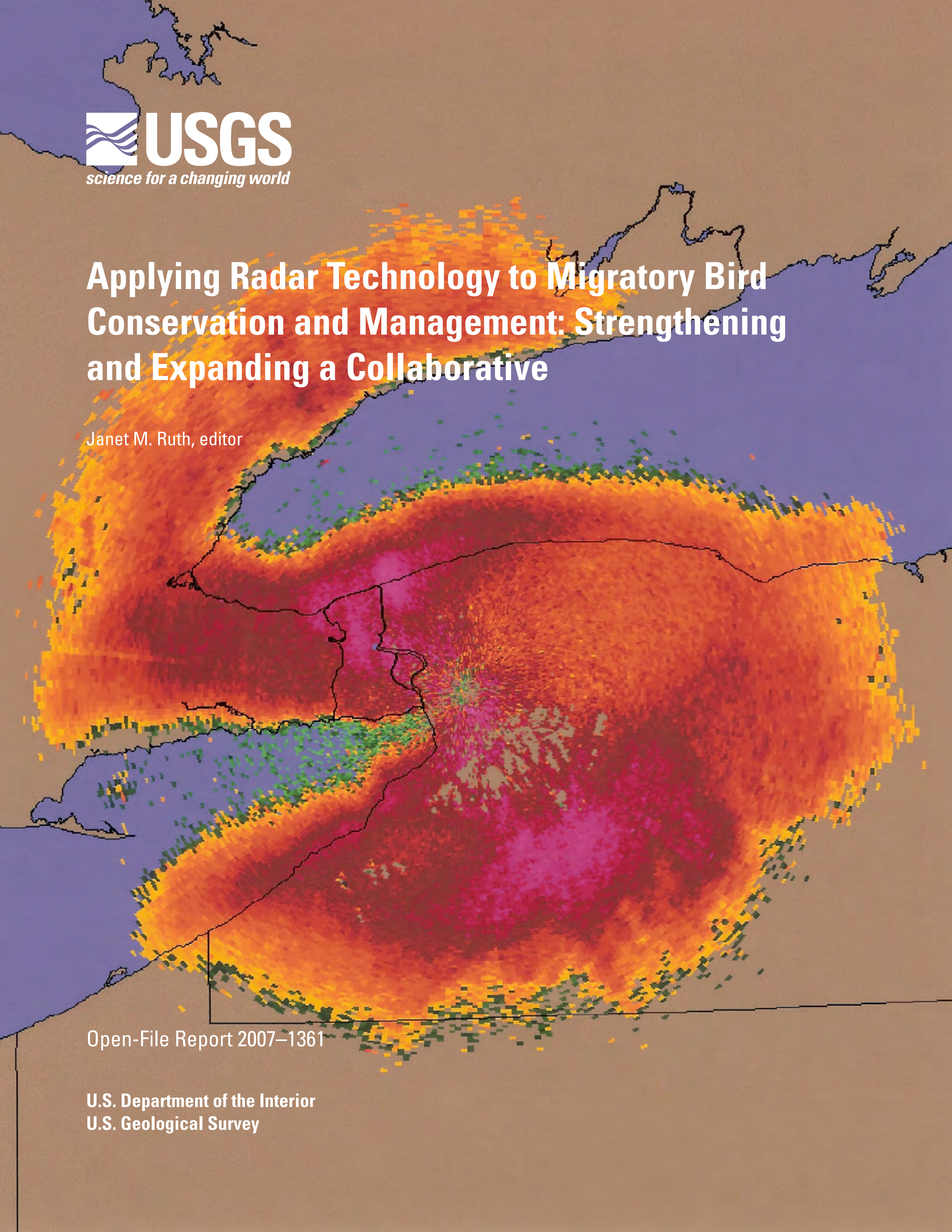

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Applying Radar Technology to Migratory Bird Conservation and Management: Strengthening and Expanding a Collaborative

Janet M. Ruth, editor

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Cover Figure: This radar image from May 16, 1999, captures the distribution of birds in the airspace shortly after the onset of nocturnal migration near Lakes Erie (left) and Ontario (right). Colors represent logarithmic differences in migrant density - lowest to highest: green, yellow, orange, red, and purple. Voids in the radar echo pattern occur over the lakes because most of the migrants are landbirds. Radar echoes caused by northbound migrants can be seen extending over the southern portion of both lakes as birds depart the coastal landscape and fly out over the water. Regions of stronger radar echo this early in the migratory flight show where in the landscape birds occurred in high density prior to the onset of migration – stopover habitat (e.g., north and south of the radar, and along the southern Lake Erie coast).

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Workshop Attendees

We are very grateful for the enthusiastic participation of workshop attendees. It is their sharing of information, ideas, questions, and concerns, and their discussions about the hopes for the future of this collaborative effort that are the core of this proceedings document. See the Contact Information section for complete contact information on each attendee, organized by affiliation.

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Wylie Barrow, USGS, Lafayette, La.
Bob Beason, APHIS, Sandusky, Ohio
Carol Beidleman, NPS, Estes Park, Colo.
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Matthew Bobo, BLM, Denver, Colo.
Gwen Brewer, MD DNR, Annapolis, Md.
Bruno Bruderer, Swiss Ornithological Institute, Sempach, Switzerland
Jeff Buler, University of Southern Mississippi, Wilmington, Del.
Louis "Coke" Coakley, FPL Energy, Juno Beach, Fla.
Paul Cryan, USGS, Fort Collins, Colo.
Deanna Dawson, USGS, Laurel, Md.
Mary Pat Day, The Lannan Foundation, Santa Fe, N. Mex.
Ryan DeGaudio, Point Reyes Bird Observatory, Bolinas, Calif.
Robert Diehl, University of Southern Mississippi, Hattiesburg, Miss.
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Ryan King, FAA, Atlantic City, N.J.
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Gail Tunberg, Forest Service, Albuquerque, N. Mex.
Charles van Riper III, USGS, Tucson, Ariz.
William Waskes, MMS, Herndon, Va.
Tom Will, USFWS, Fort Snelling, Minn.

Workshop Planning Committee

Chair - Janet M. Ruth, USGS, Albuquerque, N. Mex.
Lori Randall, USGS, Lafayette, La.
Wylie Barrow, USGS, Lafayette, La.
Albert Manville, USFWS, Arlington, Va.
Dave Krueper, USFWS, Albuquerque, N. Mex.
Scott Johnston, USFWS, Hadley, Mass.
Robert Diehl, University of Southern Mississippi, Hattiesburg, Miss.

Workshop Agenda

24 – 26 October 2006
The Nativo Lodge
Albuquerque, New Mexico

Tuesday, 24 October 2006

7:30 – 8:00 a.m.	Workshop Sign In
8:00 – 8:30 a.m.	**WELCOME TO WORKSHOP**
	- Rick Kearney (USGS HQ, Program Director, Wildlife and Terrestrial Resources, Reston, Va.)
	- Al Manville (USFWS HQ, Senior Wildlife Biologist, Arlington, Va.)
8:30 – 9:00 a.m.	**INTRODUCTION TO THE WORKSHOP**
	Radar as a Tool to Fulfill Research Needs – Partnering with our Stakeholders – Al Manville (USFWS HQ)
	History of the USGS-USFWS "Radar Collaborative" and Goals/Focus of the Workshop - Janet Ruth (USGS Fort Collins Science Center)
9:00 – 10:00 a.m.	**Primer on Radar Biology and Applications to Conservation Issues** - Ron Larkin (University of Illinois, Champaign-Urbana, Ill.)
10:00 – 10:30 a.m.	Break
10:30 - 12:15 p.m.	**CURRENT RADAR RESEARCH I** Moderator: Robb Diehl (University of Southern Mississippi, Hattiesburg, Miss.)
	Broad-Scale Habitat Relations for Birds - Wylie Barrow (USGS National Wetlands Research Center, Lafayette, La.)
	Nocturnal Migration through the Appalachians, with Stopovers on Lower Delmarva - Deanna Dawson (USGS Patuxent Wildlife Research Center, Laurel, Md.)

Regional Structure in Migratory Patterns across the Southwest - Robb Diehl (University of Southern Mississippi, Hattiesburg, Miss.)

Can Artificial Intelligence Be Used to Detect Birds in NEXRAD Data? - Rick Sojda (USGS Northern Rocky Mountain Science Center, Bozeman, Mont.)

Incorporating NEXRAD Weather Radar into Migration Studies in the Upper Mississippi River System - Pat Heglund (USGS Upper Mississippi Environmental Sciences Center, La Crosse, Wis.)

12:15 – 1:45 p.m. Lunch

1:45 – 3:30 p.m. **CURRENT RADAR RESEARCH II**

The Quantification of Bird Migration using Vertically Pointing Fixed-Beam Radar and Thermal Imaging Camera - Sid Gauthreaux (Clemson University, Clemson, S.C.)

Applications of Pencil-Beam and Tracking Radar to Understanding Flying Biota - Ron Larkin (University of Illinois, Champaign-Urbana, Ill.)

The "Superfledermaus" Radar, from Military Use to Basic and Applied Research - Bruno Bruderer (Swiss Ornithological Institute)
1 hour

3:30 – 4:00 p.m. Break

4:00 – 4:45 p.m. **CURRENT RADAR RESEARCH III**

Application of WSR-88D to Quantify Bird Distributions during Migratory Stopover - Jeff Buler (University of Southern Mississippi, Ph.D. student), Wilmington, Del.)

Characterizing Bird and Bat Movement Patterns Using Portable X-Band Radar - David Mizrahi (New Jersey Audubon, Cape May, N.J.)

4:45 – 5:15 p.m. **IDENTIFICATION OF KEY QUESTIONS AND ISSUES**
Plenary Session
Facilitator: Janet Ruth (USGS Fort Collins Science Center)

5:15 p.m. Adjourn until Banquet

6:30 – 8:00 p.m. **BANQUET with Keynote Speaker**
Radar Ornithology: The Past, Present, and Future—A Personal Viewpoint - Sid Gauthreaux (Clemson University, Clemson, S.C.)

Wednesday, 25 October 2006

8:00 – 9:30 a.m. **CURRENT RADAR RESEARCH IV AND OTHER OPPORTUNITIES**
Moderator: Robb Diehl

Wildlife Radar Research and Development - Adam Kelly (DeTect, Inc., Panama City, Fla.)

Past, Present, and Future Uses of Radar for Studying Bats - Paul Cryan (USGS, Fort Collins Science Center, Colo.)

NEXRAD Program Update - Tim Crum (NOAA), (presented by Terry Schuur [NOAA])

Detection of Birds and Insects with a Polarimetric WSR-88D Radar - Terry Schuur (NOAA, National Severe Storms Lab, Norman, Okla.)

9:30 – 10:00 a.m. **PRESENTATION REVIEW**
Plenary Session
Facilitator: Janet Ruth

10:00 – 10:30 a.m. Break

10:30 – 12:00 p.m. **KEY ISSUES, NEEDS, AND QUESTIONS FOR A RADAR COLLABORATIVE** – Plenary Session
Facilitator: Janet Ruth

12:00 – 1:30 p.m. Lunch

1:30 – 3:00 p.m. **KEY ISSUES, NEEDS, AND QUESTIONS** (cont.) – Plenary Session
Facilitator: Janet Ruth

3:00 – 3:30 p.m. Break

3:30 – 5:00 p.m.	**KEY ISSUES, NEEDS, AND QUESTIONS** (cont.) and **IDENTIFICATION OF KEY ACTION ITEMS FOR A RADAR COLLABORATIVE** - Plenary Session Facilitator: Janet Ruth
5:00 p.m.	Adjourn for the day

Thursday, 26 October 2006

8:00 – 8:45 a.m.	**PERSONAL IMPRESSIONS AND OBSERVATIONS FROM THE WORKSHOP: Common Themes and Visions for the Future** - Robb Diehl (University of Southern Mississippi) - Tom Will (USFWS Region 3)
8:45 – 10:00 a.m.	**WHERE DO WE GO FROM HERE? WORKSHOP ACTION ITEMS AND RECOMMENDATIONS** - Plenary Session Facilitator: Janet Ruth
10:00 – 10:30 a.m.	Break
10:30 – 11:30 a.m.	**WHERE DO WE GO FROM HERE?** (Cont.)
11:30 a.m. – 12:00	**WRAP-UP**
12:00 p.m.	**ADJOURN**

Executive Summary

Understanding the factors affecting migratory bird and bat populations during all three phases of their life cycle—breeding, nonbreeding, and migration—is critical to species conservation planning. This includes the need for information about these species' responses to natural challenges, as well as information about the effects of human activities and structures. Habitats and other resources critical to migrants during passage and stopover are being destroyed, degraded, and threatened by human activities. Birds and bats are also uniquely susceptible to human use of the airspace. Wind turbines, communication and power transmission towers, and other tall structures, known to cause bird and bat mortality, are being erected or proposed in increasing numbers across the country. In addition, the potential for bird/aircraft collisions poses human safety threats. Management and regulatory agencies, conservation organizations, and industry currently lack the information they need to meet their missions and statutory responsibilities. The biological data available from various radar technologies offer a unique opportunity to learn more about the spatiotemporal distribution patterns, flight characteristics, and habitat use of "aero-fauna."

Recognizing the opportunities presented by radar technologies, the U.S. Geological Survey (USGS), the U.S. Fish and Wildlife Service (USFWS), and university partners collaborated first on individual projects and then in a broader, informal "collaborative" to coordinate their radar-related research and work together to develop the suite of products needed for conservation of birds and bats. Having produced two summary documents (Sojda and others, 2005; Ruth and others, 2005), the next objective was to convene a workshop for researchers, management and regulatory agencies, and other interested parties. The focus of this initial workshop was on strengthening the existing USGS-USFWS-university partnership and expanding the "collaborative" to include new Federal agency partners. The subject matter was centered on discussing available technologies, appropriate applications, management-related needs, and ways to strengthen collaborative research and conservation efforts.

The workshop opened with presentations about the history of the "radar collaborative," a description of the workshop objectives and focuses, and a summary of resource management and regulatory needs. Scientific presentations describing current research projects or subjects followed, given by USGS scientists, as well as scientists from other Federal agencies, academia, conservation and ornithological organizations, and a private contracting firm. Presenters addressed a wide variety of management issues including siting of wind-power facilities, bird/aircraft collisions, effects of hurricanes Katrina and Rita on bird migration, bird use of Conservation Reserve Program land, defining bird migration patterns at a broad regional scale, and associating migrant birds with their stopover habitats. Presentations described a variety of radar technologies including NEXRAD weather surveillance radar, modified mobile marine radar, military tracking radar, pencil beam radar, and dual polarization radar, as well as complementary techniques and analysis methods such as acoustic monitoring, thermal imaging, artificial intelligence, and individual-based modeling.

Key issues, themes, and questions identified during the open discussions that followed fell into five main categories: (1) agency needs and challenges; (2) radar technology and applications—technical questions and issues; (3) tools and resources for managers and researchers; (4) standardization of protocols; and (5) collaborative opportunities. Participants identified the following management, regulatory, or business issues facing them which may be addressed with radar technologies: tall structures; wind turbines; identification and protection of key habitats; assessment of management activities; and bird/aircraft strikes. Participants frequently expressed the need for specific information about which radar technologies are best used for answering particular questions. User groups emphasized the importance of clear, defensible scientific information on which they can base their activities. In turn, researchers emphasized their need for clearly defined, specific questions from

managers so that they can design and conduct the required research. Discussions about technical issues requiring further research and collaboration included target identity, ground-truthing, linking migrants to habitat, and standardized protocols for applied research.

Workshop participants identified and endorsed a series of seven action items that would promote collaboration and begin to address key issues identified at the workshop:

Action Item #1: Establish a working subgroup to address large-scale surveillance radar standardization issues.

Action Item #2: Establish a working subgroup to address small-scale radar standardization issues.

Action Item #3: Bring management and regulatory agencies together to identify the three most important information needs for each key management issue relating to radar technologies.

Action Item #4: Develop Fact Sheet(s) to provide information about radar technology applications to migratory bird and bat conservation issues.

Action Item #5: Create a "radar collaborative" Website to provide information about radar biology applications, contacts, publications, and so forth.

Action Item #6: Formalize and expand the USGS-USFWS "radar collaborative."

Action Item #7: Advance basic research, such as target identity and validation, which will support and improve our abilities to apply radar technologies to conservation objectives.

