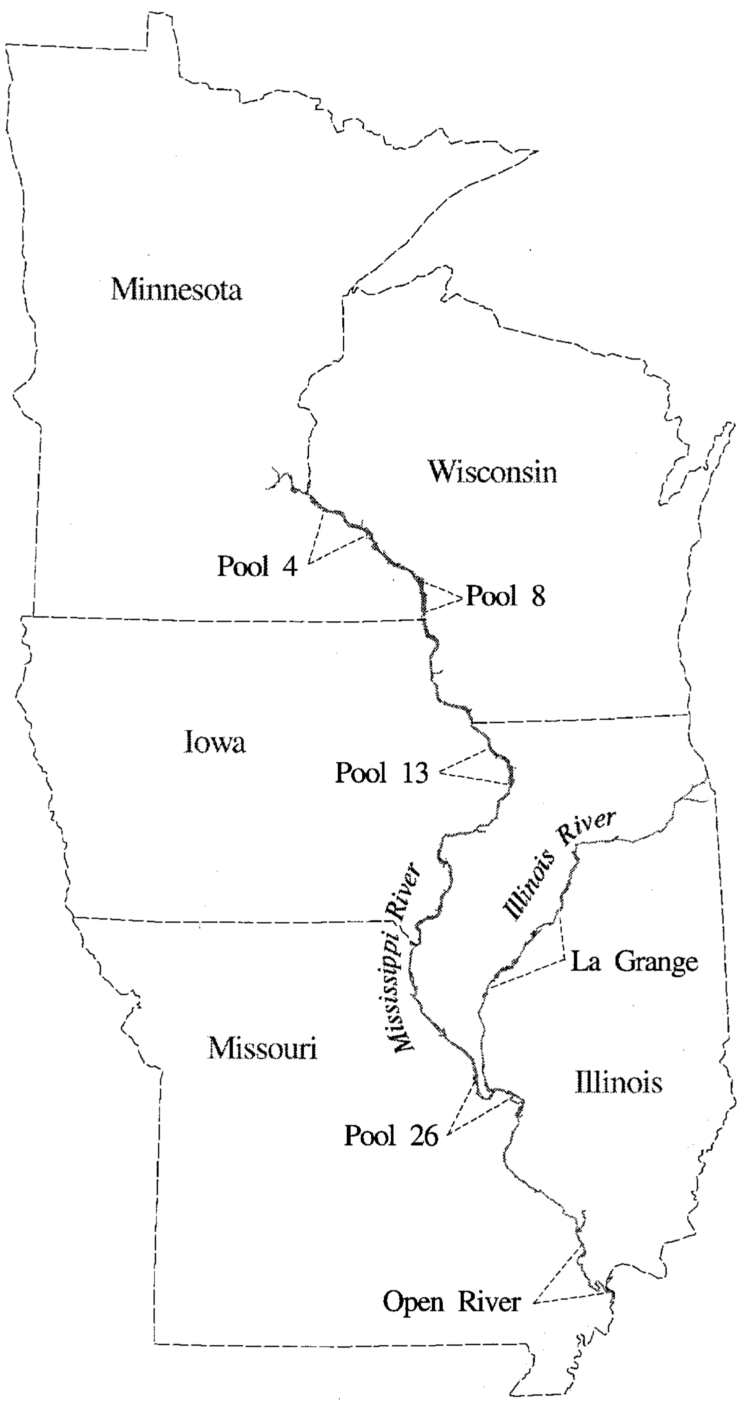

Figure 1. Long Term Resource Monitoring Program study area: The Upper Mississippi River System floodplain

(D'Erchia 1993). The aerial photographs are interpreted, transferred to base maps, and digitized to create spatial databases in an ARC/INFO GIS format (White and Owens 1991). ARC/INFO is a widely used commercial GIS software package developed by the Environmental Systems Research Institute, Redlands, California (Moorehouse 1985).

An additional source of land cover/use data is satellite imagery. The Center has produced a classified coverage for the entire floodplain of the UMRS from Landsat Thematic Mapper (TM) satellite imagery (TM imagery has a pixel resolution of 30 m). The floodplain outline was extracted from the seven full scenes required to cover the study area.

Finally, several historical databases were available for land cover/use. One was developed from aerial photography taken in 1975 under the auspices of the Great River Environmental Action Team (UMRBA 1982), and a preimpoundment perspective was obtained from the mapping efforts of the Mississippi River Commission Survey undertaken in the 1890s. The Survey maps were found to be spatially and thematically accurate at a scale of 1:20,000; therefore, land cover/use features were digitized directly from the source base maps (Fig. 2). These databases are used to analyze changes in the floodplain ecosystem.

The following review of an analytical procedure conducted on Pool 8 demonstrates the use and applications of GIS and remote sensing technologies at the Environmental Management Technical Center.

A comparison of 1891 and 1989 land cover/use for Pool 8 reveals the post-impoundment land and water changes (Fig. 3). Table 1 provides a summary of the spatial feature classes used, grouped for comparative purposes. As can be seen, there were increases in open water and marsh after impoundment and, conversely, decreases in woody terrestrial and grass and forb habitats. The area of woody terrestrial coverage not only decreased considerably by 1989, but the frequency increased substantially, resulting in a highly fragmented woody terrestrial ecosystem with many small polygons in 1989 compared with large homogeneous woody terrestrial areas in 1891. Urban areas expanded with reduced use of

Table 1. Comparison of land cover changes between 1891 and 1989 for Pool 8, Upper Mississippi River System

Classification	**Frequency (# of polygons)**	**Area (hectares)**	**Frequency (# of polygons)**	**Area (hectares)**
Open water	541	3,261	751	6,494
Marsh	52	343	3,092	2,995
Grasses/forbs	292	4,441	1,646	1,479
Woody terrestrial	581	5,834	2,326	2,614
Sand/mud	174	355	97	31
Agriculture	37	587	14	84
Urban/developed	10	238	85	1,362

