Commentary

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SCIENCE FOR AVIAN CONSERVATION: PRIORITIES FOR THE NEW MILLENNIUM

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OVER THE PAST decade, bird conservation activities have become the preeminent natural resource conservation effort in North America. Maturation of the North American Waterfowl Management Plan (NAWMP), establishment of Partners in Flight (PIF), and creation of comprehensive colonial waterbird and shorebird conservation plans have stimulated unprecedented interest in, and funding for, bird conservation in the United States, Canada, Mexico, and other countries in the western hemisphere. Key to that success in the United States has been active collaboration among federal, state and local governments, conservation organizations, academia, and industry. The U.S. Department of the Interior (DOI), which has primary statutory responsibility for migratory bird conservation and management, has been a key partner.

Despite the great strides that have been made in bird conservation science, historical approaches to research and monitoring have often failed to provide sufficient information and understanding to effectively manage bird populations at large spatial scales. That shortcoming, and the lack of an integrated strategy and comprehensive set of research priorities, is more evident in light of the goals established by the North American Bird Conservation Initiative (NABCI). The NABCI is a trinational, coalition-driven effort to provide an organizational umbrella for existing conservation initiatives. The expanded focus of NABCI and individual bird conservation initiatives is to work together in an integrated, holistic fashion to keep common birds common and to increase populations of declining, threatened, and endangered species.

To assist bird conservation initiatives in defining goals and developing new approaches to effective research, the U.S. Geological Survey (USGS), the research agency of DOI, convened a workshop, "Science for Avian Conservation: Understanding, Modeling, and Applying Ecological Relationships," on 31 October–2 November 2000, which brought together 51 scientists from USGS, as well as scientists and conservationists from other agencies and organizations actively participating in NABCI. As

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the lead federal agency involved in bird conservation research, USGS has a clear legislative mandate to provide scientific information upon which future management plans and actions will be built.

This article summarizes key issues and recommendations that arose from that workshop. The principal goal of the workshop was to guide USGS in defining its role, assessing capabilities, and directing future agency planning in support of bird conservation. A major component was to identify key areas of research needed in this new era of bird conservation science. Although tailored to the mission of USGS, workshop recommendations visualize a bold direction for future avian conservation science in which research and monitoring work in tandem with management to increase our understanding of avian populations and the processes that affect them. The USGS is a science agency whose role is to provide objective scientific information to management agencies and therefore is not directly involved in high-level resource policy-making or on-the-ground management decision making. Nevertheless, it is important to note that effective policy decision making must integrate the best available science with political and economic realities to achieve successful avian conservation—an important subject acknowledged in the workshop, but largely beyond its scope of discussion. Williams (2003) addresses questions regarding how scientific information can be effectively communicated to decision makers and incorporated into natural resource policy. Without an aggressive vision and the willingness of researchers, managers, and policy makers to implement it, conservation of North American birds is likely to proceed without the full benefit of scientific investigation. These recommendations represent the principal conclusions drawn by workshop participants and do not necessarily reflect official USGS policy.

Setting the context for avian conservation science.—Historically, avian research has been species specific, disciplinary, focused at relatively small scales, and monitoring has been disconnected from research and management activities. However, with the evolution of avian conservation efforts over the last decades, avian science has begun to focus on a more holistic systems view in which research is integrative, interdisciplinary, and focused on larger spatial, temporal, and organizational scales. Both historic and recent approaches are essential for developing an understanding of the underlying causes of ecological patterns and for identifying effective conservation actions. However, it is clear that we need to revise and broaden our fundamental approaches to addressing avian conservation science needs (Martin and Finch 1995, Marzluff and Sallabanks 1998).

Avian conservation research is necessarily multifaceted, complex, and diverse, requiring an integrated approach. Bird conservation activities are conducted at a range of geographic and ecological scales that require coordinated management at local, regional, national, and international levels. Management plans must consider a wide range of natural resource, economic, and political objectives. These challenges are compounded by avian conservation efforts that involve numerous partners, with a wide range of missions and agendas, pursuing conservation goals and activities under a variety of initiatives.