There was considerable interest in expanding the "radar collaborative" to include those agencies, organizations, and industries represented at the workshop. It was felt that the publication of the workshop proceedings, implementation of action items, and additional future meetings or workshops will be crucial in strengthening the "radar collaborative" effort and promoting the use of these valuable technologies for conserving migratory species.

Introductory Presentations

See Literature Cited section for references in this section.

History of the USGS-USFWS "Radar Collaborative" and Goals and Focus of the Workshop

- **Janet M. Ruth**, Workshop Planning Committee Chair, USGS Arid Lands Field Station, Albuquerque, N. Mex.

One of the crucial, continuing needs faced by resource managers, regulators, conservation organizations, and industry and one of the challenges faced by researchers is to improve our understanding of the factors affecting migratory bird and bat populations. Understanding how migrants use habitats through all three phases of their life cycle—breeding, "wintering," and migration—is critical to any species conservation planning. This includes the need for more information about their responses to the natural challenges (for example, severe weather, physical obstacles to migration such as mountains, large water bodies, and inhospitable terrestrial habitats, the need for migratory stopover habitat, high energy demands, predation, and so forth) they face during migration and other significant movements. It also involves gaining information about the effects of human activities and structures on migratory species. Habitats and other resources critical to birds during migratory passage and stopover are being destroyed, degraded, and threatened by human activities. Birds and bats are also uniquely susceptible to human use of the airspace. Wind-power projects, communication towers, power transmission towers, and other tall structures, known to cause bird and bat mortality, are being erected or proposed in ever-growing numbers across the United States and offshore. In addition, the potential for bird/aircraft collisions poses human safety threats to the operators and passengers on those aircraft. Management and regulatory agencies, conservation organizations, and industry currently lack all the information they need to meet their missions and statutory responsibilities—prioritizing and protecting habitat, issuing permits, managing resources, establishing policies that protect both wildlife and humans, and developing and siting structures that may have impacts on migratory wildlife.

There is a growing consensus among these groups that focusing our attention at the landscape level in addressing these issues is critical to conservation of migratory species. The biological data available from the nationwide network of large-scale Doppler weather surveillance radars (otherwise known as NEXRAD or WSR-88D) present a unique opportunity to learn more about the spatiotemporal distribution patterns, flight characteristics, and habitat use of "aero-fauna." Taxa include landbirds, shorebirds, wading birds, waterfowl, raptors, bats, and insects. In addition, a variety of other radar technologies (for example, mobile and revised mobile marine radars, airport surveillance radars, military tracking radars, and other pencil-beam radars) and complementary methodologies (for example, acoustic monitoring, thermal imaging, night-vision monitoring, and visual surveys) can be used to further our understandings of bird migration and to address conservation concerns at a more local or site-specific level.

The USGS-USFWS "Radar Collaborative"

What is a "collaborative"? At the research or management project level we know what collaboration means—the coming together of people with a common interest (researchers and managers) to identify research needs, develop proposals, share resources (for example, capabilities, money, equipment, and ideas), conduct research, interpret results, and apply information to management activities. More broadly, above an individual project level, many of the same concepts apply—coming together to improve communications and collaboration among and between researchers, managers and regulators, decisionmakers, and other interested private and commercial organizations and to exchange information about technology applications and results, identify new research needs, and develop programmatic and budgetary means to accomplish our goals.

The birth of the USGS-USFWS "Radar Collaborative" arose out of a series of individual partnering events. Over the last 5 years, collaborative research proposals and subsequent projects involving U.S. Geological Survey (USGS), U.S. Fish and Wildlife Service (USFWS), and university partners have arisen independently across the United States and are aimed at using radar data to address a variety of bird conservation management questions and issues. The principal investigators (PIs) and their management partners have come together as an informal "collaborative" to coordinate their radar-related research and to work together to develop a suite of products for conservation of birds and bats. The first tangible products of this effort are two summary documents: (1) a USGS Fact Sheet (Sojda and others, 2005) and (2) a USGS Open-File Report (Ruth and others, 2005) describing the opportunities and goals of the collaborative effort. However, the members of this informal "radar collaborative" recognized that there were many additional potential partners for this collaboration; hence the evolution and implementation of the workshop whose proceedings are presented here.

Some of the broad goals of this initial "radar collaborative", as described in more details in the two publications referenced above, include the following:

- To identify migratory pathways and stopover sites for conservation, mitigation, and landscape-scale planning
- To understand more about the importance of healthy landscapes and unobstructed airspaces for migrants
- To enable the use of radar technologies by the wider biological community, as well as other related communities
- To simplify the analysis of radar data

But perhaps more important is the focus of our efforts, which is to facilitate and further the use of radar technologies to better understand the movement patterns and habitat associations of migratory birds and other wildlife in order to inform wildlife management and regulatory decisionmaking.

As we present the proceedings of this workshop, it may be worthwhile to answer the following question with regard to the "Radar Collaborative." Why is collaboration a good thing? First of all, the use of radar technologies in applications to wildlife management issues represents a new, integrated science capability within USGS and the Department of the Interior. By working together collaboratively, we can ensure that research at various locations will be complementary as opposed to overlapping or repetitive. Collaborating also will facilitate the development of a coordinated strategy for addressing conservation needs with radar and related applications and it will enable the identification and(or) development of needed infrastructure, resources, and expertise. For this to happen, scientists and managers need to communicate regularly about research needs, methods, and results. This collaborative effort is particularly exciting because it will necessarily involve the integration of multiple disciplines and fields of technical expertise (for example, wildlife biology, landscape ecology, remote sensing, radar engineering, meteorology, software development, computer science, mapping, ecological modeling, artificial intelligence, and information technology and transfer). By working together collaboratively, the USGS, USFWS, and other partners will be positioned well to address their respective missions in an effective and efficient manner.

Goals and Focus of the Workshop

As the "Radar Collaborative" met informally, primarily through emails and conference calls, and once the initial publications previously mentioned were finalized, it became clear that there was a need to gather current collaborators and potential new partners together to strengthen and broaden the effort. The idea for this workshop developed from that realization. A workshop proposal was developed, submitted, and eventually funded by USGS headquarters in Reston, Va., and the informal group identified a Workshop Planning Committee assigned to implement this plan. The workshop, entitled "Applying Radar Technology to Migratory Bird Conservation and Management: Strengthening & Expanding a Collaborative Effort," was held on October 24–26, 2006, in Albuquerque, N. Mex. This document presents expanded abstracts of the presentations made and describes the discussions and action items approved during that workshop.

The overall goal of the workshop was to strengthen existing collaborative efforts between USGS, USFWS, and its university partners and to broaden the coalition by inviting other potential partners to join us in sharing information, discussions, and planning for further collaboration. It was the intention of the initial "Radar Collaborative" to focus the workshop on the application of the broadest possible range of radar technologies to the broadest possible range of migratory bird and bat management issues. This was driven by the desire to avoid being caught in a narrowly focused discussion of any particular type of radar technology or any particular current management issue. Such narrowly focused discussions would have precluded us from encouraging the consideration of the future for radar applications and the "radar collaborative." The Workshop Planning Committee recognized that there were many possible directions that could be taken with such a workshop. It was determined that the focus of this initial workshop would be on strengthening the existing USGS-USFWS-university partnership and expanding to include new Federal agency partners that face similar management and(or) regulatory issues and that could benefit from radar applications or have technical or other resource capabilities to bring to the table. In addition, the workshop focused on discussing available technologies, appropriate applications, management-related needs, and ways to strengthen collaborative efforts. It was not intended to develop strategies for dealing with or making management-related regulatory or policy decisions. Many other opportunities are already available that facilitate those sorts of decisionmaking discussions (for example, Wildlife-friendly wind-power development in the Great Lakes Basin, June 2006, Toledo, Ohio
http://www.fws.gov/midwest/greatlakes/windpowerconference.htm

Having determined the focus of the workshop, the Workshop Planning Committee recognized that there were some additional crucial partners that needed to be included in the discussions. There are many published non-USGS scientists who have been applying radar technologies to understanding bird migration and other movements for a long time. In this regard, USGS is the "new kid on the block." We were very pleased to include several of the key long-term players in radar-related research on bird movement patterns as presenters at this workshop. The Workshop Planning Committee also recognized that there are potential non-Federal partners with whom we want to begin dialogue, and therefore we invited some representatives from these organizations to join us. The limitations of space and the focus of the workshop meant that we were only able to invite participation of a few representatives from any particular entity, whether that was a Federal agency, researchers, or potential non-Federal partners. It is hoped that there will be additional future opportunities to continue and broaden discussions with all potential, interested parties. The same limitations applied to our ability to provide time for presentations from all other participants. All workshop participants were encouraged to participate in workshop discussions, and ample time was provided in open plenary sessions to allow the necessary questions/answers and discussions. Equally important, all workshop participants were encouraged to pass on the knowledge they acquired at the workshop to their respective agencies, groups, and peers to ensure the broadest possible dissemination of the information and opportunities presented by the "Radar Collaborative."

The workshop objectives, as developed in the funded proposal, were as follows:

- To provide basic information on radar technologies and applications
- To present a sample of current research using radar technologies to address migratory bird (and bat) management questions
- To discuss resource management questions that can be addressed with radar technology
- To provide a forum for researchers and managers to communicate with one another
- To identify actions that would strengthen existing partnerships and broaden the coalition, including recommendations for a collaborative radar applications program

An important component of the workshop agenda included the day and a half of presentations by researchers about their ongoing projects (see the abstracts of the presentations in these proceedings). Because the workshop was designed to provide information about radar technology applications in a way that would be useful to management and regulatory agencies and other interested parties, the speakers were asked to craft their presentations to address a series of questions about their projects that would facilitate this exchange. The questions included**:**

- What are the management/resource issues that my project is addressing, and who are my partners?
- What radar technologies (and other complementary methods) are being used in my project?
- Why did I decide to use these methods? What information will these methods provide/NOT provide?
- What challenges am I facing in my project? What problems have I experienced while using these methods?
- What are the next steps planned for my project? What additional resources/partners are needed?

The second half of the workshop was composed primarily of open plenary sessions to discuss key issues, themes, and questions that had been identified by speakers and participants at various points prior to the workshop and during the workshop as participants considered the research presentations during the first half of the workshop. These plenaries were facilitated, and minutes were recorded and are presented below in these proceedings. In addition, we present a series of Action Items that were identified, discussed, and endorsed by the workshop participants.

Radar as a Tool to Fulfill Information Needs—Partnering with Stakeholders

- **Albert M. Manville,** Workshop Planning Committee Member, USFWS, Division of Migratory Bird Management, Arlington, Va.

The airspace as an important habitat is a new concept for the U.S. Fish and Wildlife Service (the Service or USFWS). Our goal, as an agency, is to do no harm. My division and agency get many queries from other agencies, industry, consultants, and the conservation community about bird migration. Unfortunately, the process of migration is poorly understood for birds and is barely understood at all for bats. Migration can be episodic such as for Canada Geese where, for example, ~500,000 may migrate through a specific area within 24 hours—or migration can be drawn out for months, such as for the American Robin and the Common Loon. It is unclear exactly when migrating birds and bats are most vulnerable—possibly during take offs and landings, or during flight in inclement weather either from direct weather effects or in response to anthropogenic light sources. Until we know more definitively the height at which birds and bats fly, we cannot talk about risk to these vertebrates in a quantitative way. Radar, as we have seen in the two and a half days of this workshop, can be a major tool to help us answer these questions.

At a recent tall-structure avian risk-reduction conference in Baraboo, Wisconsin, on October 13, 2006, two questions were asked by a representative of the National Association of Broadcasters (NAB). Could the Service provide a map of all communication towers in Wisconsin and could the Service provide a map of migration "pathways" in his State? It was explained that for songbirds—the suite of birds generally most at risk from collisions with tall structures (Manville, 2005)—en masse migration "pathways" or "corridors" do not generally appear to exist, particularly in the contiguous United States. Songbird migration is best referred to as "broad-front" based on radar research (Gauthreaux and Belser, 2003b; Larkin, 2005; Gauthreaux and Livingston, 2006), which was discussed in several of the presentations at this workshop. The NAB executive also was told that migrations for songbirds and other avian species do indeed have seasonal and annual variations, as well as variations in the numbers and concentrations of songbirds. Timing of migration events is often in response to weather events.

Regarding the issue of migration timing, various radars have documented a broad array of migrating species—generally identified as "targets" or "flying vertebrates" since the identification of individual species needs to be validated using other technologies—on a nearly year round basis. Between waterfowl, shorebirds, raptors, landbirds, wading birds, marsh birds, and micro chiropterans, some species is migrating nearly all times of the year (Mark C. Shieldcastle, Ohio Department of Natural Resources, oral comm., 2006).

Radar Use and Its Applications to Our Clients

The USFWS and other agencies including USGS face increasing pressure to identify and evaluate avian and bat movement patterns, stopover sites, and habitat use during migration periods and during other seasons, nationwide. Not infrequently do we get requests from the communication tower, wind turbine, electric utility line, tall building, and other industries regarding bird migration, habitat use, and other data. We hope this workshop will be of special assistance to our "clients," especially other management and regulatory agencies represented at this workshop, or those who were invited but unable to attend. These include the Bureau of Land Management (BLM), the National Park Service (NPS), Minerals Management Service (MMS), the U.S. Department of Agriculture (USDA) Forest Service (USFS), the Department of Energy (DOE), USDA Animal and Plant Health Inspection Service (APHIS), the Natural Resources Conservation Service (NRCS), the Federal Aviation Administration (FAA), the Federal Communications Commission (FCC), the National Oceanic and Atmospheric Administration National Weather Service (NOAA/NWS), the Department of Defense (DOD), the U.S. Environmental Protection Agency (USEPA), the National Aeronautics and Space Administration (NASA), the U.S. Coast Guard (USCG), and others. It is hoped that this workshop will also be of special assistance to our clients represented by State agencies, academia, the industry and its consultants, and the conservation community.

Those aware of the general abilities of radar frequently think about its application only for use in detecting "targets" of "flying vertebrates"(Ron Larkin, Illinois Natural History Survey, oral comm., 2006) and insects, intermingled with weather and electronic "clutter." By broadening our perspective, we now see that radar technology offers many additional possibilities.

Questions Being Asked About Radar

Representatives, for example, from the electric utility and power line, communication tower, wind turbine, and building window industries frequently ask the following questions:

- Can radar identify bird and bat migration pathways?
- Where do birds and bats stop over during migration?
- What are the spatial and temporal distribution characteristics, duration and intensities, and flight behaviors of nocturnally migrating birds and bats?
- How well does Doppler weather (otherwise known as NEXRAD) radar work, and what other tools are available to validate this technology?
- Can radar determine site-specific passage rates, specific relative abundance, flight direction, and altitudes of migrants?
- How much will using radar(s) cost?
- For what purpose(s) can the resulting information be used? Can radar data be integrated and used as a problem-solving tool?

While the answers to many of these questions appear daunting, radar is becoming an extremely important tool that can help in avian and bat conservation, as we have heard from experts in the radar field during this workshop. For example, radar can help to:

- Provide site-specific information on bird, bat, and insect passage, and on their flight characteristics
- Provide information about where trans-gulf migrants touch down once they reach land
- Detect “targets” in moderate precipitation (U. S. Fish and Wildlife Service, 2005)
- Determine when not to fly in a Military Operations Area
- Provide information about direction, distance, height, ground speed, density aloft, habitat type preferences, avoidance, response to barriers, and weather conditions present
- Provide information on feeding ecology, including for example how waterfowl use agricultural lands and how bats exploit insects on the wing over agricultural fields
- Provide NEXRAD weather radar data for the wider use of the biological community, including the development of “intelligent algorithms” (models)
- Provide important information on the functional use of landscapes and unobstructed airspace for migrating wildlife
- Identify important stopover habitats both for birds and bats
- Determine how “flying vertebrates” use ridges and mountaintops

Fulfilling Management Needs

Radar can provide necessary and important information to land and resource managers. This information includes, but is not limited to:

- Protecting important stopover sites and habitats based on how the habitats are being used by migrants

- Identifying critical or key stopover habitats
- Locating important resting, feeding, roosting, loafing, staging, breeding, and related areas for "flying vertebrates"
- Extrapolating from radar research findings to recommend the most bird- and bat-friendly sites for placement of wind turbines, communication towers, power lines, and building development
- Reducing the threats of bird/aircraft collisions
- Evaluating the benefits and uses of Conservation Reserve Program lands both by birds and bats
- Determine where not to build, construct, develop, or exploit
- Monitor the effects of habitat restoration based on increased bird and(or) bat use
- Assess the effects of climate change on bird and bat migration patterns

Radar, however, is not the "silver" or "magic" bullet. As a technology, it will not solve all our problems. NEXRAD, for example, provides a broad-scale, coarse view of the spatial and temporal distribution of birds and bats aloft. It does not provide good site-specific information on migrant use of the airspace, especially that occupied by communication towers, wind turbines, tall transmission lines, tall bridges, and tall buildings (Larkin, 2005). Ground-truthing or validating NEXRAD data is therefore very important. This should be done using a variety of tools which include, but are not limited to portable marine radars, thermal imagery cameras, acoustic monitoring, visual observations (for example, binoculars and night-vision scopes), mist nets, and ground-based surveys (for example, transects and point counts).