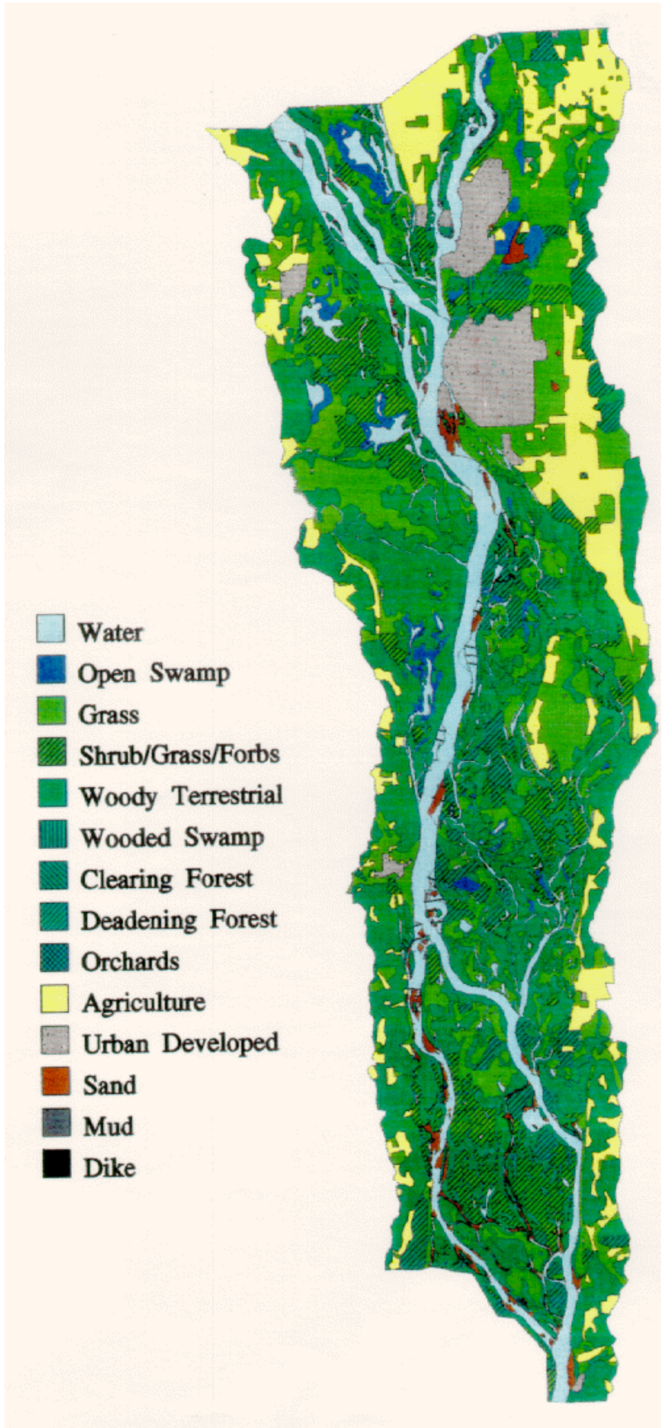

Figure 2. Land cover/use from the 1891 Mississippi River Commission Survey

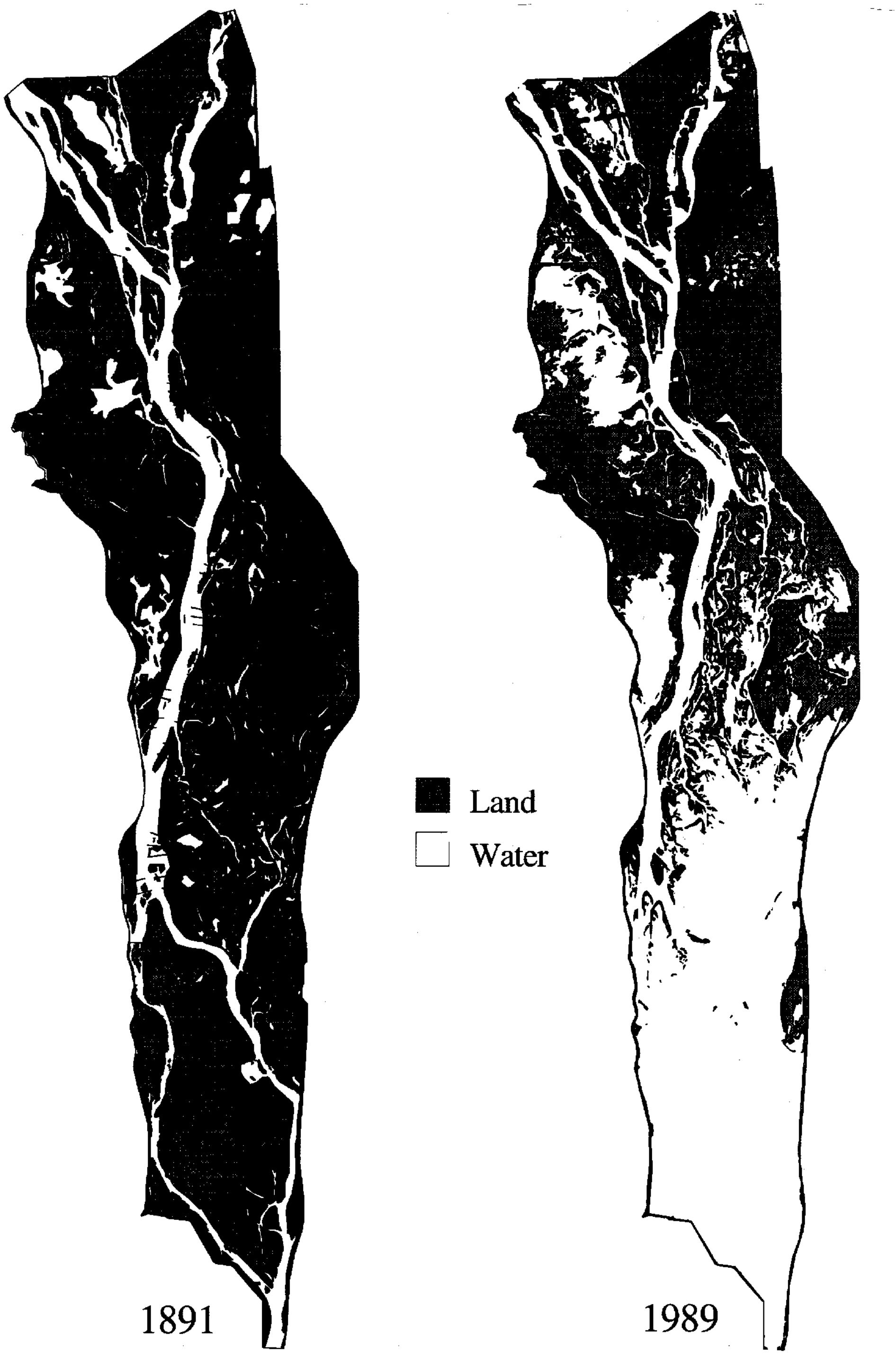

Figure 3. Comparison of land cover/use for Pool 8, Upper Mississippi River System, between 1891 and 1989

the floodplain for agriculture in this section of the UMRS. Using GIS, these coverages can be combined to display changes in open water in the floodplain of Pool 8 (Fig. 4). This analysis process provides a methodology to both visualize and quantify general pool-wide changes pre- and post-impoundment.

Through analyses of physical effects on the system, GIS can be used to study how biological resources respond to change. A time-series display of interpreted aerial photography of the lower portion of Pool 8 from 1939 to 1989 reveals a dynamic island geomorphology (Fig. 5). Erosion from wind and wave action has contributed considerably to island degradation. In a recent Environmental Management Technical Center study of island loss in lower Pool 8, bathymetric data were compared with historical water depth data collected in the 1930s (Fig. 6).

Backwaters provide migrating waterfowl with critical habitat because of their highly productive submersed vegetation, which is an important food source for a number of species. However, in recent years, backwater vegetation productivity has been on the decline (Rogers 1994). GIS techniques are used to analyze the relationships between increased sedimentation and decreased vegetation production. Areas that have experienced island loss, resulting in higher flows and increased sedimentation transport, have also displayed a decrease in submersed vegetation over time. Wind fetch models have been developed to assist in locating and evaluating artificial island placement to reduce sediment flow.