Population monitoring and traditional research activities, including studies of taxonomy, natural history, behavior, and factors affecting avian populations, have provided the biological foundation for many resource management decisions. However, intensive research is often local in scale, providing results with limited application to conservation of regional and continental populations. Many traditional research tools are not designed to provide insight into causes of bird population change. Research direction is also complicated by vague management goals and poor communication between managers and researchers (Arnett and Sallabanks 1998, Hejl and Granillo 1998). Such factors argue for significant improvements in approaches to avian research and stronger partnerships between research and management components of bird conservation. An approach that combines research results, management activities, and monitoring into a coherent system for learning from management activities while incorporating increased understanding into future management actions provides an operational framework for advancement of avian conservation science and management.

The NABCI provides a new opportunity and a new approach to bird conservation. Developed in 1998, its goal is to "deliver the full spectrum of bird conservation through re-

gionally based, biologically driven, landscape-oriented partnerships" (U.S. North American Bird Conservation Initiative Committee 2000a). The NABCI's guiding principles include the need for (1) integration of management needs and actions across species and landscapes; (2) a standardized ecological framework for efficient planning, implementation, and evaluation; (3) the best available scientific information; and (4) an adaptive approach to bird conservation to build knowledge in concert with management actions. The NABCI goals and principles reinforce the need to broaden traditional avian conservation science, emphasizing an integrative, interdisciplinary, holistic approach to problem solving that not only combines research, management, and monitoring into a coherent system, but also incorporates a diverse array of scientific disciplines and tools.

Proposing comprehensive, process-based solutions to the dilemmas facing avian conservation—how to best integrate science and management on the ground, and how to ensure participation of decision makers and enforcement of policies—was beyond the scope of the workshop. The workshop presented the broad context within which future avian conservation must be conducted and demonstrated the need for integrated solutions. However, participants, primarily research scientists, addressed this challenge at the level more appropriate to their expertise—identifying science that should be conducted and science approaches that should be used to accomplish these complex, integrated solutions.

Science needs in support of NABCI.—Research activities in support of avian conservation must be closely linked to NABCI and its partner programs and should provide the scientific foundation required to guide conservation and management decisions. The USGS workshop participants identified five priority research areas needed to support integrated avian conservation efforts: (1) avian life history, populations, and ecology; (2) habitat and environment; (3) integration of ecological information; (4) bird conservation planning; and (5) communication of ecological information.

Avian life history, populations, and ecology.—Detailed ecological information needed for effective management of many species is still largely lacking despite nearly 100 years of surveys, monitoring, and natural-history-based studies. Basic ecological research can be gathered through observational and retrospective studies and manipulative experiments, and can involve management actions applied in an adaptive framework.

Basic ecological research should be directed at factors that affect population dynamics on breeding, migration, and wintering areas; understanding the relationships between breeding and wintering populations; and identifying source and sink populations within larger metapopulation complexes. Research must be directed at increasing our understanding of the distribution, life history, and limiting factors, as well as population and metapopulation dynamics of high-priority species as they are defined by the various bird-conservation initiatives.

Accurate assessment of current population status and trends of avian species is needed for assessment of management activities. Monitoring programs must be designed, developed, and implemented for breeding, migration, and overwintering populations of high-priority species. Those monitoring efforts should be closely tied to management objectives and activities, and should be sensitive to the geographic scales at which populations are managed.

Reliable scientific information about bird populations should be collected in a broad variety of scientific and conservation settings (e.g. documenting results of conservation efforts and validating models). Even primary data sets such as the North American Breeding Bird Survey (BBS) need validation. Bird population information should provide unbiased estimates of population attributes, be collected at appropriate spatial and temporal scales, and be coordinated with collection of information on relevant environmental covariates. To ensure credibility, survey designers must establish clearly defined and achievable objectives, explicitly address issues of detectability and sample frames, evaluate usefulness of estimates to support predictive modeling, and maintain the integrity and metadata of the database.