The Collaborative Effort

Nearly 2 years ago, USGS scientists from the Fort Collins Science Center, the National Wetlands Research Center, the Northern Rocky Mountain Science Center, and the Patuxent Wildlife Research Center initiated this "radar collaborative" with USFWS migratory bird biologists. We since have expanded this effort to university partners, and today we are expanding it even farther. As a followup to a very positive briefing with then-Deputy Interior Secretary Lynn Scarlett in March 2005, with this workshop we are reaching out to our new partners, including MMS, BLM, DOE, APHIS, USFS, USCG, FAA, FCC, industry, consultants, NGOs (nongovernmental organizations), and others. We continue to work with NOAA on analytical software. We are creating artificial intelligence-based filters to separate biological from weather-related radar echoes. We also are developing additional tools to facilitate use of radar data. Last, we are applying these new tools to priority Interior Department and other challenges.

The future of this initiative and collaboration is very bright. It should provide us with the ability to assess the effectiveness of landscape-scale conservation programs and practices. It should provide us with the capability to evaluate avian and bat responses to long-term trends including habitat loss, changes in land use, climate change, and development. It should help raise public awareness through outreach that will help support agency conservation efforts. Finally, it will assess the importance of radar as a tool to help minimize the effects to wildlife trust resources and to their habitats. To help meet these important goals, the collaborative team of scientists from USGS and USFWS has been working diligently to advance this "radar collaborative."

Summary

In conclusion, the Service favors (1) conservation of wildlife in the public trust; (2) development of renewable energy, placement of tall structures, and performance of related activities that are bird, bat, and habitat friendly; and (3) use of informed decisions based on adequate environmental assessment and sound science.

Acknowledgments

We would like to acknowledge the monetary support for the workshop that was provided by USGS Headquarters (Reston), USGS Fort Collins Science Center (Fort Collins, Colo.), and the Lannan Foundation (Santa Fe, N. Mex.). In addition, the involvement of the Workshop Planning Committee members in the planning and implementation of the workshop was invaluable. Finally, without the participation of the speakers and workshop attendees, this workshop and these proceedings would not have been possible.

Abstracts of Workshop Research Presentations

This section provides extended abstracts of the research presentations given on the first day and a half of the workshop. (Presenting Author's name is in bold; full contact information for presenting authors is found in the "Contact Information" section; see "References Cited" section for full reference citations).

Disclaimer *– All presentations at the workshop were for informational purposes only. Neither the USGS nor the USFWS endorses any products promoted during the workshop.*

Primer on Radar Biology and Applications to Conservation Issues

- **Ron Larkin**, Illinois Natural History Survey, Champaign, Ill.

This lecture is based primarily on two book chapters (Larkin, 2005; Diehl and Larkin, 2005). The brief summary here does not do justice to those more thorough treatments of the subject. Because bats make up an unknown and possibly appreciable part of the radar-echo-producing flying animals in many situations, and because arthropods are also often prominent, it is best to speak of radar biology rather than radar ornithology and "flying vertebrates" rather than "birds."

Terminology

Large Doppler radar refers to pencil-beam radars with parabolic antennas commonly called "weather radars." However, to take the current National Weather Service workhorse, the WSR-88D, as an example, the original design was driven by optimum performance when no substantial, visible weather is present. This condition, called "clear air" by radar meteorologists, determined the large antenna size and other pertinent characteristics of the radars. In clear air conditions, "The particulate scatterers in most cases appear to be insects and, less frequently, birds" (Wilson and others, 1980). Thus, these radars are almost always able to register radar echoes from flying vertebrates at a great distance, and the radar horizon often determines their effective range for observing flying vertebrates. The Doppler-measured speed is the radial speed of flying animals, not the speed over the ground, except when the animals are flying directly toward or away from the radar. In general, data from these radars are usually used to describe large-scale patterns of movement because more than one animal or flock usually constitutes an echo, and the large minimum sampling volume (pulse volume) precludes the depiction of detailed patterns. These large radars are not transportable and are operated on fixed schedules not designed for biological studies. However, when such a radar is located where an event of biological interest is "visible" with the radar, it can reveal movement patterns of unparalleled interest at a range of useful scales.

Smaller radars on trucks or trailers commonly are purchased specifically for biological work. They often have short wavelengths (X-band) and are designed around commercial marine radar transmit/receive units. They may or may not have their original antennas, an important determinant of beam pattern and ability to locate flying animals.

Marine radar is not discussed in detail in this lecture because it is the equipment used for gathering data in several other talks at this meeting. Briefly, marine radar "out of the box" rapidly sweeps a beam that is narrow in one direction (1 or 2 degrees) but broad in the other direction (20 degrees or more). Swept horizontally, tracks of animals across the Earth can be plotted with some error if animals fly high near such radars. Swept vertically, height distributions and rates of passage overhead can be accumulated, assuming that the radar is properly oriented with respect to the paths of the animals. Operating marine radars in both modes simultaneously or in quick temporal alternation is advantageous because it permits verification of tracks and heights of the same populations. In situations in which the taxonomic identity of the echo-producing animals is not known by other independent techniques, marine radar "out of the box" is poor at any but the coarsest taxonomic distinctions. Marine radars may also be fitted with different antennas selected for more precise biological work.

Stationary-beam radar refers to a different strategy of collecting data on flying animals, namely keeping a narrow radar pencil beam fixed in position while birds, bats, and arthropods pass through it. Similar to vertically-scanning marine radar, the direction of travel of flying animals cannot be measured without additional data. Because of the narrow beam, sample size is small when flying animals are sparse. But, in general, the narrow beam gives usually precise, three-dimensional location information on each flying animal or flock, information that can be assembled into a picture of temporal variation in height and density of movements. Also, when animals are slow enough or far enough distant from the radar to remain in the beam more than about a second, wing beats and other motions of the animals can be recorded as rapid fluctuations in the strength of the radar echo, permitting some estimation of target identity. Variations on this technique include conical-scan radar, with a beam motion that describes a narrow cone overhead.

Tracking radar follows one radar echo (one animal or a closely spaced flock) in three dimensions automatically. It is a specialized technique useful for very detailed characterization of the three-dimensional path of an animal and calculation of airspeed and heading by comparing animals' tracks with those of radar-tracked ascending balloons. Because the antenna of a tracking radar aims directly at the “target" being tracked, a long record of wing beats can be recorded and analyzed. Of course, the number of animals that can be tracked is limited when each individual animal is tracked for long periods.

In the future, novel kinds of radars will enter the picture, such as tiny (size of an oatmeal box) vehicle radars and smart, distributed meteorological radars.

Wavelength

The body length or wing length of a bird or bat is similar to the wave length of radars used to observe birds and bats in flight, a special domain of reflectivity called the Mie region. Rather than simply reflecting radar energy back to the radar, the bodies of birds and bats interact with the similar-size radar waves in complex ways. Not only is the relationship between bird (or bat) body size and strength of the radar echo from the animal not linear, larger vertebrates do not necessarily yield stronger radar echoes. That non-monotonicity greatly complicates the job of discriminating different taxa, even different phyla, of flying animals.

The wave length (band) of a radar does make a difference, but the difference is seldom critical to the outcome of research using radar on flying vertebrates. Longer wave lengths such as S-band penetrate dense clouds and hydrometeors better than shorter wave lengths such as X-band. Shorter wave lengths are more prone to confusing arthropod echoes with those of vertebrates. However, in most other respects, radar wave lengths used in biological work are less important than other radar specifications such as pulse length and polarization.

Aspect

Unlike raindrops, snow, dust, chaff, seeds, and other inanimate airborne objects, flying animals often orient collectively. Because a collection of such co-oriented flying animals reradiates radar microwaves with different efficiency in different directions, a radar among them receives more echo in some directions than others, an unambiguous sign of flying life. Bodies perpendicular to the radar beam reflect the most energy. The resulting distribution of echo around a radar shows stronger echoes perpendicular to the collective body orientation of the flying animals.

The Size of the Earth

Depending on atmospheric conditions, the electromagnetic energy from a radar antenna ordinarily travels approximately straight. Radars with large antennas, which have great range, can easily detect echoes at a distance where almost all flying animals are below the radar horizon and therefore invisible because of the large-scale geometry, not the radar's power or sensitivity. This is the cause of the roughly circular images often seen during nocturnal migrations. It also means that large radars have limited useful range for specifically low-height observations, such as birds and bats interacting with wind turbines and birds taking off from migratory stopover.

Biological Details

Study of flying vertebrates with radar must contend with a large and varied aerial arthropod fauna, especially migrating insects. Examples are given of insect movements in cold months (early March in Illinois) as well as in warm months. Other kinds of confusing radar targets (see Larkin, 2005) are illustrated, including intrusive ground clutter from "X-band soybeans" in a field setting that was otherwise almost featureless.

Flying vertebrates rising from different habitats in the agricultural Midwest after presumed spring migratory stopover illustrate the potential of an X-band short-pulse stationary-beam (pencil beam) radar in studies relevant to conservation of migrants. In a 30-minute period at dusk, more than twice as many flying vertebrates passed through a conical volume north of a wooded patch as through an equal volume north of barren row-crop fields. (No attempt was made to ascertain if the conical volume being monitored was on the actual takeoff trajectories of most of the birds and bats inhabiting the wooded patch, or was merely in its vicinity.) This work was carried out with Dr. Robert Diehl, now of the University of Southern Mississippi.

A computerized animation of vertebrates and insects passing through such a stationary beam shows the potential of automated data collection combined with the pinpoint precision of a small stationary-beam radar. Individual animals with obviously different wing-beat frequencies are automatically labeled and registered as their radar echoes appear, wax, wane, and disappear again. Figures 7 and 14 in (Larkin, 2005) show “targets” passing through a radar beam and showing wing beats, but without animation.

This research was performed with the assistance of the University of Illinois, Federal Aviation Administration, National Science Foundation, U.S. Fish and Wildlife Service, State of Illinois, The Nature Conservancy, and Chicago Wilderness. Gillette Ransom and Lisa Pasquesi generously permitted field work to be performed on their property.

Broad-Scale Habitat Relations for Birds

- **Wylie C. Barrow, Jr.**, and Lori Johnson Randall, USGS National Wetlands Research Center, Lafayette, La.

The Need for Broad-Scale Research

All migratory birds in North America are designated as trust species and are managed and protected by the Department of the Interior as mandated in the Migratory Bird Treaty Act of 1972. There is now compelling evidence that the populations of many of these trust species have declined over the past 40 years due to a variety of disruptions (for example, habitat conversion, pollution, invasive species) occurring throughout their geographic range (Askins, 2000). Migratory birds are likely to encounter increasingly altered landscapes on their coastal stopover and wintering grounds because of two broad-scale phenomena: human development of habitat associated with rapid expansion of human populations in coastal regions (National Oceanic and Atmospheric Administration, 1998), and projected changes in habitats due to disturbances (for example, hurricanes, fire, and invasive plant species) associated with climate change (Emanuel, 1999; Dale and others, 2000; Webster and others, 2005).

Our Approach

The U.S. Geological Survey (USGS) recognized the need for new research tools that allow biologists to study complex bird/habitat interactions at broad spatial scales. In 2004, the USGS funded a pilot study to work collaboratively with the University of Southern Mississippi (R. Diehl) on the development of software tools that facilitate use of radar data to estimate bird densities. Because biologists are faced with the challenge of determining the identity of radar echoes, we decided to begin this project by improving upon existing methods used to discriminate between birds and insects. We are now applying these algorithms to all subsequent research that uses data generated by the National Oceanic and Atmospheric Administration's Weather Surveillance Radar-1988 Doppler (WSR-88D) network.

Gulf Coast Joint Venture. The next step was to demonstrate how radar data could be coupled with Geographic Information System (GIS) land cover data to determine landscape-scale habitat relations for migrants using Louisiana's imperiled coastal zone. As a result, an alliance with the Gulf Coast Joint Venture was formed to support their conservation planning activities for waterfowl, passerines, and colonial waterbirds. Our initial research has focused on understanding nocturnal feeding flights of wintering waterfowl. Preliminary results from the winter of 2004–2005 demonstrated that WSR-88D radar echoes could be attributed to large numbers of mixed species of waterfowl that make daily flights between roosting and foraging sites. These mixed species flights were corroborated by direct visual observations near sunrise and sunset and by radiotelemetry. Radar proved to be a useful tool for monitoring these feeding flights because most of the daily feeding flight activity occurred under darkness when direct visual observations were not useful.

U.S. Fish and Wildlife Service. In 2005, during autumn migration, Hurricanes Katrina and Rita wreaked havoc on the Louisiana coast by toppling forests over vast areas and by stripping away canopy foliage, vine tangles, epiphytes, and the associated insects and fruits that migrant landbirds depend on. At the request of the U.S. Fish and Wildlife Service, we used archived WSR-88D radar data before and after Hurricane Katrina to assess the immediate effects of the hurricane on autumn migrants. Response of migrants stopping over in the bottomland hardwoods of the Pearl River Basin just after Katrina's landfall and up to several weeks after hurricane passage was to increase their use of the surrounding less-disturbed, pine-dominated woodlands. At about 5 weeks post-Katrina much of the surviving forest canopy in the Pearl River bottoms began to sprout new foliage, and we observed a corresponding increase in migrant use of the bottomland hardwood forest.

U.S. Department of Agriculture. In 2005, the National Wetlands Research Center radar laboratory entered into agreements with the Farm Service Administration (FSA) and the Natural Resources Conservation Service (NRCS), Agriculture Wildlife Conservation Center, to provide science support for assessing migratory bird use of sites enrolled in conservation programs authorized by the Farm Bill. The USGS–FSA partnership is using a portable marine radar to assess bird use of Conservation Reserve Program (CRP) sites in the Mississippi River alluvial valley. The marine radar has a smaller spatial resolution than WSR-88D. These radars can track individual biological targets (for example, birds, bats, and insects) and thus determine use of distinct habitat patches (fine-scale) like CRP fields. Radar surveys were conducted in 2006 during autumn migration and will be repeated during spring migration in 2007. As part of the Conservation Effects Assessment Project–Wildlife Component (CEAP–Wildlife), the USGS–NRCS partnership will gather data and conduct analysis on Wetland Reserve Program (WRP) sites in the Central Valley of California (CVC). This project will assess migratory bird use of WRP sites (for example, use during pre- and post- restoration phases), develop statistical models that aid in restoration planning within a landscape context, and advance data-analysis methods by developing data correction algorithms. The findings from the CVC regional assessment will be used to support U.S. Department of Agriculture national-level reports of conservation activities supported by Farm Bill programs. Output from this effort will also be used to inform the CEAP Wetlands Component.

Use of Radar Data to Support Migratory Bird Conservation

North America is facing global change, such as climate change (and its effects on disturbance events), vegetation redistribution, and anthropogenic changes, especially in coastal areas. Given the scale of habitat changes, there is a general consensus that landscape-level planning is vital to bird conservation. Weather radar data combined with land-cover data at multiple temporal and spatial scales is one way of collecting objective reference data on bird-habitat relation changes in order to support the North American Bird Conservation Plan decisionmaking process.

Nocturnal Migration through the Central Appalachians, with Stopovers on Lower Delmarva

- **Deanna Dawson,** USGS Patuxent Wildlife Research Center, Laurel, Md., Tim Jones, USFWS Atlantic Coast Joint Venture, Laurel, Md., Sarah Mabey, Sweet Briar College, Sweet Briar, Va., and David Mizrahi, New Jersey Audubon Society, Cape May Court House, N.J.