The U.S. Army Corp of Engineers (through the Environmental Management Program) is responsible for development of habitat rehabilitation projects to improve and prolong the longevity of the study area as a multiple-use resource for fish, wildlife, and recreation. These projects focus on island construction by strategic placement of channel dredge material. A GIS application conducted at the Environmental Management Technical Center used existing land cover/use data in combination with terrain elevation to analyze the effects of levee placement (McConville, in review). An interface was developed to allow the novice GIS user to locate levees by on-screen digitizing. The model analyzes effects on the habitat based on levee placement and elevation and the rise of floodwaters. Information provided through this research and analysis effort will help guide construction projects to maximize benefits to riverine habitat.

Once analytical models and interfaces are developed for demonstration pools, they can be extrapolated and applied to any pool where similar databases exist. Efforts are under way to complete automation of detailed land cover/use GIS coverages for the entire study area from the aerial photography collected in 1989. This coverage will provide the database for a landscape analysis of the entire system based on the pool-wide models currently under development at the Center.

In addition to pool-specific studies, systemic analyses at a lower resolution are being conducted using satellite imagery. Landsat TM imagery has been used to classify the entire study area, and research on systemic change detection was conducted in 1994 (Laustrup and Lowenberg 1994). While databases derived from satellite imagery are not as detailed as those developed from low-level aerial photography, they are adequate for systemic landscape analysis (e.g., broad categories within the floodplain can be quantified). Detailed land cover classes from the interpreted aerial photography can be generalized to match the satellite imagery-derived classes and comparisons then can be made to evaluate change over time. Satellite imagery provides a means to discern broad-based ecosystem changes over time in generalized landscape characteristics such as wetlands and forested areas.

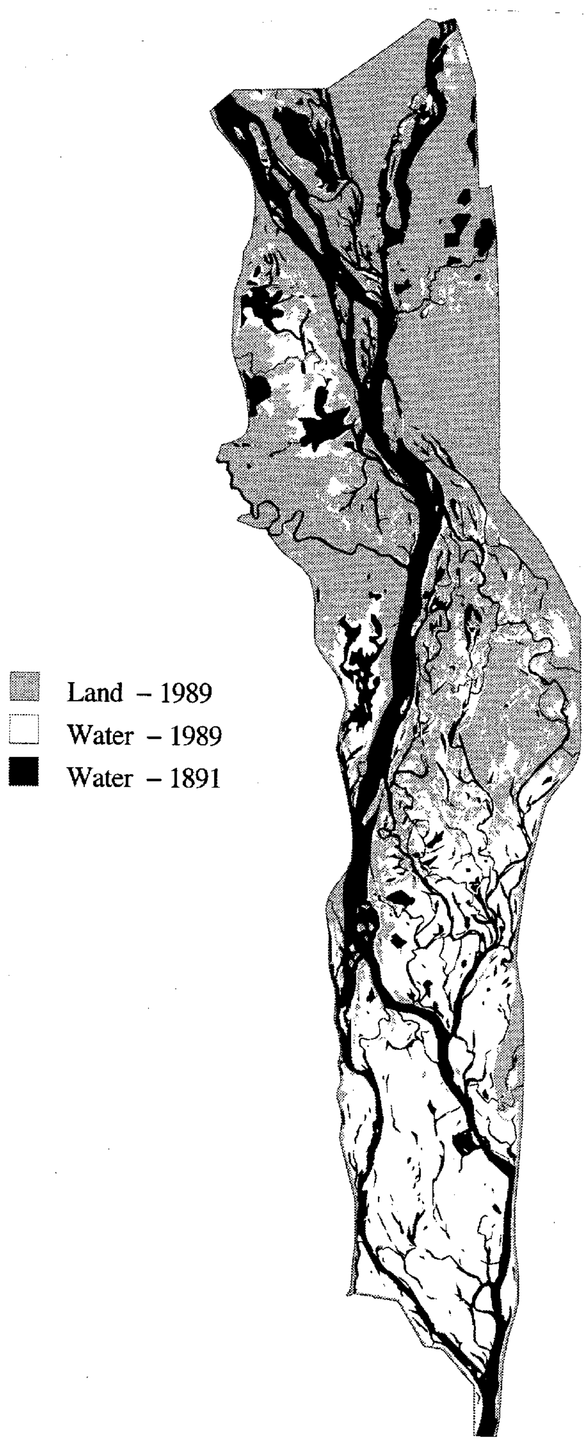

Figure 4. Change in open water for Pool 8, Upper Mississippi River System, from 1891 to 1989