Bird population monitoring programs, when not explicitly linked to research, are of limited use in determining causes of population changes. Consequently, research efforts need to be strengthened to develop new sources of information on avian survival and productivity, refine survey methods, and develop approaches in which survey data can be used to assess causes of population change.

Conservation of bird populations is typically accomplished through preservation and management of habitats upon which they depend. Many habitats are subject to large-scale disturbances (e.g. selective cutting, burning, habitat restoration). Research is needed to assess the response of bird populations to various land-use changes, configurations, and management actions and to use tools such as multiscale, predictive models to provide managers with relevant information describing implications of alternative management scenarios.

To avoid being accused of suggesting there are no existing attempts to address the recommendations offered here, we present a few examples incorporating these concepts. Examples are primarily "in-house" (mostly USGS-related), focus on the theme of this article (bird conservation), and involve partnerships among federal and state agencies, academia, and nongovernment organizations. We recognize the long-standing North American BBS (Peterjohn et al. 1996), as well as newer programs that are focused on monitoring demographic parameters, including the Monitoring Avian Productivity and Survivorship (MAPS) program of the Institute for Bird Populations (DeSante 2000) and the Breeding Biology Research and Monitoring Database (BBIRD) (Conway and Martin 2000). Such programs provide valuable information, but continue to struggle to expand sampling coverage and address questions related to scale, site selection, sampling techniques, and analyses (Peterjohn et al. 1995, DeSante and Rosenberg 1998).

Habitat and environment.—Habitat management and preservation are critical elements of virtually all bird conservation work, underscoring a need for research and monitoring activities to understand the role of habitat quality, quantity, and distribution on bird populations. In addition to priorities listed below, many needs related to bird monitoring and information management apply equally to habitat monitoring.

Effective bird conservation requires information on status of environmental factors influencing population change, collected at scales consistent with management and monitoring activities. Efforts must be made to assess and monitor key determining factors (e.g. hydrology, climate, habitat, food, disease agents) of avian abundance and distribution.

Assessment and monitoring of ecologically relevant habitat components (physical, biological, and environmental features) provide a means for conservationists to document status and trends in habitat quantity and quality and evaluate progress toward habitat-based goals and objectives. An important research challenge is the development of the ability to recognize biologically relevant attributes and diagnostic features of habitat effects on avian population dynamics. Capabilities must be developed that allow for remote and field collection of habitat information at appropriate temporal intervals and spatial scales.

Habitat management is one means by which vegetation, food resources, and other features of the environment are maintained to support avian populations. Research is needed to guide distribution and intensity of habitat management, restoration, and enhancement activities by land managers. Ideally, that work should take place as part of an adaptive management program in which models are used to predict consequences of habitat manipulation and monitoring is used to assess the results of management on avian populations.

Many existing sources of habitat and environmental data can be applied to avian conservation, including the National Gap Analysis Program (Scott and Jennings 1997), the National Land Cover Dataset (U.S. Geological Survey 2001a), and the Environmental Protection Agency's Environmental Mapping and Assessment Program (Preston and Ribic 1992). The challenge is to integrate that information into avian conservation science.

Integration of ecological information.—Ecological models are critical tools for predicting consequences of management actions, integrating information across spatial and temporal scales and among disciplines, supporting conservation decision making, and identifying key uncertainties and topics for future investigation.

Population models for high priority avian species are necessary to guide conservation planning, improve the design of avian monitoring programs, and provide predictions that can be used in management decision making and tested in the field. Key needs in the development of models include investigations of density-dependent population growth, bird-habitat associations at local and regional scales,

and development of statistical methods for modeling bird abundance where estimates of vital rates are unavailable.

The ability to identify relevant avian habitat factors and patterns requires a linkage among biological, physical, and socioeconomic processes as sources of population and habitat variation and change. New quantitative methods and approaches relating environmental factors (e.g. water quality, climate, geomorphology, contaminant distribution, habitat dynamics, and human population distribution) to bird population dynamics that can be used in predictive models would be especially valuable for avian conservation.