Interest in developing wind power as an alternative renewable energy source has increased in recent years. In the Eastern United States, exposed summits or ridge crests in the Appalachian Mountains have high wind-power potential, and numerous wind-power projects are being developed or proposed. Large numbers of birds and bats are believed to follow or cross these landforms during their seasonal migrations, creating a critical need for information on their distribution and flight characteristics as they pass through the region. We are studying the spatiotemporal distribution and flight patterns of birds and bats that migrate nocturnally through the central Appalachians. The overall objective of the research is to increase our understanding of the characteristics and dynamics of nocturnal migration through the region, so that informed and scientifically sound recommendations can be made to reduce the risk to migrants of proposed and operational wind-power projects.

Data from weather surveillance radar (WSR-88D: NEXRAD) stations (Pittsburgh, Pa.; Charleston, W. Va.; Roanoke, Va.; Knoxville, Tenn.) are being analyzed to document broad-scale migration patterns through the region. Although these radars generally cannot detect birds or bats within the altitudinal zone occupied by wind turbines, and their coverage of the region is incomplete, the data provide information on the densities and movements of migrants as they approach and pass over the Appalachians. Two ground-based techniques are being used to sample the distribution and movements of migrants within the lower airspace. During four seasons (fall of 2005 and 2006, spring of 2006 and 2007) we conducted acoustic monitoring at 29 sites (31 sites, spring 2007) in Maryland, Virginia, and West Virginia, recording the calls made by birds in flight to index their abundance and species composition. At three sites in 2006, we also used portable marine X-band radars to sample nocturnal migration, providing an independent estimate of migrant passage rates, plus information on their flight altitudes and directions. The data collected will be used to model the effects of geographic location, topography, weather, and other variables on migrant abundance and flight in order to identify where and when migrants might be at risk from wind power development. Project partners include the States of Maryland, Virginia, and West Virginia; U.S. Forest Service (Monongahela, George Washington, and Jefferson National Forests); U.S. Fish and Wildlife Service (USFWS, Region 5, Canaan Valley National

Wildlife Refuge [NWR]); The Nature Conservancy (Virginia and West Virginia); and Cornell Laboratory of Ornithology.

In another project, stopover sites in the Lower Chesapeake Bay region, used in fall 2004 and 2005 by passerine birds that migrate nocturnally, were identified from radar data (NEXRAD, Wakefield, Va., and NPOL, a polarimetric Doppler research radar installed at Oyster, Va.). Birds were detected by the radars as they left daytime stopover sites to resume their migration; exit locations were mapped through the season to identify sites that received high or consistent use. Field surveys were conducted on the Lower Delmarva Peninsula to "ground-truth" the radar results. A capture-mark-recapture/re-sight study was conducted on Fisherman Island NWR to collect data for estimation of migrant abundance and nightly exodus; birds also were captured and banded at the long-term banding station at Kiptopeke State Park. Counts of birds were conducted repeatedly through the fall in forest patches in southern Northampton County and in scrub habitats on the Eastern Shore of Virginia NWR. Results will aid in the evaluation of radar as a tool to identify important stopover sites, track bird migration patterns, and provide direct input to habitat conservation programs. Project partners include the Center for Conservation Biology, College of William and Mary; The Nature Conservancy (Virginia Coast Reserve); National Aeronautics and Space Administration (Observational Sciences Branch, Wallops Flight Facility, Goddard Space Flight Center); USFWS (Atlantic Coast Joint Venture, Eastern Shore of Virginia and Fisherman Island NWRs); and the State of Virginia (Departments of Game and Inland Fisheries and Environmental Quality).

Regional Structure in Migratory Patterns across the Southwest

- **Robert Diehl,** University of Southern Mississippi, Hattiesburg, Miss., Rodney Felix, University of Southern Mississippi; and Janet Ruth, USGS Arid Lands Field Station, Albuquerque, N. Mex.

In North America, research on bird migration often occurs at relatively small spatial scales and in idiosyncratic locations, and usually somewhere east of the Great Plains (with notable exceptions, see Lowery and Newman, 1966, Gauthreaux and others, 2003). Probably this is a consequence of both convenience (most migratory biologists work in the Eastern United States) and biology (most migration probably occurs toward the east as well). In the past decade, the physical location of migratory biologists has become slightly less important as the United States established a network of digital weather radars and streamlined access to their data via the internet (Del Greco and Hall, 2003). Moreover, data from these large radars enables migration biologists to increase the spatial scale and geographic variability of their research as well as to generalize across species. Still, the continent-scale bias remains. Our understanding of migratory biology west of the plains remains poor even as concern grows over the fate of migratory birds facing challenges both on the ground from effects on habitat and aloft from the proliferation of tall anthropogenic structures (for example, communications towers, wind turbines). Our radar-based studies of bird migration span the Southwestern U.S. borderlands region from eastern Texas to western Arizona and focus on (1) how migrants' density and movement patterns vary across the Southwest, and (2) whether those patterns exhibit regional or seasonal variability. These large-scale patterns will inform future work to identify habitats preferred by birds during migratory stopover.

Preprocessing and analyzing large volumes of data comprise the bulk of effort in this project and highlight a need to automate as much of this process as possible (Sojda and others, this volume). We retrieved ~200 gigabytes of radar data from seven radar sites across the southwest during spring and fall of 2005. Data dominated by nonbiological echoes, ground clutter, and other sources of "noise" were culled from analysis. Remaining "biological" echoes were again screened for those that were “birdlike.” In areas where topographic relief partially or completely obstructs the radar’s beam, we created spatial filters to retain only uncorrupted data. One-way analysis of variance (ANOVA) was used with Tukey multiple comparison tests to determine whether migrant densities and movement patterns varied across the Southwest.

Overall, migrant densities in spring differed significantly across radar sites with multiple comparisons, showing a downward trend in density from east to west (fig. 1). Spring ground speeds also differed significantly and exhibited a similar downward trend east to west. These patterns were not upheld in fall. In spring, direction of movement was northward with greater variability in direction toward the west. Direction at the easternmost Texas sites, Brownsville and Laughlin Air Force Base, were particularly consistent. The presence of weaker radar echoes toward the west is consistent with migratory birds favoring an easterly passage. However, biological targets in the west also had lower ground speeds (and lower airspeeds) and greater variability in direction. Such patterns are difficult to explain. Most likely, arthropod “contamination” as a proportion of biological echoes is higher in the west, with more bird dominated migrations occurring at eastern locations.

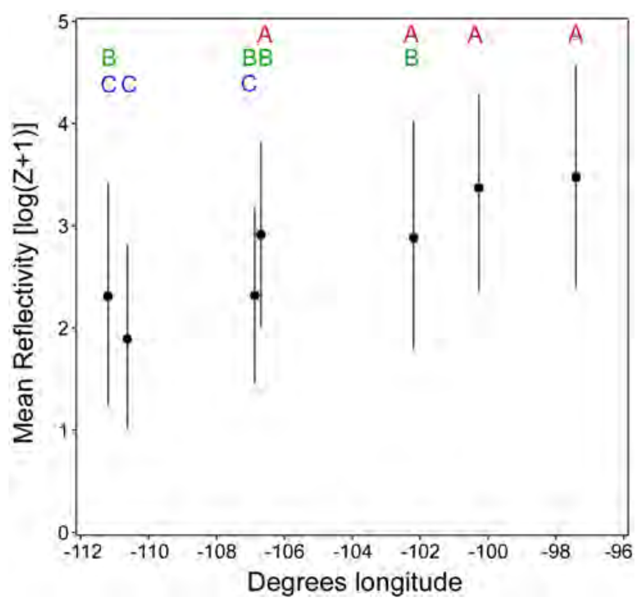

Figure 1. Mean ± SD log reflectivity measured at 33–37 kilometer range at seven radar sites across the Southwestern United States. Data from Brownsville, Tex. (KBRO) are constrained to 270˚ – 330˚ azimuth relative to the radar.

Comment on a New Approach to Modeling Migratory Behavior

- **Robert Diehl**, and Yufang Wang, University of Southern Mississippi, Hattiesburg, Miss.

Spatial irregularities in the way birds occupy habitats during stopover leave a footprint on migrant distributions aloft as seen on weather radar shortly after the onset of migration (for example, Gauthreaux and Belser, 2003b). Increasingly, biologists are exploiting this capability of weather radars to identify habitats used by birds during migratory stopover (Buler and others, this volume). However, weather radars as broad-brush instruments are not designed to detect patterns of echo with high spatial resolution. For this reason, and because birds initiating migration usually become dispersed before detection, weather radars offer a somewhat blurred view of these habitat-migrant associations (fig. 2).

A rich theoretical and empirical literature describes the mechanics and behavior of individual birds in flight (Pennycuick, 1975). However, we have little understanding for how variation in the behaviors of hundreds of thousands of individuals, shaped by heterogeneous landscapes, geographies, and weather conditions, "scale-up" to describe distributions of migrants in the habitat and aloft. Presumably, some combination of habitat preferences during stopover, together with flight behaviors exhibited during the onset of migratory flight, gives rise to the patterns observed on radar (fig. 2, right). Although these radar data do not directly reveal habitat preferences and flight behaviors, the distribution of echoes does constrain the range of possibilities for these behaviors. For this reason, there should be a narrow range of habitat preferences and flight behaviors that, if exhibited, gives rise to the patterns observed on radar. Can we use these radar patterns to determine spatially explicit habitat preferences during stopover as well as flight behaviors exhibited during takeoff?

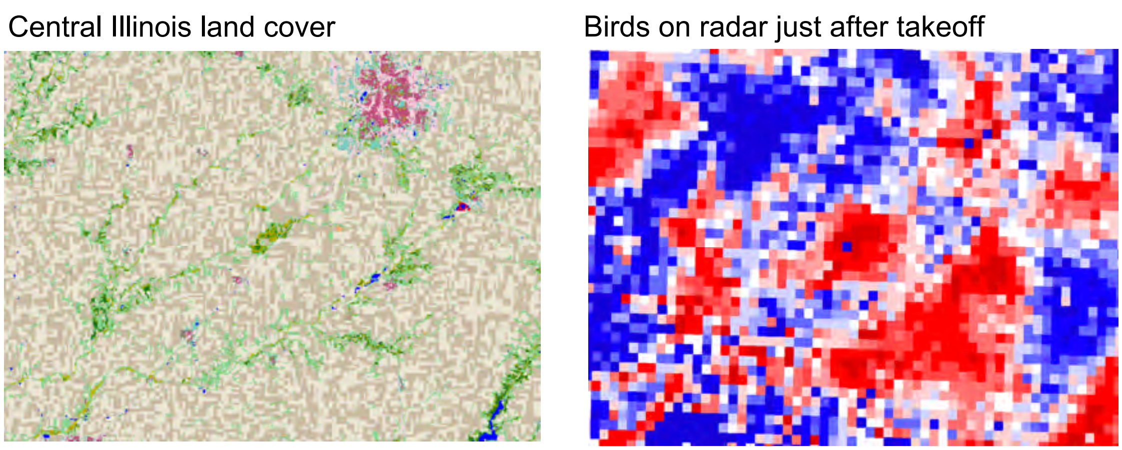

Figure 2. Left – Highly agricultural Illinois landscape where urban areas appear as shades of pink, cropland as shades of brown, grassland as light green, and forest land as dark green. Right – Bird distributions aloft as detected by local weather radar over the same Illinois landscape just after the onset of migration. Higher concentrations of migrants (reds) are generally spatially associated with nonagricultural habitats.

The approach outlined here models 3-dimensional trajectories of birds into the airspace beginning with their distributions in the landscape. This project uses existing weather surveillance radar and satellite-based land-use/land-cover databases, in combination with compute-intensive, spatially explicit, individual-based modeling (IBM) approaches, to statistically converge on avian migratory behaviors which reveal fine-scale habitat-use patterns and migratory exodus behaviors. Software iteratively converges toward model parameters that yield the smallest difference between expected (model) and observed (radar) bird distributions aloft (fig. 3). In the converged model, nearly a dozen parameters describe the behavior of migratory birds before and after the onset of migratory flight. In the scenario depicted in figures 2 and 3, 28,500 birds are modeled occupying and departing an agricultural landscape. In this model, habitat preferences are based on the three dominant habitat types in this landscape: agriculture, grassland, and forest. The dispersion of birds into the atmosphere during takeoff is determined by flight behavior and is presumably less idiosyncratic than the habitats of a given landscape. Parameters of flight most likely to influence distributions aloft include mean and standard deviation in ground speed, climb rate, and direction of travel. In the converged model, birds exhibited a 100:1 preference for forested habitat over agricultural habitat, a ca. 30:1 preference for grassland over agricultural land, departed with a ground speed of 11.0±3.3 m/s, a climb rate of 1.0±0.2 m/s, and direction toward 160±50˚.

These IBMs have wide potential application. (1) As “null models,” they may be constructed to detect and measure behavioral responses to ecologically important barriers to migration, for example from weather, relief in terrain, and large bodies of water. (2) Such models resolve fine-scale habitat use patterns by migrants across large spatial scales. (3) They extend the map of habitat use during migratory stopover to areas outside radar coverage. (4) They allow biologists to estimate what proportion of migrating birds use different habitat types; this could serve as an indicator of habitat importance. (5) As years of data accrue, these models could aid in understanding how large-scale disturbances such as widespread habitat loss/restoration and climate change influence habitat use, timing of migration, and other behaviors.

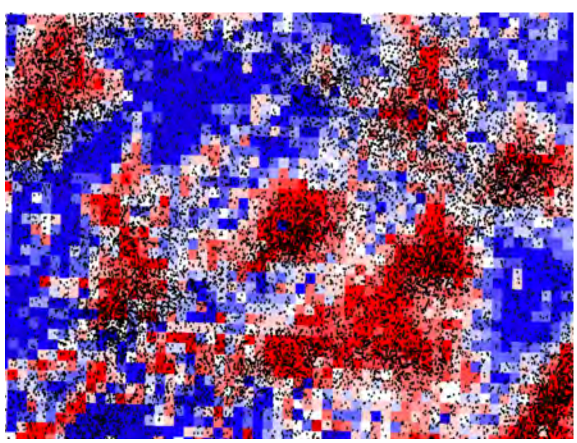

Figure 3. Distribution of model birds (black dots) over radar observations. Highest densities of birds detected by radar (red) are coincident with highest concentration of modeled birds.

Can Artificial Intelligence be used to detect birds in NEXRAD data?

- **Richard Sojda,** USGS Northern Rocky Mountain Science Center, Bozeman, Mont., Rafal Angryk, Montana State University, Bozeman, Mont., Robert H. Diehl, University of Southern Mississippi, Hattiesburg, Miss., Robert W. Klaver, EROS Data Center, USGS, Sioux Falls, S.Dak., Reggie Mead, Montana State University, and John Paxton, Montana State University

We hypothesize that Doppler weather radar data archived by the National Oceanic and Atmospheric Administration (NOAA) for the past 10 to 15 years will be useful in delineating migration corridors, for example, as historically documented for waterfowl. We do not know whether such corridors exist for all birds, and there is evidence that land birds may use large landscapes across broad fronts during their actual migration flights. With NEXRAD data, a handful of expert biologists exist who can visually examine successive images and assess the presence and absence of birds associated with specific landscapes and at specific points in time. It is, literally, an impossible task to have them process all the terabytes of data that have been archived since the late 1980s for all the NEXRAD stations across the United States. We propose to automate the process and to use the power of computing machinery to do the analysis. We will investigate whether artificial intelligence methods can be used to identify the presence of birds in NEXRAD data. If this proves useful, our subsequent research will apply our methods to process large amounts of data in an attempt to better understand 2- and 3-dimensional components of bird migration.

There are a number of artificial intelligence methodologies that are capable of identifying complex patterns from sets of observations by executing a learning process applied to existing, classified data. For example, neural networks have been used in weather forecasting, signature analysis, mortgage application screening, monitoring credit card transactions for unusual activity, air quality forecasting, and so forth. We are unaware of automated methods for recognizing birds in NEXRAD data that have been reported in the scientific literature. However, neural networks have been used to classify clutter (birds and weather) in other radars.

Once NEXRAD data have been acquired, we perform five preprocessing steps on those data: (1) the 0.5° elevation sweep is extracted, (2) the data are truncated at the range corresponding to the maximum distance common to all three base products, (3) the first 20 km of data is removed to eliminate ground-clutter problems, (4) bad and range folded values are removed, and (5) the spatial resolution of pulse volumes is normalized because velocity and spectrum width have smaller pulse volumes than reflectivity. Therefore, an average velocity value and an average spectrum-width value are calculated and associated with a single, related reflectivity value.