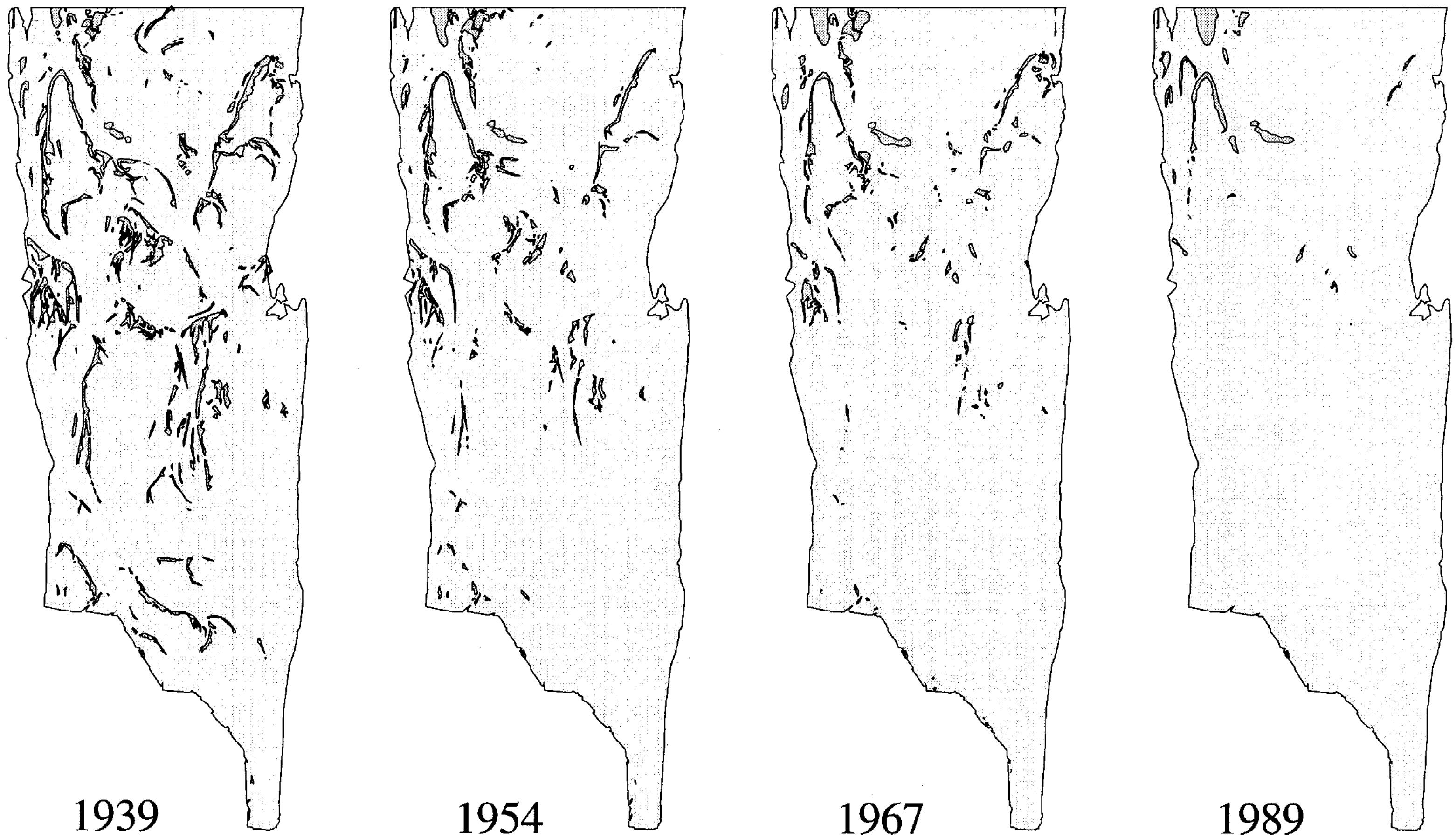

Figure 5. Geomorphology of lower Pool 8, Upper Mississippi River System, between 1939 and 1989

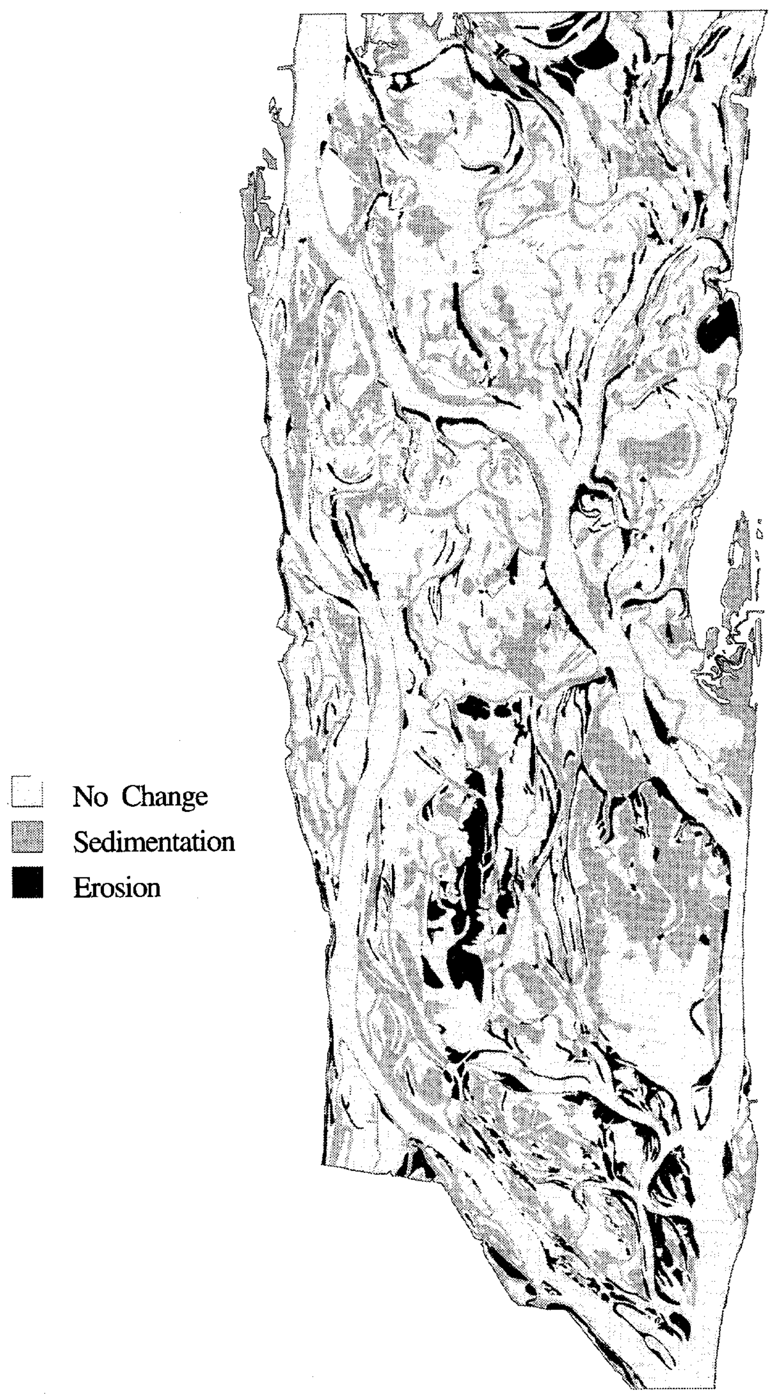

Figure 6. Elevations of lower Pool 8, Upper Mississippi River System, between 1939 and 1989

Case Study 2: Migratory Bird Analysis

Background

Three National Wildlife Refuges are located within the Upper Mississippi River basin: the Upper Mississippi River National Wildlife and Fish Refuge, Mark Twain National Wildlife Refuge, and Trempealeau National Wildlife Refuge. The Mississippi River corridor is a major waterfowl flyway during spring and fall migration. In addition, the river environment of backwaters, wooded bottomlands, open water, and wooded bluffs serves as a migration corridor to over 290 species of raptors, shorebirds, and songbirds (NBS and USFWS 1995).

In an effort to take a proactive approach to manage the habitats used by migratory bird populations in the Upper Mississippi River basin, a pilot study was undertaken to analyze migratory bird habitats using GIS and remote sensing technologies. Agency representatives of the states of Illinois, Iowa, Minnesota, Missouri, and Wisconsin, the U.S. Army Corps of Engineers, the National Biological Service, and the U.S. Fish and Wildlife Service have agreed to implement a migratory bird management strategy for the River corridor. The Environmental Management Technical Center was selected to conduct the spatial analysis for the pilot project (Lowenberg, in review).

Study Region

The study area for the migratory bird project includes the Upper Mississippi River corridor from Wabasha, Minnesota, to St. Louis, Missouri. Pool 8 was selected for the pilot study. This River reach includes the impounded water above Lock and Dam 8 near Genoa, Wisconsin, to Lock and Dam 7 at Dresbach, Minnesota (Fig. 7).

Methods

The spatial analysis for this project used land cover/use maps developed from 1:15,000-scale aerial photography of the floodplain. Some models included satellite imagery to extend the boundaries into the bluffs above the floodplain and to evaluate the possible substitution of satellite imagery for modeling where detailed data are unavailable.

First, a literature search was conducted to determine life cycle habitat requirements of a selected sample of migratory birds. This search identified parameters for habitat critical to the selected migratory bird species (Jacobson 1993). Next, matrices linking these habitat descriptions with land cover/use spatial data coverages were developed. Individual range maps could then be generated for each migratory bird species.

Information from this search and other sources provided the means to categorize habitat use based on several life cycle variables (spring migration, pre-breeding, nesting, brood rearing, post-breeding, fall migration, and wintering). The habitats identified were linked with the land cover/use classes of the GIS database and were used to generate GIS-predicted range maps. Some models were derived directly from matrices that cross-referenced vegetation types with bird species. Other models were more complex, requiring distance and neighborhood analyses.