Integration of population and habitat attributes and processes will require development of innovative methods for constructing, visualizing, analyzing, and verifying behaviors of complex ecological systems. Those integrated models provide a basis for conservation planning and future learning.

The wide range of models that have developed to understand the needs and responses of waterfowl to habitat, weather, food resources, and wetland conditions (Johnson et al. 1987) is an example of the integrated modeling required for other priority species. Integrated models will provide a valuable basis for conservation planning and future learning (Raphael et al. 1998, Villard et al. 1998).

Bird conservation planning.—Application of research results to development of credible, effective bird conservation plans is a key component of NABCI. Avian conservation is most successful when plans are built on strong scientific foundations, conservation actions are based on collaboration between researchers and managers, and policy makers are "on board" to ensure implementation of integrated approaches.

Scientifically credible and defensible population and habitat objectives are intended to form the cornerstone of bird conservation plans. Yet quantitative, measurable objectives may not always reflect the most defensible scientific and ecological information, due to our lack of understanding of associations among population size, available habitat, and other limiting factors. Additional scientific guidance is needed to help construct legitimate, defensible, and quantitative population and habitat objectives for conservation plans.

All plans are built upon an incomplete understanding of ecological and environmental factors affecting population and behavioral dynamics. Rigorous research that evaluates the validity of the fundamental assumptions associated with each plan can enhance their credibility. Research activities should identify assumptions used in developing conservation plans and should test and revise those assumptions as additional information becomes available.

Conservation actions that benefit one focal species or area may conflict with population and habitat objectives established for other species or areas. Managers need to develop strategies that optimize regional benefits for multiple species and minimize detrimental effects to priority species or areas. Scientific guidance is needed to effectively integrate the goals, objectives, and management actions of frequently conflicting species and regional conservation plans.

Bird conservation in the northern tallgrass prairies exemplifies the assistance provided by scientists to conservation planners in testing conservation assumptions. The USGS Northern Prairie Wildlife Research Center is testing assumptions behind the Bird Conservation Area concept incorporated in various bird conservation plans (Winter et al. 2001). Results of this research will inform (and possibly result in revisions to) future bird conservation planning and implementation.

Communication of ecological information.—An implicit goal of avian conservation science is to provide scientific information about avian populations and habitats that can be applied to management and policy decision making. The manner in which data, models, or related information are delivered and applied, as well as the degree of cooperation between scientists and managers, plays a key role in the ultimate value of research (Arnett and Sallabanks 1998, Hejl and Granillo 1998). All these requirements can be facilitated through effective data and information management and dissemination.

The ability to synthesize and integrate information depends on comprehensive, coordinated systems for data management, display, and analyses. A distributed, electronic network linking existing data sets, applications, models, and other information products should be a high priority. That information enterprise should be capable of moving data and information among scientists, managers, policy makers, and the public. It should be defined in terms

of three components—customers, content, and computer and information technology. That will require development of information standards and protocols for ensuring that data are comparable within and across projects, scales, and disciplines.

Novel approaches to information management and delivery are key to keeping pace with increasing demands for access to information, rapidly evolving technologies, and expanding and geographically separated customer bases. Packaged results must be responsive to the pertinent conservation issue that stimulated research in the first place. Several key themes should be incorporated into development of application tools: (1) collaboration (between scientist and end-user) in building decision support tools; (2) a rigorous decision-making process for conservation; (3) direct, unambiguous linkage between scientific information, priority management questions, and conservation decision making; and (4) user-friendly access to ecological models and other decision support tools.

The National Biological Information Infrastructure (NBII) is an example of the new generation of programs addressing those needs. It is an electronic information network that links diverse, high-quality biological databases, information products, and analytical tools maintained by widely distributed partners. The NBII recently introduced a Bird Conservation Information Node (U.S. Geological Survey 2001b), whose primary focus is to provide access to bird habitat and population data needed for management and conservation.