Our initial approach has been to process data at the pulse volume level. Individual elevation sweeps can be classified by an expert and designated as being dominated by precipitation, insects, birds, and so forth. To date, only sweeps that are at least 80 percent dominated by a particular designation (using visual inspection) are being used. Every pulse volume contained in those sweeps is then tagged with that dominant classification. The preprocessed and classified training data are then used to build a learning model using a K-nearest neighbor learning algorithm. Each data point (pulse volume) is added to a 4-dimensional coordinate space (range, reflectivity, spectrum width, and mean radial velocity). Test points are classified by averaging the classification of the K-nearest training points in the coordinate space (K can be specified by the user; we have started with K=1). The model is then evaluated using tenfold cross validation. In our preliminary efforts, 21,000 pulse volumes were randomly sampled from four elevation sweeps. The expert had originally classified two of the sweeps as dominated by precipitation and two by diurnal arthropods. Using tenfold cross validation, the algorithm classified 91 percent of pulse volumes correctly. The model required 0.09 second to build and 592 seconds to validate.

The next steps in our research are to generate and organize more training data, moving to the smaller scale of whole sweeps. We plan to experiment with various neural networks and empirically validate which are effective. In the process, we will try methods that exploit the spatial and temporal autocorrelation in NEXRAD data and incorporate expert knowledge into the system to increase model effectiveness. We have yet to work with biologists from the U.S. Fish and Wildlife Service to choose three stations on which to apply our prototype system. Eventually we will work to include both maps and real-time data analysis into decision support frameworks for wind-power projects.

Impediments to our work include finding funding to apply methods to regional and flyway landscapes. Data-storage requirements and computer processing power likely will become problematic as we expand to bigger datasets at smaller (for example, flyway) scales. We support the establishment of a USGS laboratory to develop nationwide training data and have begun preliminary discussions to craft a U.S./Canadian joint effort and database. We welcome opportunities to coordinate NEXRAD analysis with real-time field validation, possibly using portable radars, national wildlife refuge waterfowl fly-out surveys, and other methods.

Incorporating NEXRAD Weather Radar into Migration Studies in the Upper Mississippi River System

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In April 2006 we expanded a study of spring migration along the Upper Mississippi River (UMR) to incorporate NEXRAD radar data collected from La Crosse, Wis., and Davenport, Iowa. Our goals were to (1) contrast and compare the timing, abundance, patterns of habitat use, and physiological condition of migrant songbirds using two different habitats, upland and flood plain forest, at two different locations along the UMR corridor; and (2) understand migratory timing, spatial patterns, and stopover locations and habitats across Minnesota, Wisconsin, Iowa, Missouri, and Illinois. Our objectives were to collect songbird migrant and habitat-use data that would inform habitat restoration and enhancement and other land protection actions. Our southern study site included the area between Andalusia and Oquawka, Ill., and our northern site encompassed the area between Winona, Minn., and Lansing, Iowa. Transect surveys were conducted at both locations from April through May and banding was conducted at 10 locations (5 upland and 5 flood plain) within the northern study site during the same time period. Preliminary findings suggest that birds use habitats within the river corridor differently. More individuals and more species of neotropical and short-distance migrants were detected in flood plain forests than in the adjacent upland forests. Similar numbers of resident birds were detected in flood plain and upland forests. Radar data suggested two peaks of migration—the first and third weeks of May—at both the northern and southern study sites. Distinctly different species assemblages were captured in the two habitat types. Gray catbird (*Dumetella carolinensis*), northern waterthrush (*Seiurus noveboracensis*), common yellowthroat (*Geothypis trichas*), and song sparrow (*Melospiza melodia*) were captured more often at flood plain sites than upland sites, whereas American redstart (*Setophaga ruticila*), rose-breasted grosbeak (*Pheucticus ludovicianus*), and white-throated sparrow (*Zonotrichia albicollis*) were captured more often at upland sites. Preliminary investigations of blood plasma metabolites indicated that birds captured in the flood plain had higher levels of triglycerides and lower levels of beta-hydroxybutyrate than birds captured in the uplands, indicating that birds in the flood plain were actively migrating. Initial comparisons of ground-based data with NEXRAD data yielded mixed results. Waves of migration were detectable with NEXRAD and corroborated by capture rates at banding stations, but preliminary results comparing transect data with radar imagery captured within a few hours of sunrise prior to transect surveys were not correlated. Data analyses are continuing and include a more thorough investigation of the NEXRAD data at several periods during the evening migration in relation to the transect survey data. Our results suggest that the Mississippi River flood plain forests are important to migrating birds and that the peak of migration along the river ranges from early to mid-May. NEXRAD data have the potential to help us better understand the timing and spatial patterns of migratory flight and to pin point important stopover habitats within the areas covered by radar systems.

The Use of Thermal Imaging and Vertically-Pointing Fixed-Beam Radar to Quantify Bird Movements Displayed on Radar

- **Sidney A. Gauthreaux, Jr.,** and Carroll G. Belser, Clemson University, Clemson, S.C.

The displays of bird migration at night on WSR-88D have been quantified (Gauthreaux and Belser, 1998, 1999a), but the quantification of displays of bird migration arriving on the northern coast of the Gulf of Mexico during daylight hours in spring is a challenge because many of the birds are in flocks that vary greatly in size. In an effort to quantify the displays, we used a technique that combines two different approaches: high resolution vertically-pointing fixed-beam radar and thermal imaging. This system can be used to obtain accurate computations of migration traffic rate (the number of birds crossing a mile (1.609 km) of front per hour) for altitudes above 30 m (Gauthreaux and Livingston, 2006). The thermal-imaging camera (TIC) provides data on radar echo identification (migrating birds or insects), flight characteristics (wing-beat patterns), direction of movement, and flock size, and it can detect individual birds out to a range of 2–3 km (depending on weather conditions). The vertically-pointing radar (VERTRAD) is used as a range finder and measures the altitude of a target. Additional details of the system are found in Gauthreaux and Livingston (2006).

To quantify the displays of arriving trans-gulf spring migration on weather surveillance radar (WSR-88D, or NEXRAD) we extracted the number of birds passing through the sample volume of the TIC above 250 m when clouds were not present. We recorded the altitude of each individual target or flock. Most of the targets detected below 250 m were excluded because we did not want local foraging birds to be included in the samples. Because the diameter of the cone of observation increases with altitude, correction factors were applied to each bird (based on its altitude) to equal the number of birds at a 1-mile diameter (1.609 km). We computed the migration traffic rate (MTR)—the number of birds crossing a mile of front (1.609 km) per hour—and converted MTR to a density (birds per km^3), by dividing MTR by the radial velocity (km/h) of the migrants measured in the base velocity product of the WSR-88D.

To relate data gathered with the VERTRAD/TIC to the WSR-88D data we sampled that portion of the WSR-88D display over the VERTRAD/TIC site on the upper Texas coast near the entrance to McFaddin National Wildlife Refuge. We used the Lake Charles, La. (KLCH) radar when it was available and the Houston, Tex. (KHGX) radar when KLCH was not operational. From KLCH we collected radar reflectivity data (dBZ values) from a total of 25 pulse volumes between 90 and 94 km along five radials centered on the radial at 240°. From KHGX we collected radar reflectivity data (dBZ values) from a total of 25 pulse volumes between 99 and 103 km along five radials centered on the radial at 73°. We transformed the relative reflectivity (dBZ) data into mean reflectivity (Z). Mean Z values were computed for the 25 pulse volumes and then fit linearly to the bird density values from the VERTRAD/TIC data by using JMP software (release 5.0).

The relationship between the density of birds and mean Z values (reflectivity) is highly significant ($P < 0.0001$), but the variation in bird density accounted for only about half the variance in mean Z values ($R^2 = 0.5033$). Several factors may contribute to this. Flock sizes varied greatly, and in dense flocks some birds may have blocked other birds so that reflectivity was not proportional to the number of birds. Not all individuals in a flock were detected in the TIC because not every individual in a flock passed through the cone of observation. Because the altitude of the radar beam of the WSR-88D changes depending on atmospheric conditions and the land/water interface, the exact altitude of the radar sample may have changed depending on atmospheric conditions. Low-flying birds (below 500 m) were probably missed by the WSR-88D samples taken at ranges of 90–94 km from KLCH and 99–103 km from KHGX, and very high-flying birds above 3 km detected by the WSR-88D likely were missed by the TIC. Not all of the targets aloft are birds, and high-flying insects may have contributed to reflectivity values on the WSR-88D but would not have been included in the VERTRAD/TIC data. Future studies will be made at a site that permits better overlap of the VERTRAD/TIC and WSR-88D data.

Applications of Pencil-Beam and Tracking Radar to Understanding Flying Biota

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This presentation concerns X-band radars that are short range and thus can emit pulses rapidly because echoes from targets of interest return quickly. These radars have narrow, symmetrical beams that can pinpoint one flying animal in space. During the time an animal is in the radar beam in stationary-beam mode or while being tracked in tracking mode, changes in body conformation and wing beats associated with flying produce variations in the amount of energy returned. The resulting time series of echo strength, with a fundamental rate of fluctuation often ranging from 2 to about 30 per second, has been termed a "wing beat signature" for several decades. However, simple analyses of the overall rate of fluctuation, performed by Fourier analysis or by filtering the time series and counting major waves, were shown to be largely incapable of discriminating species at a 1972 conference at Clemson University.

Counting waves in the time records, Larkin and colleagues in Illinois categorized echo time series from tracking radar in eastern North America into "vertebrate-like" (recognizing that bats as well as birds migrate) and "non-vertebrate-like" (unidentified targets, mainly arthropods, insects). The latter group show low-amplitude fluctuations presumably related to their hard body surface and largely radar-transparent wings. Their wing beats are variable but predominately higher than about 26 per second. (60 per second electrical noise was nearly absent from the records.) Flap-coasting targets, which probably include many small birds, range from 10 to 20 per second. Steady-flapping targets were mostly 8 to 13 per second. Multiple targets (two or more flying animals) had fluctuations spanning the range of vertebrate echoes, though concentrated in the 6 to 16 per second range.

We used three modern techniques of analyzing these frequencies. Ensemble (short-term) Fourier transforms and S-transforms are based on the mathematics of sine/cosine waves. These techniques assume a long data set, a stationarity, and a fundamentally linear process generating the series (Huang and others, 1998); they failed to provide a precise indication of wing beats, probably because the tracking radar data did not meet these assumptions. Empirical Mode Decomposition (EMD) was designed to characterize time series without imposing the assumptions, by finding modes of oscillation empirically (Huang and others, 1998). Unfortunately, because the tracking-radar time series are not sinusoidal oscillations, EMD also failed to characterize them.

Time series of flap-coasting targets show non-sinusoidal but highly regular oscillations. An example time series is presented with peaks (maxima) at the wing-beat frequency of a small bird, with a standard deviation of 6 milliseconds. The S-transform finds the first harmonic of the wing-beat frequency, not the frequency itself.

Autocorrelation, a method of analysis that remains in the time domain rather than assuming sinusoidal oscillations and presenting results in the frequency domain, identified the period of the wing-beat frequency with high accuracy in many cases, including wing beats of multiple targets. We are applying time-domain analysis to time series of radar targets in hopes of characterizing them beyond the fundamental frequency of a sinusoidal waveform.

Adapting a Military Tracking Radar for Ornithological Research—The Case of the "Superfledermaus"

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This is an extended summary of a one-hour presentation given at the workshop. Reviewing the main steps of development of radar applications in Europe, it aims at providing access to the cited original publications. Many of these publications are available as PDF-files on the following Web site: *http://www.vogelwarte.ch/*. Click on "Infonet," then "Publications"; enter search word "Bruderer." Many of the papers are in English or have English abstracts.

The "Superfledermaus" and Its Use in Ornithology

Over the last 38 years the German word "Superfledermaus" has become a well-known term in radar ornithology. This term stands for a military tracking radar that is housed in a 5-ton trailer with attachable tent (or container), and is characterized by 3.3-cm wavelength, 150-kW peak pulse power, 0.3-µs pulse length, and a pencil-beam with a nominal width of 2.2°. Automatic tracking is achieved by the beam conically scanning at a rate of about 30 Hz and with an offset of 1° around the optical axis of a parabolic dish antenna, and a distance gate locked on the target. The nominal tracking accuracy is 0.06° in azimuth and elevation, and ±10 m in distance. Minimum distance for detection is about 100 m, maximum range for tracking a single chaffinch (*Fringilla coelebs)* in tail-on view (that is, with minimal radar cross-section) is 4 to 4.5 km. Used in a fixed-beam mode (and with improvements on the receiver side, see below), the maximum range increases to 7 km for small passerines seen from below or from the side.

The "Superfledermaus" became the standard radar for tactical air defense in the Swiss Army from 1963 onwards. For military surveillance, the radar could either cover a chosen sector by rapid vertical scanning or it could use the so-called "helical searching," the beam rotating as in airport radars, but scanning different elevation angles in a sequence of rotations, thus providing additional height information. It was equipped with MTI (Moving Target Indicator for electronic clutter reduction) from 1969 onwards, and was gradually replaced by the "Skyguard" radar after 1975. In ornithological research the radar was used without MTI whenever possible. This is in order to avoid reduction of targets with low radial speed, and thus implicitly restricting detection to targets exposing reduced radar cross sections to the radar (when flying toward the radar or away from it). To screen the radar off against ground clutter, a natural or artificial hollow with ideally a 30- to 40-m radius and an altitude of the surrounding dam of about 2.5 m was required. The radar remained the same over the years; only a few modifications were implemented to improve performance for ornithological research. The main modification (in the mid-1990s) was the replacement of the IF-Preamplifier and the additional installation of a Log-Amplifier for precise measurement of radar cross sections. Both amplifiers had improved stability compared to the original ones. The main development occurred with the improvement of the recording system.

From the beginning of ornithological work in 1968, the radar was used for the acquisition of three types of data: (1) data on the quantity and spatial distribution of migrating birds over time; (2) data on the flight paths of tracked birds and wind-measuring balloons (the latter providing information on winds at the altitude of bird flight and allowing calculation of headings and airspeeds of tracked birds); and (3) echo-signatures of tracked targets providing information on the amplitude variation of the echoes, and thus allowing target identification, including wing-beat pattern of birds.

The present paper uses the historical development of the "Superfledermaus" to demonstrate the most important steps of methodological improvements over time, referring to available publications for technical details, and avoiding reference to ornithological results. A methodological overview including other radars is available in Bruderer (1997a), and a summary of major achievements of radar ornithology since Eastwood (1967) is given in Bruderer (1997b). For reviews of our research in the region of the Alps, see Bruderer (1996); for the studies in the Middle East consult Bruderer (1999) and Bruderer and others (2000); data on migration in the western Mediterranean are summarized in Bruderer and Liechti (1999) and Bruderer (2001). Note that the studies with tracking radar were combined with other methods throughout. These methods comprised airport surveillance radar, moon-watching, infrared observations, orientation studies with caged birds, banding, taking physiological data of caught birds, and studies on flight mechanics (for example, using wind-tunnel experiments). The basic methodological outline of the ornithological use of the "Superfledermaus" is given in Bruderer (1971). Major technical progress is included in Bloch and others (1981), Bruderer and others (1995), Liechti and others (1995), and Schmaljohann and others (in press).

Major Steps of Methodological Development

1968–1970:

Quantification of passage was done with a vertical beam and an additional low-elevation beam (perpendicular to the principal direction of migration), this to cover the dead zone in the first 100 to 150 m of the vertical beam. In a first approach, the echoes appearing above a sensitivity time control (STC)-threshold (adjusted approximately to the fourth power law) were counted by eye on the R-scope and recorded orally on tape. In a second approach, we used a continuously moving film to record the Z-modulated R-scope. Thus, we obtained filmstrips showing 4-km range on the y-axis and time on the x-axis (Bruderer, 1971; summary in Bruderer and Steidinger, 1972). Our first method to obtain flight paths was to take photographs of the radar instruments showing the three polar coordinates of a tracked target every 30 seconds, with the date, a running number for each object, and the time as additional information on each photograph. Data analysis occurred by punching the data on punch cards and calculating the flight path (of birds and wind-measuring balloons) with one of the big computers used at that time (Bruderer and Steidinger, 1972). For the recording of wing-beat pattern we modulated a carrier frequency of 400 Hz with the amplitude of the automatic gain control. Thus, we were able to record the fluctuations of the echoes while tracking a target and could actually hear the wing flapping of the birds. This allowed us not only to separate insects and birds, but also to distinguish singly flying birds, two birds, and groups of more than two birds, thus providing information on changes in flocking behavior in the course of the day. We could also show that passerines are characterized by intermittent flapping, while echoes with continuous fluctuations mainly represent waterfowl and waders (Bruderer, 1969, 1971; Bruderer and Steidinger, 1972). In similarly shaped birds the wing-beat frequency decreased with increasing size. A special study was dedicated to calibrate the radar by tracking metal spheres of various diameters and to show the variation of birds' echo sizes with changing aspect (Bruderer and Joss, 1969).