A simple nesting habitat matrix association model for the Pileated Woodpecker (*Drocopus pileatus*) is displayed in Figure 8. The literature search revealed that the Pileated Woodpecker prefers mature dense forest stands with high snag densities (Bull 1975). The land cover/use database included tree height and percent vegetation cover. By selecting for the tallest trees with the greatest percent cover, it is assumed that mature dense forest stands are selected and that they contain a large quantity of snags. This prediction of snag density is crucial, since snags provide

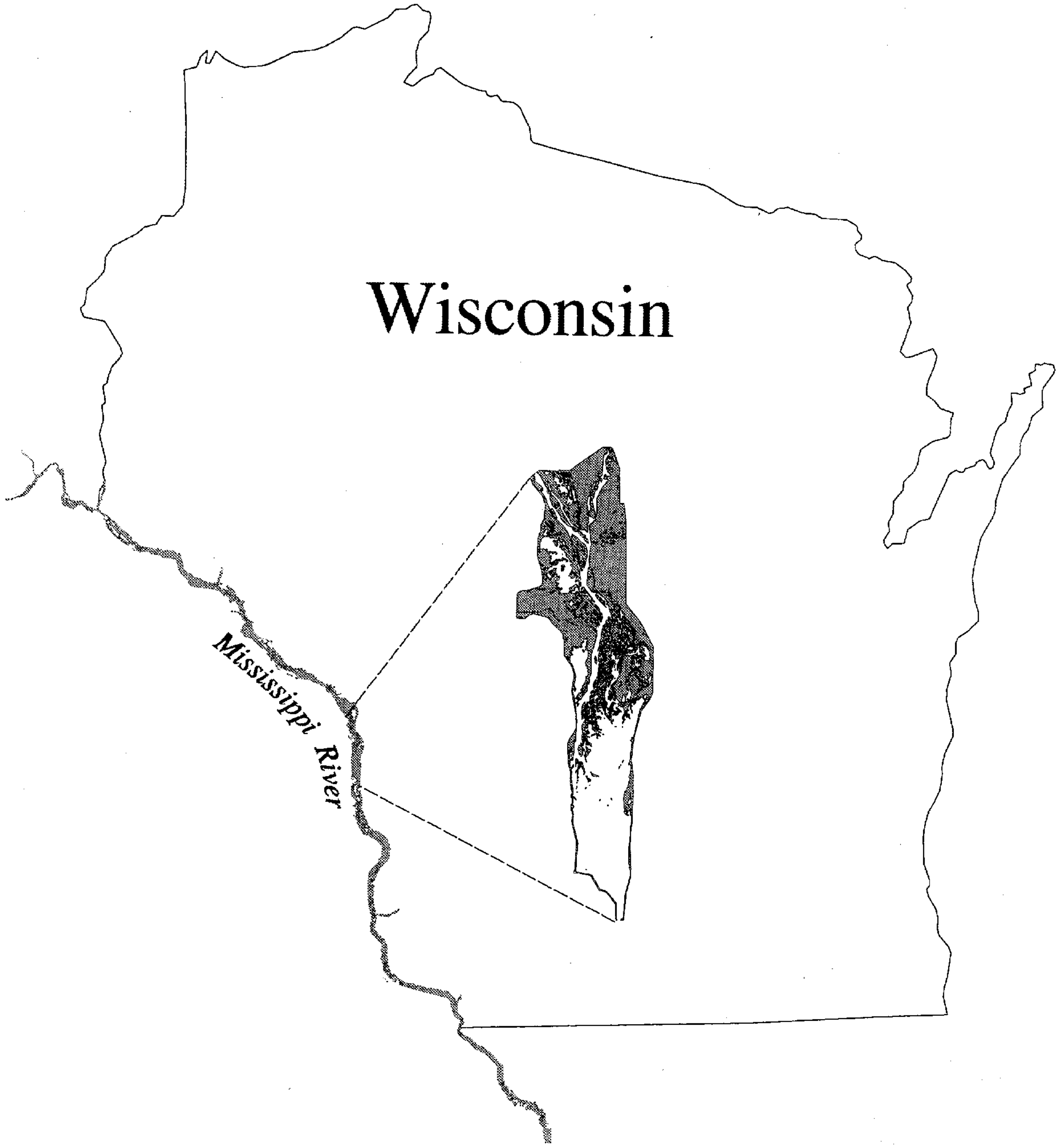

Figure 7. Migratory bird study area: Pool 8, Upper Mississippi River System

Figure 8. Pileated Woodpecker life cycle habitat preferences

nest sites for the target species. Field verification is necessary to confirm these assumptions.

Another migratory bird model in the pilot study demonstrates the use of GIS to analyze habitat using neighborhood analysis techniques. The American Bittern (*Botaurus lentiginosus*) was found to nest in thick marsh grass, sometimes adjacent to stands of willow and tamarack, within 6.1 m of water (Bohlen 1989). Habitat analysis was carried out using GIS procedures to create a 6.1-m buffer around all aquatic areas. Then, terrestrial habitats that met nesting requirements were selected from within this buffer (Fig. 9). Although this type of buffer analysis is not complex using GIS, an analysis of preferred habitat with this requirement would be very difficult, if not impossible, to perform manually. Identification of critical habitat delineates areas to be considered for protection to help maintain populations of target species.

Use of Satellite Data

We have thus far discussed migratory bird habitat within a reach of the floodplain of the Mississippi River. Because an ecosystem approach was desired, spatial data from Landsat TM satellite imagery were combined with the floodplain data, allowing comparison of the high-resolution floodplain data and the coarser satellite imagery.

For this exercise, a 32-km swath of TM imagery on either side of the floodplain was classified for forested areas, grasslands, wetlands, urban, and agricultural areas. The floodplain data cover bluff to bluff, and the satellite imagery covers land cover on the bluffs. Due to the coarser TM resolution, small wetland areas could be misclassified; therefore, digital wetlands data from the National Wetlands Inventory (Cowardin et al. 1979) were incorporated into the TM imagery. Digital wetlands data were available for all but the southwest portion of the study area.

Two migratory bird species were chosen for this application, the Cerulean Warbler (*Dendroica cerulea*) and the Canvasback (*Aythya valisineria*). Cerulean Warbler habitat includes forested areas >16.2 ha (Bond 1957), while Canvasback require large open bodies of water (Korschgen 1989). Cerulean Warbler habitat within the floodplain is somewhat restricted, which could lead to the conclusion that this species' habitat needs protection, but when the search for the bird's habitat requirements is extended above the bluffs, we find that abundant habitat exists (Fig. 10). Conversely, Canvasback habitat would be restricted to the large body of open water at the lower end of Pool 8, with no adequate habitat available in the bluffs above the floodplain. In this example, a resource manager could make a more informed decision regarding habitat protection with the extended knowledge of the conditions in the area immediately surrounding the floodplain. By studying the landscape, it becomes apparent that, in this case, sufficient habitat for the Cerulean Warbler exists in the adjacent blufflands. Therefore, management objectives in the floodplain may be better served by focusing on Canvasback habitat.