Adaptive resource management (ARM) is a promising approach for applying ecological information to resource conservation decision-making processes (Williams and Johnson 1995, Lancia et al. 1996, Marzluff et al. 2000). It provides a framework to facilitate development, testing, and use of predictive models, guide management actions, and improve scientific knowledge about systems. Adaptive resource management is an iterative process that links monitoring and assessment programs, and integrates science into decision making. When management decisions are iterated (in space or time), knowledge gained from one decision can be applied to the next decision (Conroy 2000). Williams (2003) discusses ARM and its application to resource conservation policy in more detail.

Decision support systems, by providing both models and information to managers, are an important part of ARM. A variety of decision support systems can be developed that cover the continuum from a general data and information framework (with an emphasis on "support") to an expert system (with an emphasis on "decision"), depending upon needs of the user and availability of necessary data. Such tools help managers determine the scope of issues, enhance communications, identify and present relevant data, oversee and refine processes, visualize future options and outcomes, and focus on endpoints and decisions.

Adaptive resource management requires clear definitions of management goals, integration of research results into predictive management models, implementation of selected management actions, monitoring to assess the consequences of actions, and updating and revising models based on monitoring and additional research. Development of ARM frameworks for scales at which birds are to be managed (e.g. local management units, regional conservation areas, etc.) is an important first step in implementing this management philosophy.

Decision support systems should: (1) adopt an interdisciplinary, coordinated approach; (2) address processes at various spatial scales; and (3) help deliver bird conservation in an adaptive framework that explicitly reviews results and revises actions based on those reviews.

A number of theoretical aspects of decision analysis require further research to provide tools for avian conservation, including (1) a better theoretical understanding of how spatial replication affects learning in an adaptive management context; (2) integration of learning at multiple spatial and temporal scales; and (3) the nature of multidimensional decisions.

Efforts associated with the Management Strategy for Migratory Birds of the Upper Mississippi River (UMR) have resulted in a type of place-based decision support systems. The USGS Upper Midwest Environmental Sciences Center website currently makes available 17,000 files on fish, vegetation, macroinvertebrates, water quality, water levels, aerial photography, satellite imagery, scientific publications, and geographic information system data (U.S. Geological Survey 1998) to planners and managers. The decision support system framework facilitates an integrated, ecological, and proac-

tive scientific approach to management of UMR resources and provides for an adaptive management approach to decision making and project evaluation (C. Korschgen unpubl. data).

Finally, although not a science need as such, the existence of real or perceived institutional and cultural barriers to integrated science programs continues to hamper collaborative activities and delivery of ecological information. For example, difficulties in communicating across disciplines and organizational boundaries, as well as ambiguity in management objectives can stifle collaboration. The fact that these issues are regularly raised in conservation discussions emphasizes the need for immediate attention.

Summary.—Considerable gains in our basic knowledge of avian ecology and avian conservation have been made in the past few decades. Avian conservation science is now at a stage where more refined, integrated approaches will facilitate even greater advances. The advent of NABCI offers both an opportunity and some clear directions for conducting research and monitoring activities required to accomplish avian conservation goals. It is encouraging to note that, in a process implemented by the federal subcommittee of the U.S. NABCI steering committee, a very similar set of future research and information needs was identified: (1) monitoring, (2) integrated modeling and analysis, (3) decision support, (4) adaptive management, and (5) information management (U.S. North American Bird Conservation Initiative Committee 2000b). The NABCI offers a vehicle by which science organizations can direct their activities, in collaboration with management organizations, toward accomplishing avian conservation goals. We can imagine a scenario in which scientists, managers, and policy makers are brought together to identify priority research. That science is conducted in an adaptive management context where research and monitoring address priority issues at the relevant scale, and the results feed back in such a way that alters future research, monitoring, management, and policy to promote bird conservation. Accomplishing those goals will require involvement and support of scientists, managers, policy and budget decision makers, and will rely on innovative thinking far beyond the scope of the workshop. In other words, the process by which research priorities are identified, addressed, and applied is just as important in implementing avian conservation as is the focus of that research.

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