1971 – 1980:

In order to increase the space under surveillance for the quantification of migratory passage, we started an experiment, using photographic recording of the range-height indicator, the radar beam vertical scanning in a plane perpendicular to the principal direction of migration. A rough analysis of the data showed, however, too many limitations of the new method (Bruderer, 1980). We never proceeded to a serious scientific analysis of data and did not use this method later on. Note, however, that many of the new ship radar studies are based on this method (the fan beams of these radars augmenting the problems).

Improvement of flight path recording was achieved by a multiplex-pulse-length modulation of the Cartesian coordinates provided by the computer of the radar. This allowed recording of the flight paths on the second track of the audiotape containing the echo signatures on the first track. For the analysis, track data and echo signatures had to be decoded, thus being transformed into simple electric signals proportional to the echo amplitude and coordinates, respectively. These signals were on the one hand visualized on 2- or 3-dimensional plotters, on the other hand transferred to an analogue-digital-interface and analyzed in an IBM 3033 computer. For details see Bloch and others (1981).

The interpretation of echo signatures was improved by recording tracked birds and their echo signatures simultaneously on the video and audio track of a video camera, and by using Fourier transformation to analyze mathematically the frequencies contained in the echo signatures and thus to estimate wing-beat frequencies (Bloch and others, 1981). In order to increase the number of known wing-beat patterns, birds were released in front of the radar, then tracked visually by the operator sitting next to the antenna, and handed over to the radar operator for automatic tracking before they disappeared from sight (Bruderer and others, 1972). At night the released birds were made visible for optical tracking by the luminescent substance "Cyalume" (Bruderer and Neusser, 1982), first by smearing the substance to the tip of the tail feathers, later by fixing a Cyalume-filled gelatin capsule to a thread and gluing the other end of thread to the base of the tail.

A radar study at an Alpine pass in 1974 and 1975 marks the starting point of a long-term scientific program on the influence of ecological barriers on bird migration. At this site we released not only birds for identification but also some bats; an analysis of the data was, however, only envisaged after a request from outside (Bruderer and Popa-Lisseanu, 2005).

1981 – 1990:

This was the main period of radar studies in and around the Alps (Bruderer, 1996), characterized by the combination of various methods on the same subject (Bruderer and Jenni, 1990). This decade was also the main development phase of mini- and microcomputers. In 1982 synchro-digital converters were connected with the instruments of the radar to digitize directly the polar coordinates given by the position of the antenna and the distance gate. These were first recorded on tape and later analyzed in our first personal computer (PC). In the following year, online transmission to the PC was possible. For the studies in the approach area to the Alps in autumn 1987 we had at our disposal a fully computerized recording system based on an interface sampling the data provided by the radar, and transmitting them to a PC. Flight path data as well as conical scans of the radar beam could be presented on the computer screen. One year later, online presentation of echo signatures on the computer screen became possible. The tracks and echo signatures were also visualized on the traditional plotters as back-up (Bruderer and others, 1995).

Conical scanning at several elevation angles was chosen as the new standard method to measure the number and distribution of birds in a half-sphere of 6-km radius around the radar. Migration traffic rate (MTR) was to be calculated by multiplying the density (birds/km^3) by the average ground speed. The paper by Bruderer and others (1995) explains the procedure of data recording and analysis. In particular it shows quantitatively the effects and the compensation of variations in detection probability with distance, elevation angle, and aspect. Considering this paper when intending quantification of bird migration will help to reduce negligent interpretation of radar data, which unfortunately became too frequent with the off-the-shelf availability of cheap ship radars in recent years.

1991 – 2000:

This decade was devoted to radar studies in the eastern and western Mediterranean. It also comprised the first applied project, an environmental impact study for a planned antenna array of Voice of America and Radio Free Europe in the Arava Valley (Israel), leading eventually to many results providing important new insights into bird migration (Bruderer, 1999; Bruderer and others, 2000). Progress with respect to the quantification of bird migration involved the use of a mathematically exact STC to compensate for the R^4-law up to 3-km range. Two radar stations, one on the Negev Highlands, the other in the Arava Valley, showed that an ideally constructed dam around the radar could efficiently eliminate ground clutter (photographs in Bruderer, 1999; Bruderer and others, 2000). An important step forward consisted in the use of an efficient long-range infrared system, allowing us to cross-calibrate the three counting systems: radar, passive infrared, and moon-watching (Liechti and others, 1995). Directing all three against the moon allowed us to determine the detection range of the two optical systems by radar (roughly 2 km for the moon, 3 km for the infrared, good visibility provided). On the other hand we could show that the operational opening angle of the radar beam within these distances was about twice the theoretical beam width. Mounting the passive infrared parallel to the radar antenna and tracking birds temporally with this device allowed us to switch off the radar transmitter during short periods and thus to show that switching the transmitter on and off did not alter the flight paths of tracked bird, while a strong spotlight had a considerable influence on the flight behavior of the tracked birds (Bruderer and others, 1999). A new presentation of flight paths and wing-beat pattern (figure in Bruderer, 1999) was another step forward.

Toward the end of the decade we compared the passage of migrants across the Balearic Islands and the Iberian Peninsula (Bruderer and Liechti, 1999). The main progress on the technical side was the development of a control program for the radar, allowing automatic searching, target selection, and tracking by the radar (thus avoiding personal bias by the operators).

The interpretation and application of tracking data and echo signatures continued with a comparison of the flight behavior of swallows in a wind tunnel and in free flight (Liechti and Bruderer, 2002). A first publication on the flight characteristics of birds (Bruderer and Boldt, 2001) dealt with radar-measured speeds. A second publication, following in 2007, will deal with wing-beat frequencies.

2001 – 2006:

After having dealt with the barriers of the Alps and the Mediterranean Sea, we continued with the Sahara. The design of the project on bird migration in the western Sahara (Mauritania) provided for two fixed and one mobile radar stations, one of the fixed stations at the coast, another one 500 km inland, the mobile radar moving from the coast about 800 km inland (see *http://www.vogelwarte.ch/sahara/*). The mobile radar consisted of a transmitter-receiver system of the "Superbat" and the antenna moving in the vertical plane only. At the cost of losing the tracking capability, the weight of the array was reduced to less than one ton, and the power consumption to about 1 kW, the whole array together with the recording system mounted on a 7-ton truck. This mobile radar was one reason to revive the old fixed-beam method. Another reason was that the operational range for birds increases from about 5 km in the scanning mode to about 7 km with the fixed beam due to more hits per target and improved data recording and processing techniques. For the quantification of bird migration in the Sahara we continued on the one hand with our established conical scanning method at the fixed radar stations. In parallel we applied the fixed-beam method, but now with fully computerized recording, at the fixed stations as well as on the mobile radar. The fantastic thing compared to the earlier photographic recording is that each target passing through the beam provides its wing-beat pattern. The scanning rate along the beam is 130 Hz, sufficient to detect even high wing-beat frequencies. For each chosen target, the wing-beat frequency is automatically extracted by fast Fourier transformation (FFT) and provided on the computer screen.

Note that even in the desert the radars as well as the recording systems were regularly calibrated. The calculation of MTR runs automatically: STC compensation for the R^4-law is done mathematically in the computer, in the standard case up to 3 km (but adjustable if needed). A subsequent computer program detects all remaining targets and extracts a number of variables for each target. These variables are fed to a program that runs a discriminant function analysis and differentiates between birds, insects and "other signals." The bird targets will be extracted for further use and afterwards corrected for distance, elevation and aspect as previously shown for the conical scanning method (Schmaljohann and others, in press).

Quantification of Bird Migration by Fixed Pencil-Beam Radar

1. We need calibrated radar. We need to know what the radar detects.
2. Energy reflected from various objects is detected by the radar according to the critical signal-to-noise ratio of the system and the equally critical filtering systems of the radar (for example, STC, clutter reduction by MTI or other means).
3. A threshold defines which echo amplitudes enter our sample and are transferred as blips to the radar screen or as pixels to a digital unit.
4. An STC (compensation for the R4-law) is applied to this sample. In the computer the amplitudes per recording cell are transformed into dB-values. The result is standardized echo sizes.
5. At this stage we exclude permanent clutter by a clutter mask and eliminate variable clutter (for example, rain clouds) interactively.
6. The next step is echo identification, discriminating birds and insects, assigning bird echoes to bird classes, and measuring the size of each echo.
7. Quantification then starts with defining the recording area per echo size, based on the known antenna diagram and the empirically established detection range per echo size and elevation of the beam. This includes implicitly the earlier distance correction. Estimating the frequency distribution of different echo sizes provides the possibility to define a mean detection range across the size classes (if not, one defines a mean detection range over all echoes).
8. The next step considers aspect variation with flight directions.
9. We then divide the echo numbers recorded per unit time and distance-interval by the surface of the recording area in each interval considered. This provides us with a migration traffic rate per 1 km^2 in all height intervals of each beam-elevation. Combination of the results from all elevations results in migration traffic rates per height zone.
10. Dividing the MTR (given in bird passage per hour and recording area of 1 km^2) by the ground speed provides densities (that is, birds per km^3).
11. In case of conical scanning, the outcome of the measurements is bird density (birds per km^3), which has to be multiplied by average ground speed to obtain MTR for height zones of 1 km. Summing up all height bands results in total MTR.

Possible Applications

After successful application of our radar and recording system to estimate the potential effects of a huge antenna system of Voice of America and Radio Free Europe in Israel (Bruderer and others, 2000), the system was recently used to study the potential effects of a planned offshore wind turbine park in the Baltic Sea on common crane (*Grus grus*) migration. Other wind turbine projects are envisaged. In this context it is important to note that our system can provide the flight paths and spatial distribution of bird migration in the area of a planned turbine project, as long as the observations are not too severely impeded by surrounding obstacles (for example, by mountains along a narrow valley). It cannot, however, provide flight paths of birds flying through a wind park or passing a single turbine at distances of less than 100 m. It is therefore not a valid tool to see the reactions of single birds in the immediate vicinity of turbines. The same is true with respect to other obstacles. A recent study to estimate the potential effects of a large bridge on bird migration provided the percentage of birds theoretically colliding with a structure of the bridge. After construction of the bridge it would, however, not be possible to document flight paths within the immediate neighborhood of the bridge.

Acknowledgments

The radars as well as considerable technical support were initially provided by Oerlikon-Contraves AG; later we obtained the radars on loan and eventually as a gift from the Swiss Army. In 2005 two additional pieces of apparatus from Contraves complemented our radar fleet. The Swiss National Science Foundation supported most of the scientific projects; the most recent grant was number 31-65349, the Sahara-Project. Jürg Joss was the main mentor for careful data interpretation from the beginning. The development of the recording equipment started with Alfred Bertschi from Contraves, continued with Raymond Bloch, and was led to perfection by Thomas Steuri from 1980 onward. Many students helped with collecting the field data. Members of the radar working group at the Swiss Ornithological Institute, in particular Felix Liechti, were permanent active partners during field work and data analysis. Thomas Steuri and Felix Liechti reviewed the present manuscript.

Application of WSR-88D (NEXRAD) to Quantify Bird Distributions during Migratory Stopover

- **Jeffrey J. Buler**, Robert H. Diehl, and Frank R. Moore, University of Southern Mississippi, Hattiesburg, Miss.

By detecting birds in the air at the onset of nocturnal migration, the national network of WSR-88D (NEXRAD) weather radars is capable of revealing the spatial and temporal distributional pattern of birds during migratory stopover across large geographic areas. We discuss aspects of several research projects for which we have quantified bird densities using NEXRAD data to rapidly assess the importance of stopover sites and to evaluate factors that influence stopover habitat use by migrants at landscape and regional scales. For one project, we identified migrants' use at four radars along the northern coast of the Gulf of Mexico to help guide The Nature Conservancy's efforts to conserve important stopover for birds as part of their Gulf Wings Project. We characterized stopover use into three broad categories based on the seasonal mean and coefficient of variation of radar reflectivity (fig. 4), which is the standard measure of the amount of radar echo caused by targets in a sampled volume of airspace and a relative measure of bird density. These categories distinguish between sites used most consistently and in the greatest densities throughout the season, like extensive bottomland forests along coastal rivers, from sites used in moderate densities and sites where bird densities are the most variable throughout the season, like barrier islands. For another project, we used NEXRAD to quantify relative bird densities within 5-km-radius hexagon landscapes along the Mississippi coast and used linear regression modeling within an information theoretic approach to determine the relative importance of several variables for explaining variation in bird densities. We found that, during spring and fall, seasonal migrant density was greater and more consistent within landscapes with greater hardwood forest cover. Additionally, migrant densities increased with proximity to the coastline during spring.

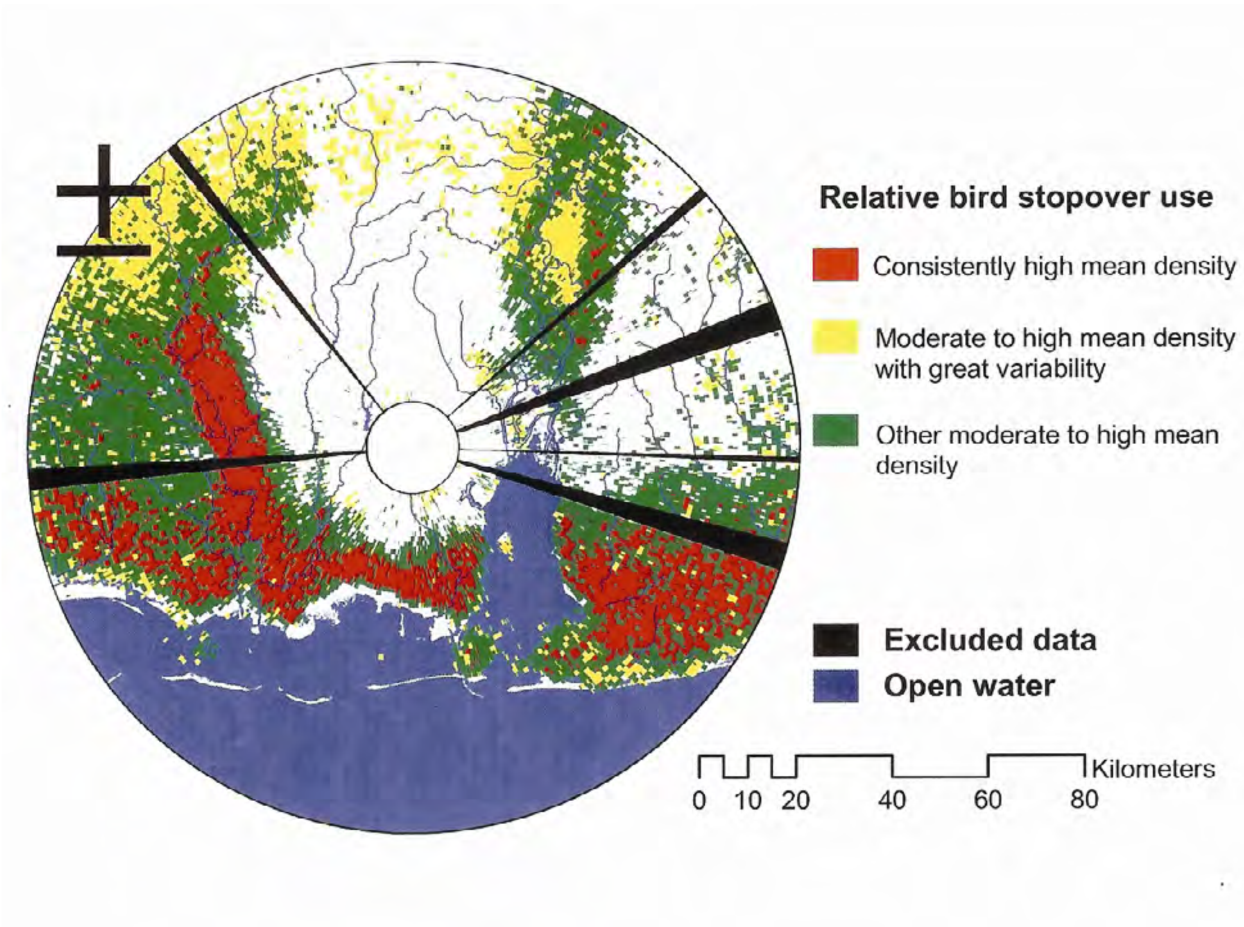

Figure 4. Classified map of relative bird stopover use based on the seasonal mean and coefficient of variation (CV) of radar reflectivity between 10 and 80 km of the KMOB radar in Mobile, Alabama, during spring (n = 17). Red areas with mean ≥ 50th percentile and CV ≤ 25th percentile. Yellow areas with mean ≥ 50th percentile and CV ≥ 75th percentile. Green denotes remaining areas with mean ≥ 50th percentile.