The pilot study combined all subject species' habitat ranges to develop a simulated map of species richness. Selected species data on preferred nesting habitat within the floodplain were combined and polygons were ranked according to number of species present (Fig. 11). By overlaying the habitat requirements of multiple species, critical areas can be identified. This information is provided to resource managers and others responsible for wildlife habitat management and acquisition, who can then make decisions based on the conglomerate map, taking into account the status of individual species. Areas of importance to large numbers of species of concern (e.g., listed or declining) could be given a higher priority in proactive management decisions and habitat mitigation efforts.

The next step in the pilot study was to verify the models, which was accomplished by comparing migratory bird sightings during field studies with GIS-predicted habitats. Great Blue Heron (*Ardea herodias*) rookeries were located and plotted on a base map that displays the GIS-

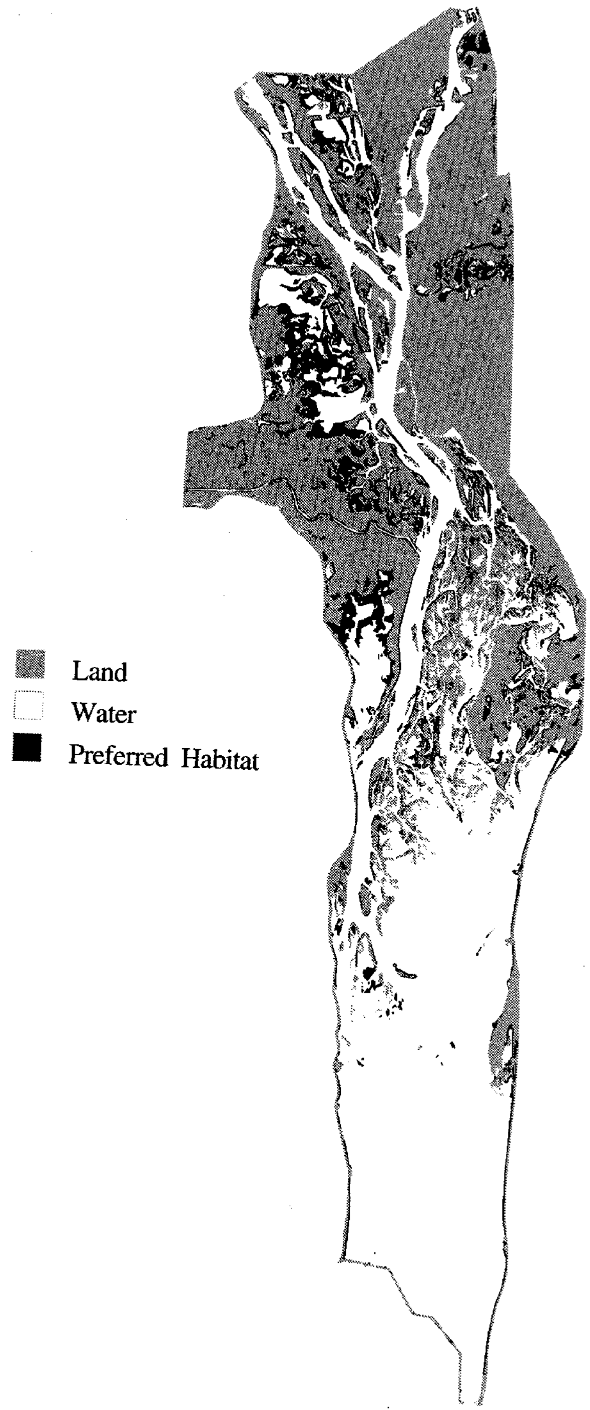

Figure 9. American Bittern nesting habitat preferences

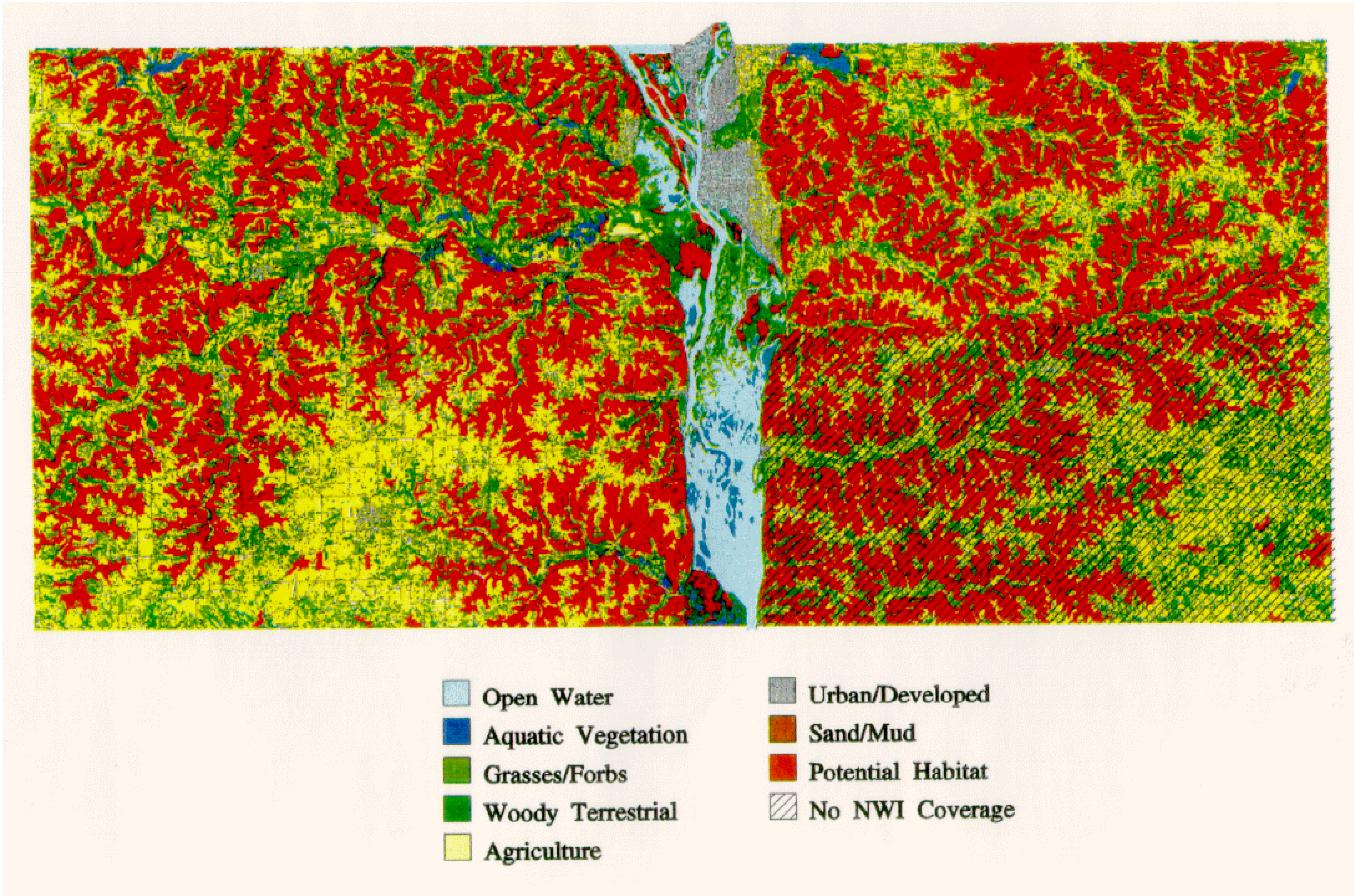

Figure 10. Cerulean Warbler habitat preferences derived from aerial photographs and satellite imagery

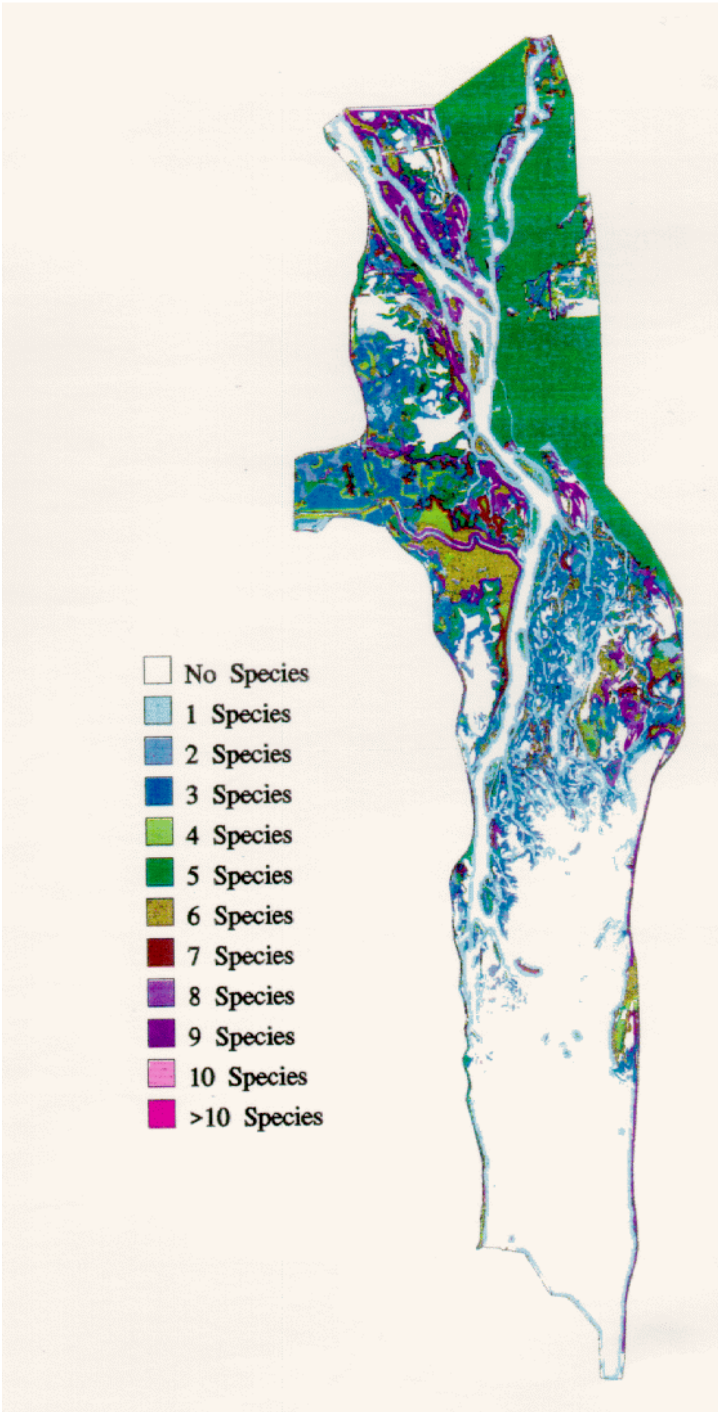

Figure 11. Species-rich map of nesting habitat for a combination of several migratory bird species

base map that displays the GIS- predicted preferred habitat for the species (Fig. 12). The association between known sightings and GIS-predicted habitat preferences is needed to refine the model and verify the results of the analysis. Field sightings and other field information helped fine-tune the models for each migratory bird species in the pilot study. The verification process provides the information necessary to validate and/or update models.

Management of critical habitat for the benefit of groups of wildlife species, particularly migratory birds, was the focus of this analysis rather than taking a single-species approach. If the methodologies applied to a sample area prove useful, the protocols could be applied over a larger area. Once the models are verified, a GIS interface will be developed to provide managers with an easy-to-use tool for analyzing habitat.

Case Study 3: Upper Midwest Gap Analysis Program

Background

The Gap Analysis Program is a nationally implemented National Biological Service effort which seeks to identify the degree to which plant and animal communities are or are not represented in areas being managed for the long-term protection of biological resources. Natural communities not adequately represented in such areas constitute "gaps" in biodiversity conservation (Scott et al. 1993). Cooperating organizations include private business corporations, non-profit groups, and state and federal government agencies.

Gap Analysis projects typically are completed on a state-by-state basis. However, because of the contiguous biologically diverse habitat in the Upper Midwest, the Environmental Management Technical Center proposed initiation of a multi-state approach in the region to ensure consistency and continuity of land cover and other spatial databases across political boundaries. In cooperation with the state, federal, and non-government agencies in the region, the Center has begun development of a land cover database for a three-state area (D'Erchia et al. 1993).

Study Region

The study area covers the states of Michigan, Minnesota, and Wisconsin. This area includes a portion of the Upper Mississippi River ecosystem and extends into the watershed beyond the floodplain.

Methods

The Gap Analysis Program in the Upper Midwest is currently in its initial stages. Land cover will be mapped using Landsat TM satellite imagery. To accomplish the goals of this three-state effort, Landsat TM scenes will be acquired for full coverage of the study area. To assist in classification discrimination, especially of tree species, a second date for each scene will be acquired to incorporate the temporal variations between scene dates. Scene pairs, with dates that coincide with peak biomass and leaf senescence, will be selected from the available cloud-free inventory of images not more than 3 years old. Several methods are possible for integrating the two-date scenes, including separate scene classification, combining all bands from both images, or some combination of principal components. Ancillary information such as aerial photography and existing digital land cover data will be integrated with the satellite imagery where it is available consistently for the three states (Lillesand 1993).

The standard minimum mapping unit for the Gap Analysis Program is 100 ha; however, the Upper Midwest effort will maintain the 30-m pixel resolution of the TM imagery for land cover mapping. Uniquely classified individual pixels will be grouped with surrounding pixels, maintaining a minimum mapping unit <1 ha. This system will result in a higher resolution, uniform