Accurately quantifying bird densities using NEXRAD is challenging due to appropriate selection of data and several sources of bias in the measures of radar data that are introduced by the behavior of migrating birds and the characteristics of how the radars operate. Thus, we also discuss how we have addressed some of these challenges in our analyses. For example, range bias appears as a decrease in radar reflectivity with range from the radar as the beam increasingly passes over migratory birds in the atmosphere. We have developed a correction for range bias by taking into account radar beam geometry and the mean vertical distribution of birds in the airspace that we sampled using vertically-pointed mobile radar on 12 different nights. We are currently developing a new approach to improve objectivity in selecting data for analysis. Ideally one should sample the exodus of migrants from their stopover sites at the same relative point in time for every night and across radars. However, the temporal resolution of NEXRAD is too coarse relative to the short window of time that exodus occurs to accommodate this constraint. By fitting a simple growth curve through mean reflectivities during the exodus period from the initiation of migration to the point where the peak numbers of birds in the atmosphere occurs, we can interpolate reflectivities at any point in time along this “exodus” curve. One can then empirically assess the relative point in time along the exodus curve (cast in terms of the proportion of the peak mean reflectivity) that the strongest migrant-habitat associations occur so that one can objectively sample data at this relative time-point, thereby minimizing sampling noise across nights and between radars. We also demonstrate, using the curve-fitting technique, that there is significant bias in radar reflectivities caused by variation in the timing of the onset of migration due to the passage of the sunset terminator. Thus, this curve-fitting technique can also be used to correct for this sunset bias.

In the future, we envision sharing our analytical techniques and algorithms for accurately quantifying bird distributions with NEXRAD through software that will enable a wider community of interested users to use radar data to study bird migration and rapidly assess conservation needs over broad geographic areas in an efficient, cost-effective manner.

Characterizing Bird and Bat Movement Patterns by Using Portable X-Band Radar

- **David S. Mizrahi,** and Robert Fogg, New Jersey Audubon Society, Cape May Court House, N.J.

Understanding temporal and spatial movement patterns in birds and bats is critical to evaluating mortality risk before constructing tall structures (for example, wind turbines, communication towers) that obstruct flight paths. New Jersey Audubon Society is conducting projects in coastal New Jersey and the mid-Atlantic region's Appalachian Mountains, areas known for high-density bird migration, to assess the potential effects of future wind-power projects. Specifically, our objectives are to (1) quantify nightly and seasonal patterns of bird/bat movements through our study areas, (2) similarly quantify patterns in altitudinal distribution, (3) quantify flight direction and velocity during migration events, and (4) investigate meteorological conditions that might affect migrant flight dynamics and behavior.

To monitor nightly bird/bat movements we use two, simultaneously operating, 25-kW X-band (3-cm wavelength) radars. Each is fitted with a 6.5 foot open array "T" bar antenna that rotates at 24 rpm and transmits an electromagnetic beam 1.23° x 20°. One unit operates with the antenna rotating in the horizontal plane (i.e., parallel to the ground). Data collected in this mode provide target density estimates (that is, birds per unit volume) and direction and velocity of movements. The second radar's antenna rotates in the vertical plane (that is, perpendicular to the ground), which collects data on target altitudes and density.

The radars are configured as "black box" units so that the signal processors send raster image data directly to computers. A frame grabber installed in each of two computers and scheduling software allow us to automate raster data collection. Generally, we collect data during five successive antenna revolutions, every 10 minutes, from sunset to sunrise the next morning (that is, ~360 images/night/radar). At a minimum, data collection occurs during major portions of migration seasons (for example, spring: April 15 to May 31, fall: August 15 to October 15).

Given the volume of data we collect (15,000–30,000 images/season/radar), automated data processing is essential for efficient data analysis. We developed several software programs to automate an integrated data-processing routine that addresses several needs. First, our software uses an entire night's image set to create a stationery target (that is, ground clutter) map. These data are subtracted from images during subsequent processing steps. The program then identifies remaining targets and imposes a 2-dimensional Gaussian transform on them. This smoothes target intensity, which renders a discrete target centroid that is marked.

Using the radar's *x*-, *y*- coordinates and pixel's dimensions, our software calculates a target's *x*-, *y*- coordinates or altitude above radar level, depending on operation mode. The program produces a text file with spatial and signal strength information for each target and a raster image of the processed data file showing all marked target centroids. We analyze text file outputs with software that summarizes flight pattern metrics (for example, target count, mean flight altitude, percentage of targets at or below a designated altitude) at user-defined intervals (for example, 10 minutes, hourly, nightly).

We believe that a dual X-band radar system is an effective tool for evaluating potential collision risk at project scales because it can (1) detect individual bird/bat targets, (2) provide data to estimate target density or passage rates, (3) provide data to estimate altitude, and (4) provide estimates of target velocity and direction. X-band radar, with its relatively short transmission wavelength, also provides good resolution of passerine-sized targets.

Although open array antennas have poor spatial resolution in the 20° beam dimension, the 1.23° dimension provides very good spatial resolution in the horizontal and vertical planes when two radars are used simultaneously. Additionally, automated data collection, raster image processing, and data output validation are attainable. Finally, the overall cost of a fully equipped dual X-band radar system is relatively inexpensive (~$50,000) compared with other remote sensing systems (for example, X-band/S-band system, thermal imaging).

Several issues must be considered when using X-band radars. Target detection is hampered in precipitation (for example, rain, fog) and small targets such as insects are good reflectors of 3-cm wavelength electromagnetic energy. When using a two-radar system, regardless of type (that is, dual X-band, X-/S-band combination), spatial relationships between targets detected simultaneously on horizontal and vertical radars are unknown.

Furthermore, inherent physical properties of radar, regardless of wavelength or system configuration, require consideration. Target detectability depends on reflectivity, the amount of electromagnetic energy returned to the radar's receiving unit after being reflected by a target. Reflectivity is positively proportional to a target's cross-sectional area, which varies with a target's orientation to the radar beam (for example, head-on, profile). It is inversely proportional to the square of a target's distance during both transmitting and reflecting phases (that is, fourth power law). Additionally, reflectivity and consequently detectability are affected by a target's position in the radar beam (that is, central > peripheral).

Given these properties, estimates of target density and altitude must be corrected for detection probabilities. They also make assigning targets to size classes, and thus species groups (for example, waterfowl, shorebirds, passerines), or distinguishing between flocks and individuals problematic. Size, as represented on the radar's outputs (for example, monitor, raster image data), is dependent on reflectivity. Therefore, variation in target distance and orientation relative to the radar can result in different sized targets looking similar on radar outputs.

Although not often undertaken, radar calibration can quantify the relationship between target cross-sectional area and size as represented in radar outputs. Calibration also can quantify how this relationship varies with target distance and its position and orientation in the radar beam. Thus, data derived from a calibration exercise can help inform inferences about target size.

Wildlife Radar Research and Development

- **T. Adam Kelly**, DeTect, Inc., Panama City, Fla.

Bird/aircraft strikes pose a significant safety hazard to military and commercial aircraft, causing over $1.2 billion in estimated costs annually worldwide from damage to aircraft, equipment out-of-service delays, and lost aircraft (Allan, 2000). Even more important are the more than 400 lives that have been lost in bird-aircraft strike related crashes (Richardson and West, 2000). Over 5,000 strikes are reported annually in the United States; however the Federal Aviation Administration estimates that this represents only about 20 percent of the strikes that actually occur (Wright and Dolbeer, 2002). The hazard level is increasing due to increased air traffic and the resulting interactions with birds, necessitating increased and improved control measures.

The United States Air Force (USAF), the U.S. Geological Survey (USGS), the U.S. National Aeronautics and Space Administration (NASA), and other government and private sector groups have various in-house and contract programs to apply meteorology, radar engineering, and remote sensing methods to address bird-aircraft strike threats as well as to support migratory research and environmental assessment of projects with avian issues. This presentation presents an overview and update of U.S. Federal Government bird and bat radar detection programs and contracts on which the author has worked as the principal and(or) research scientist, with specific focus on operational technologies to provide risk-based decisionmaking under short timelines to provide near real-time or real-time information and resulting applications of the technologies for scientific research and environmental studies. Specific programs discussed include:

- The Avian Hazard Advisory System (AHAS) which was developed and is operated for the USAF, and uses the national weather radar network (NEXRAD) to provide near-real time advisories on bird strike hazard risk to U.S. military flying units for low altitude flight routes and bombing ranges for the lower 48 States via the Internet (*http://www.usAHAS.com/*),
- Small Mobile Avian Radar Systems that are used to detect and track birds on airfields and bombing ranges in real time to provide bird-strike avoidance information.

The AHAS System

The AHAS program was established by the USAF in October 1998 to provide U.S. military flying units with a system to provide, in near real time, information on the bird-strike risk for low-level flight operating areas and routes in the lower 48 States (Kelly, 2005). The system downloads the U.S. Next Generation (NEXRAD) weather radar data in real time from all of the NEXRAD sites in the lower 48 States, Alaska, Hawaii, and Guam, processing the data to prepare bird strike risk estimates in near-real time. Users can query the system at all hours through the AHAS Web site (fig. 5) and receive the bird-strike risk rating for a specific route, range, airfield or military operating area (MOA). All radar data handling and image generation is fully automated in a central computer network at the AHAS processing center located in Florida.

The high-resolution 1-kilometer (km) data from each individual radar are merged into a mosaic, which retains the 1-km resolution of the individual radar images and provides three times the resolution of commercially available radar products. Additional safeguards are used in the processing of the data

Figure 5. The AHAS public Web site is located on the Internet at *http://www.usAHAS.com*

to ensure that bird target information is retained, especially in areas where two or more radars overlap. The advantage of a large mosaic is that bird movements can be tracked over long distances, and very long, low-level routes covering hundreds of miles can be evaluated in a single processing step. The mosaics are created in an open raster Geographical Information System (GIS) file format.

To be able to automatically detect birds, weather, and other non-biological targets must be removed from the radar data. NEXRAD was designed to detect weather as this is the predominant target type in the imagery. AHAS uses neural network algorithms to detect and remove non-biological targets from the radar datasets. The neural network algorithms look in a 3-dimensional neighborhood to classify each grid cell as predominantly scattering from biological or non-biological targets. The system is currently being upgraded from Level 3 to the higher resolution Level 2 NEXRAD data (to be operational in 2008).

As NEXRAD can currently only be used to determine the presence of biological targets in the atmosphere, the data have to be weighted for the potential of a serious strike with data that comes from a GIS-based model of known concentrations of birds hazardous to aircraft. These data were derived in the AHAS system from Christmas Bird Count (CBC) and Breeding Bird Survey (BBS) data in the USAF Bird Avoidance Model (BAM), which is used as a GIS-based subset of the AHAS system (see fig. 6). The BAM is also currently being updated to use archive data from NEXRAD to generate a risk surface with significantly less interpolation in space and time than the current BAM version. Such GIS datasets for biological targets have application in other areas of research such as migratory research and risk assessment for projects with bird mortality concerns such as wind farms. The capabilities of AHAS will be further improved and refined as dual polarization data are available from operational NEXRAD radars. The foundations for this transition are currently being implemented as part of the transition of the system from Level 3 to Level 2 NEXRAD data.

The use of algorithms to automatically classify NEXRAD data reduces the risk of bias that can be introduced into the data through manual handling and interpretation of radar data. Such manually induced bias can result from differing levels of experience and expertise, fatigue, and error (Skolnik, 1980). AHAS also does not use wind-speed data to try to eliminate insects from the dataset because the developers concluded that the only unbiased data for winds aloft available was from sounding balloons that are launched just twice a day and therefore lack the required level of temporal resolution. A

Figure 6. USAF BAM Web interface located at *http://www.usahas.com/BAM/home/*

sounding even one hour old is unlikely to still be accurate for either speed or direction of the winds aloft, particularly during the rapidly changing conditions of frontal passages that are known to be related to large bird-migration events. Further, data for winds aloft from radar are frequently contaminated by birds or insects and are thus "auto correlated" and not an independent set of data (O'Bannon, 1995). Discarding radar returns that appear to be moving with the prevailing winds therefore eliminates critical data during optimal bird migration conditions and is not acceptable in a system designed for evaluating the potential for bird/aircraft strike risk. Any insect data that are present in the data within AHAS were considered acceptable by the developers, and any bias introduced is upward and subsequently "errs" on the side of caution with respect to flight safety.

Other research that is currently (2007) ongoing for AHAS is the use of Google™ Earth maps for presenting current, forecast, and historical bird-strike risk data in the low-level airspace along with other datasets such as weather visually through the Internet (AHAS risk information is currently presented in a tabular format upon querying the system through the AHAS Web site). The Web-based visual data presentation allows users to look at 1-km data over a broad geographic area in near real time and provides a much more "user-friendly" interface for delivery of information (fig. 7). The Google™ Earth data-mapping application also is easier to use and more stable than many GIS systems and offers advanced features such as "fly throughs." Such Web-based visualization tools may also have applicability for other wildlife radar applications as previously mentioned.

Small Mobile Avian Radar Systems

Small Mobile Avian Radar Systems (SMRs, fig. 8) are typically based on commercial off the shelf (COTS) or military surplus radars and have been used extensively for ornithological survey and research (Blokpoel, 1976; Cooper, 1995; Kelly and others, written communication, Dare County Range Bird Avoidance Model, 1995; Harmata and others, 1999). Until recently, bird target data from a radar had to be manually identified and counted by an observer watching the screen (Harmata and others, 1999) or by video taping the radar screen and playing back the image on a television monitor (Kelly and others, written communication, Dare County Range Bird Avoidance Model, 1995). Current systems increasingly are using advanced signal processing to track and count biological targets in real time.

Like the AHAS system, automating small-scale bird radars eliminates observer bias between different observers in a research team and allows for data collection over months and years of very large

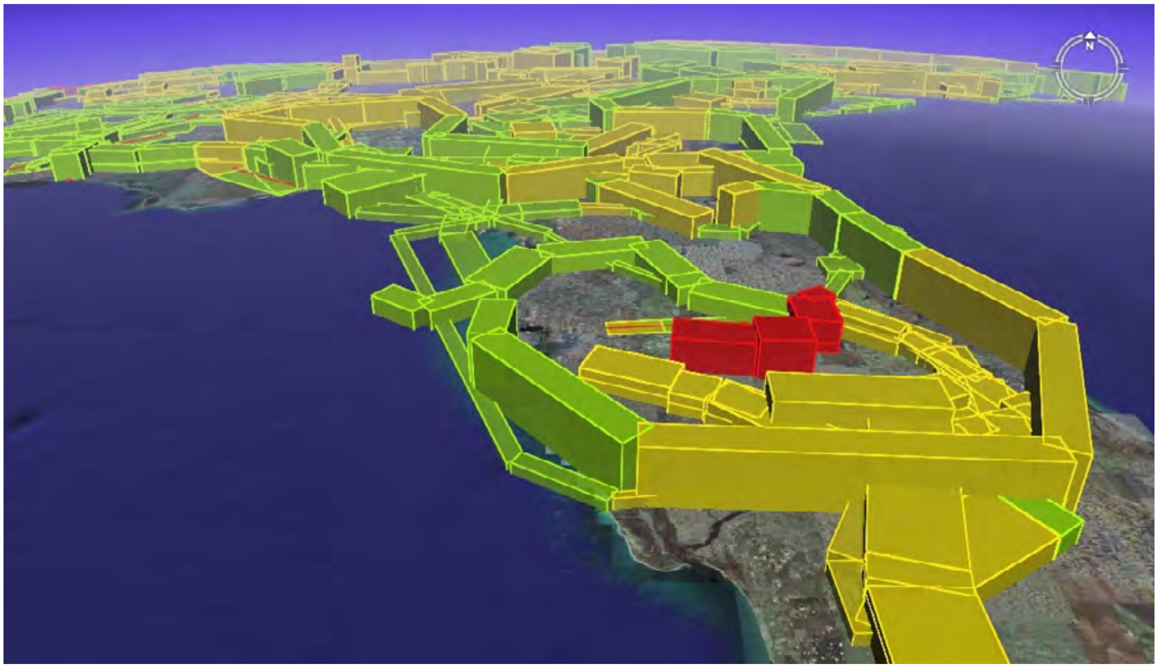

Figure 7. Google™ Earth map from the AHAS system showing the location and height of low-level training routes in Florida and the Southeastern United States color-coded for bird-strike risk. The Google Earth application is interactive and allows the user to turn on/off various data and information layers.