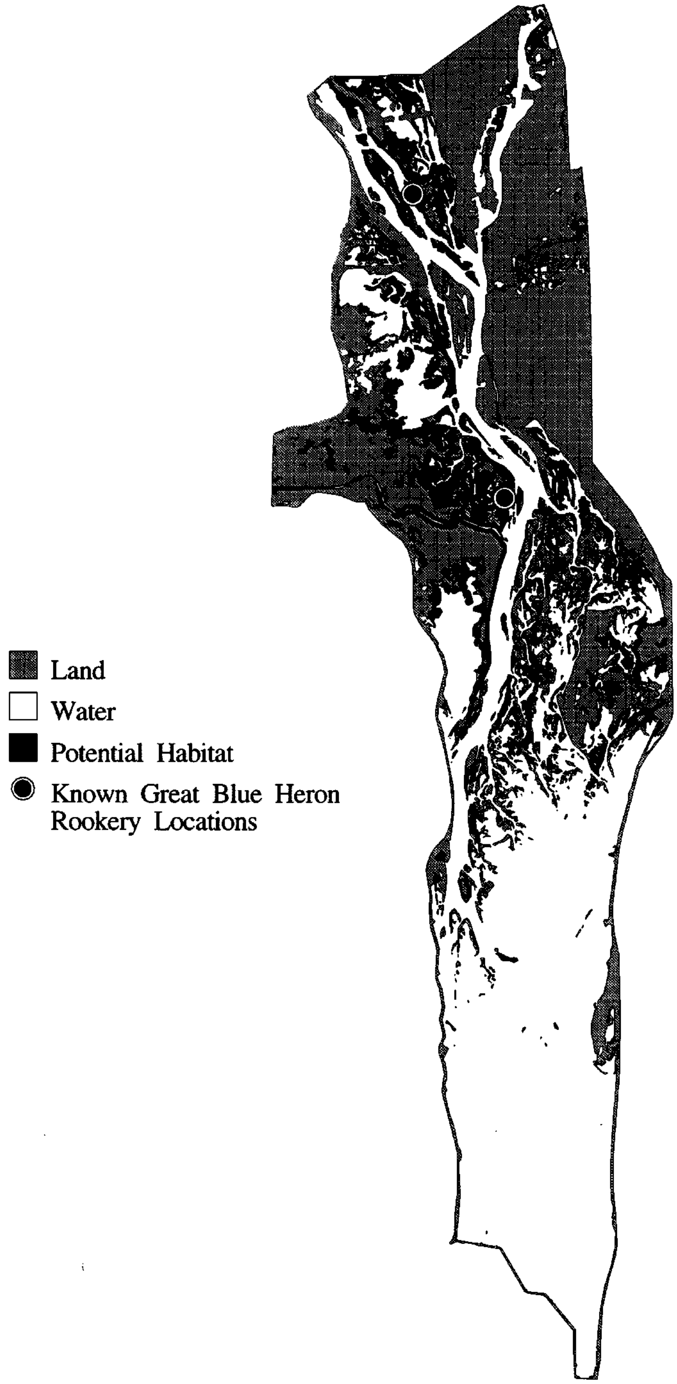

Figure 12. GIS-predicted Great Blue Heron preferred habitat and known rookery locations

classification across the three states. In addition, mapping of presettlement vegetation will be completed for the three states. Using a habitat association approach, wildlife species range maps will be generated to link potential habitat for a variety of wildlife species with the habitat types in the land cover maps. Land ownership maps will also be developed for the three-state area.

Wildlife-habitat relationships are developed by linking vegetation classes with preferred habitats of individual wildlife species. A species-habitat matrix has been developed for the forested areas of the upper Great Lakes region, which includes portions of the states of Michigan, Minnesota, and Wisconsin (Benyus et al. 1992). This habitat matrix displays 389 species of birds, mammals, reptiles, and amphibians with their associated habitats. Additional work will be required to develop habitat associations with land cover types for the lower portions of each state, as well as additions and enhancements to the existing information.

Maps of species-rich areas, individual species of concern, and overall vegetation types will be generated. Several species range maps will then be combined to identify the species-rich areas for the subject wildlife group. Using GIS, this information can be overlaid on maps of land stewardship to display those areas not adequately protected, identifying where efforts need to be focused to most efficiently achieve conservation of biodiversity.

Conclusions

The Long Term Resource Monitoring Program is an ongoing effort to evaluate and understand the dynamics of a changing floodplain environment. It is the goal of the Monitoring Program to conduct research and analysis in an effort to link environmental effects with the physical parameters operating within the floodplain ecosystem. The results of Monitoring Program studies are used by state and federal agencies in implementing management strategies.

Successful application of GIS technology in the migratory bird pilot study has demonstrated how this tool can provide valuable information to resource managers. A methodology was needed to assist resource managers in implementing a landscape approach to proactive habitat management of the migratory bird flyway in the Upper Mississippi River corridor. By evaluating habitat abundance for individual species and combining all species to predict areas of critical importance, GIS technology will provide resource managers with the information needed to make informed management decisions. Additional information, such as identification of keystone or indicator species' habitats and determination of their role in the ecosystem, can also be displayed in GIS maps.

The migratory bird pilot study utilizes a Gap Analysis approach in identifying species-rich areas; in addition to the migratory bird component, the Gap Analysis Program analyzes habitats for native birds, mammals, and other vertebrate species. The Upper Midwest Gap Analysis effort represents a broad landscape approach to the Upper Mississippi River and Great Lakes Basin ecosystem and will yield information critical to resource managers in this region.

Many federal land management agencies are moving toward ecosystem management objectives. The U.S. Fish and Wildlife Service is reorganizing its Divisions into Ecosystems based on watershed boundaries (James Fisher, USFWS, Winona, Minnesota, personal communication). The U.S. Forest Service is also shifting toward an ecosystem management approach, focusing on large-scale ecological regions that go beyond National Forest boundaries (Thomas 1995).

Successful migration from the historical systems of monitoring and managing biological resources within agency boundaries to implementing large-scale, multi-temporal assessments will require access to GIS and remote sensing technologies. Data collected via satellite, aerial photography, or videography will provide a historical record, and

GIS can be used to automate, manage, and analyze the information collected. The Global Positioning System provides biologists and managers with the ability to collect accurate locational information in the field which can be related and integrated with other spatial data using a GIS.

In an effort to define ecosystem management through an in-depth literature review, Crumbine (1993) found that one of the specific goals frequently endorsed was the incorporation of data on human use and occupancy within an ecosystem. GIS provides ample opportunity to integrate social and economic factors into the analysis of ecosystems. The technology is recognized as a viable and valid scientific tool and is being increasingly used to enhance the broad landscape-scale analysis required for ecosystem management.

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Ecosystem management requires a more holistic approach than the focused practices of the past. Wildlife management traditionally concentrated on maintenance of specific habitat types used by a limited number of wildlife species. An ecosystem approach demands that managers take a broader view of the landscape, beyond political boundaries, and necessitates an understanding of the interrelationships among not only the wildlife and habitat components but also the human component of the ecosystem. Geographic information systems and remote sensing technologies provide tools for resource managers to use in analyzing ecosystems, allowing the manager to visualize and quantify the available information. Three case studies using these computer technologies are discussed: a landscape approach to resource management in the Upper Mississippi River System; a proactive approach to habitat modeling for migratory birds in the Upper Mississippi River corridor; and an overview of Gap Analysis, a national biodiversity effort, in the context of a tri-state project in the Upper Midwest.

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The Long Term Resource Monitoring Program (LTRMP) for the Upper Mississippi River System was authorized under the Water Resources Development Act of 1986 as an element of the Environmental Management Program. The mission of the LTRMP is to provide river managers with information to maintain the Upper Mississippi River System as a sustainable large river ecosystem given its multiple-use character. The LTRMP is a cooperative effort by the National Biological Service, the U.S. Army Corps of Engineers, and the States of Illinois, Iowa, Minnesota, Missouri, and Wisconsin.