Figure 8. Small Mobile Avian Radar deployed on a landfill, monitoring bird activity on and around the property. This unit uses both vertical and horizontal scanning radars to collect area and height data simultaneously.

data sets including unattended operation in remote areas such as offshore. Ornithological radar also offers several benefits to the study of bird movements as it can sample large volumes of airspace and identify birds of all sizes, well beyond the capabilities of an observer with a spotting scope (Eastwood, 1967; Blokpoel, 1976).

SMRs are currently in use by USAF for detecting and tracking birds around airfields and training ranges for bird/aircraft strike hazard reduction. The coupling of advanced signal processing techniques to COTS radars, as previously outlined, has made possible applications that were impossible just a few years ago. It is in the calibration of NEXRAD radar data where this coupling is likely to become most powerful. Rather than looking at the relationship of bird numbers to dBz values, as has been done in the past, this approach will be used to unlock the potential of dual polarization data (see Schuur, this volume) to monitor different groups of biological targets moving across the landscape. Deploying large numbers of mobile radar systems in the coverage of one NEXRAD radar, such as the experimental dual polarization radar in Norman, Oklahoma, in an orchestrated campaign could provide ground-truthed datasets for many researchers to work from. These data will have great utility in developing target classification algorithms to extract the full potential of the NEXRAD system for monitoring of biological targets. In mid-2006 the technology was harnessed by NASA to detect turkey vultures (*Cathartes aura*) and black vultures (*Coragyps atratus*) prior to launch of the space shuttle to prevent the possibility of bird-strikes damaging the shuttle.

As the technology is further refined and the capabilities of the technology expanded, more applications will be found in scientific research. SMRs have been and are being used extensively for bird and bat surveys for migratory research and environmental studies (Cooper and others, 1991; Desholm and others, 2005). Preliminary data collected by USGS staff from the National Wetlands Research Center in Lafayette, Louisiana, using an SMR demonstrated the ability of the technology to detect and track extensive bat activity over and near conservation resource areas in northeastern Louisiana in the fall of 2006. The preliminary data were presented at a workshop to indicate the potential of these systems to find previously unobserved activity of wildlife. Studies with an SMR at the Tennessee Valley Authority (TVA) Buffalo Mountain Windfarm in Tennessee conducted for the Electric Power Research Institute (EPRI) have also demonstrated the ability of these systems to detect bats near turbine blades with image resolution capable of showing the individual turbine blades in motion—a level of resolution not possible with the standard displays on the COTS radars upon which these systems are derived. This opens up the possibility to better understand the underlying causes of bat collisions with wind turbines.

At 10-cm wavelengths (S-band frequencies), it is now possible to detect and track birds in rain by using advanced signal processing techniques on COTS radars. This further expands the possibilities for the scientific research of bird migration and activity in rain and snow. In the past few years this technology has shown that rain, snow, sleet, and low visibility do not stop birds from migrating or making local flights to roosting sites. Under low-visibility conditions the potential exists for birds to collide with wind turbines, tall towers, and other structures. S-band radar on Small Mobile Radar Systems coupled with visibility sensors offers the opportunity to understand the effects of reduced visibility on the numbers of birds that are active and their ability to "see and avoid" obstacles in their flight path (Kruse, 1996; Larkin, 2000).

Conclusions

Use of radar technology for detection, tracking and study of birds and bats continues to advance as the level of available technology improves and as the number of systems in operation increases, both in research and commercial operation. The use of advanced signal processing, new radar sensors, and new data interfaces will continue to validate and expand the capabilities of the technology as well as reduce deployment costs.

Past, Present, and Future Uses of Radar for Studying Bats

- **Paul Cryan**, USGS Fort Collins Science Center, Fort Collins, Colo.

Approximately 45 species of bats occur in the United States, all of which fly during the night and sequester themselves in cryptic roosts during the day. These habits make bats very difficult to study. Although species diversity of bats in North America is only a fraction of the diversity seen among migratory birds, we know relatively less about the lives of bats. For example, we have only a limited understanding of the seasonal whereabouts and basic habitat requirements of several common and widely distributed bat species in the United States. Such information gaps impede conservation and management assessments and actions.

Radar has tremendous potential for helping to uncover the mysterious lives of bats. The story of bats and radar began with the appearance of strange signals on early weather and military radar systems. Huge colonies of Mexican free-tailed bats (*Tadarida brasiliensis*) emerging from caves in Texas appeared as distinct phenomena on radar. Since the 1960's, data gathered from military and weather surveillance radars in the Southwestern United States have been used to study the flight behaviors, dispersal patterns, and foraging habits of free-tailed bats. Although free-tailed bats are migratory, none of this work was done during migration periods. Prior to the year 2000, few studies used radar to intentionally study migrating bats. However, the emerging problem of large numbers of migratory bats dying at wind turbines (> 500 per autumn at some sites) is driving an urgent need to observe their nighttime behaviors. Wind turbines are particularly affecting a group of migratory bats that roost in trees throughout the year ("tree bats"); these bats appear to be most susceptible during autumn migration. Bat mortality at wind turbines presents a unique opportunity to refine and advance the application of radar technology toward a pressing conservation and management issue. Portable radar systems have recently been used to study flight behavior of nocturnal animals at wind turbine sites, and progress is being made toward learning more about the interaction of bats and turbines (Kunz and others, 2007). However, with the exception of the huge emergence flights of free-tailed bats from known caves in Texas, there are currently no reliable means of differentiating birds from bats by using radar alone. Differentiation of migrating birds and bats by using radar is contingent upon learning more about the behaviors and population sizes of migratory bat species. Our knowledge of how, when, and why bats migrate is extremely limited. There have been no successful attempts to actively pursue bats during long-distance migration flights (for example, more than 300 km) and there is likely considerable overlap in the morphology and flight behaviors of migrating birds and bats. Unknown aspects of bat migration include: timing, degree of aggregation, route specificity, flight characteristics (for example, height, speed, wing-beat rate, climb rate, or changes in track), seasonal variation in behavior, importance of stopover sites, and the influence of weather on movement. Furthermore, very little is known about the population sizes of migratory tree bats; thus, it is difficult to know how many bats might be moving through the night sky at any given time and place. Although the number of bat species that migrate is proportionally low compared to birds, the possibility exists that bats outnumber nocturnally migrating birds in some regions during certain times of year. Clearly more data are needed. Our best chance of differentiating migrating birds from bats on radar may be to use radar, in combination with other techniques, to compare and contrast their respective behaviors. These challenges are daunting, and the most likely path to success is through collaboration. Biologists who study different animals that fly at night (that is, birds, bats, and insects) will likely benefit by openly communicating and integrating their knowledge and experience.

NEXRAD Program Update

- Tim Crum, NOAA/NWS WSR-88D Radar Operations Center, Norman, Okla. (presented by **Terry J. Schuur** in Tim Crum's absence)

Introduction

In addition to meteorologists, ornithologists, and many other non-meteorological disciplines have had a long history of using Weather Surveillance Radar –1988, Doppler (WSR-88D) data for research and specific applications. The National Oceanic Atmospheric Administration's National Weather Service (NOAA/NWS) has made considerable progress in making real-time and archived WSR-88D data more readily available for users. The product data are available in real time at many Internet sites, from private vendors, and at the NWS Radar Product Central Collection Dissemination Service (RPCCDS). The National Climatic Data Center (NCDC) has made its archives of product and Level II data available electronically for FTP download. In 2004, networkwide (134 sites) electronic collection and redistribution of Level II data have made these datasets readily available (Crum and others, 2007) for real-time use and enabled more reliable delivery of data to the NCDC archives. Most recently, the NWS Office of Science and Technology completed the deployment of the Open Radar Data Acquisition (ORDA) upgrade to the WSR-88D systems (Cate and Hall, 2005). This upgrade enables the addition of new technologies (for example, super resolution data, dual polarization) to enhance WSR-88D capabilities.

Planned Changes

Several changes are planned for the WSR-88D during the rest of this decade.

- Beginning in May 2007, the Radar Product Generator (RPG) CPU will be replaced by a LINUX-based PC platform. Among other improvements, the accompanying software, Build 9, implements software that improves range unfolding and reduces Doppler aliasing.
- In April 2008 Software Build 10 will enable generation and collection of "Super Resolution" data. At the lowest two or three elevation angles (depending on scan strategy being used), the azimuthal resolution of all data will be increased to 0.5° compared to the current 1°; the reflectivity data range resolution will be increased from 1 km to 0.25 km; and the Doppler data will be provided to a range of 300 km (230 km currently). The NOAA/NWS is examining how Level II Super Resolution data can be distributed to external users since the bandwidth required for the lower elevation angles data increases considerably.
- Beginning in 2009, the WSR-88D systems will be modified to provide a dual-polarization capability. Among the benefits this change provides will be improved accuracy in radar estimates of precipitation accumulations, discrimination between liquid and frozen precipitation, and classification of radar returns as either meteorological or non-meteorological in origin (Schuur, this volume). Also, the NOAA/NWS is examining how Level II dual-polarization data can be distributed to external users since the bandwidth required, once again, increases considerably.

Additional Information

Many sources of information to help users of WSR-88D data are available on the Internet, such as:

- NCDC Radar Resources: Order Level II and Level III archive data via FTP, use NCDC Java Viewer to view Level II and Level III archive data, and so forth: *http://www.ncdc.noaa.gov/oa/radar/radarresources.html*
- The central database of WSR-88D products is at the Radar Product Central Collection Dissemination Service: *http://www.nws.noaa.gov/tg/rpccds.html*
- RPG Software using a LINUX platform and Level II: The Common Operations and Development Environment (CODE): *http://www.weather.gov/code88d/*
- Level II updates and information: *http://www.roc.noaa.gov/NWS_Level_2/*

Detection of Birds and Insects with a Polarimetric WSR-88D Radar

- **Terry J. Schuur**, NOAA/National Severe Storms Lab, Norman, Okla.

In the spring of 2003, the NOAA/National Severe Storms Laboratory (NSSL) upgraded the KOUN WSR-88D radar, a research and development radar located in Norman, Okla., to include dual-polarization capabilities (Doviak and others, 2000). Dual-polarization radars, otherwise known as polarimetric radars, transmit and receive at both horizontal and vertical polarizations, thereby providing more information on the physical characteristics (that is, size, shape, dielectric constant) of the targets that produce the backscattered signal. Polarimetric variables measured by the KOUN radar, which uses a novel simultaneous horizontal/vertical transmission scheme (Doviak and others, 2000), include radar reflectivity (Z), differential reflectivity (Z_{DR}), correlation coefficient (ρ_{HV}), and differential phase (Φ_{DP}). A complete description of these variables can be found in Doviak and Zrnic (1993) and Zrnic and Ryzhkov (1999). The KOUN radar will serve as the prototype for a polarimetric upgrade on the operational NEXRAD network, which is scheduled to begin in approximately 2009.

For weather radar applications, polarimetric radars provide many benefits over conventional radars, including the abilities to improve data quality through the elimination of non-meteorological artifacts, to discriminate between different precipitation types, and to improve rainfall estimation. The ability to easily identify non-meteorological targets, which are primarily identified through their comparatively low correlation coefficients, is of particular interest to the radar ornithology community. Through the use of "fuzzy logic" algorithms that combine information garnered from all polarimetric variables, non-meteorological categories for ground clutter, anomalous propagation, and biological targets are now being routinely produced as part of the more extensive polarimetric "precipitation classification" algorithm. In the future, this classification product might be used by the radar ornithology community to help extract information on biological targets from operational NEXRAD data.

While work at the NSSL focuses on the development of algorithms to detect weather hazards, a small amount of effort has already been devoted to understanding the polarimetric signatures associated with biological targets. Using data from the NSSL Cimarron polarimetric radar, Zrnic and Ryzhkov (1998) suggested that the combined use of Φ_{DP} and Z_{DR} might be used to discriminate between birds and insects, with birds being characterized on average by large differential phase and small differential reflectivity, and insects being characterized by somewhat smaller differential phase but larger differential reflectivities (see their fig. 2). More recently, Zhang and others (2006) examined the azimuthal dependence of polarimetric signatures associated with biological targets. They found a marked diurnal variation in the polarimetric radar variables with azimuth, which was largely attributed to migrating birds. Bachmann and Zrnic (2006) examined spectral densities of the polarimetric variables. The spectral density analysis, which examined a power density spectrum of all of the polarimetric variables, showed remarkable skill at being able to separate the flight direction and speed of birds from that of insects, as well as from the direction and speed of the wind. While these studies have shown that polarimetric radar data can provide valuable information on the physical characteristics and flight patterns of biological targets, it is also clear that much more remains to be learned. This opportunity will become available on a much wider scale basis with the eventual polarimetric upgrade to the operational NEXRAD network.

Radar Ornithology—The Past, Present, and Future: A Personal Viewpoint

- Banquet Address - Sidney A. Gauthreaux, Jr., Clemson University, Clemson, S.C.

The Beginning of Radar Ornithology

Eric Eastwood (March 12, 1910–October 6, 1981) was one of the first to use radar to study the movement of birds, and many of his studies and those of other pioneers are summarized in his book, *Radar Ornithology* published in 1967. He was elected as Fellow of the Royal Society 1968. In the *Biographical Memoirs of Fellows of the Royal Society,* Vol. 29 (November 1983), p. 177–195, F.E. Jones said the following about Eric Eastwood: "An observation that was to prove of great interest to Eastwood in later years was made by operators at a very early CHL type radar station installed at Happisburgh, on the Norfolk coast. Some echoes were positively identified as coming from a flock of geese crossing the sea. This observation, made in 1940, was the first record of the flight of birds being followed by radar and it led to extensive investigations by Eastwood in later years and to the publication of a book on the subject (Eastwood, 1967)." The CHL (Chain Home Low) radar system was developed to counter the low-level air defense threat to the United Kingdom in 1939.

The WSR-57 Years (1957–1993)

In 1957 the first WSR-57 (Weather Surveillance Radar 1957) radars were placed around the northern coast of the Gulf of Mexico as part of a national network of about 50 units. Nine WSR-57 radars were positioned around the Gulf of Mexico from Brownsville, Tex., to Key West, Fla., to monitor the landfall of hurricanes. The systems were very sensitive and could easily detect very light rain in the atmosphere. As a junior in high school with a deep interest in bird migration, I wondered if these powerful weather radars could detect the moisture in the bodies of migrating birds, and soon discovered that on nights when birds were migrating (verified by moon-watching [Lowery, 1951] and flight call counting), the display of the WSR-57 showed an extensive cloud of snowy targets that disappeared when no migration was underway. I continued to work with the WSR-57 at the New Orleans Weather Bureau during my undergraduate college years (1959-1963) at Louisiana State University in New Orleans (now the University of New Orleans).

During the early 1960s, Frank Bellrose (August 20, 1916–February 19, 2005) of the Illinois Natural History Survey started his investigations of bird migration with the WSR-57 at about the same time that I started my Master of Science thesis research at Louisiana State University in Baton Rouge under the guidance of George H. Lowery, Jr., and Robert J. Newman. I was interested in characterizing the arrival of trans-gulf migrations in the spring and used the WSR-57 at the Lake Charles Weather Bureau in Louisiana for my studies in 1964. While gathering radar data I attempted to identify the sources of the echoes displayed on the radar screen by making observations with a vertically pointing telescope during daylight hours and moon watching at night when the moon was not obscured by cloud during the full-moon period. When the moon was not visible I made observations of migrants passing through the fixed-beam ceilometer at the Lake Charles Weather Bureau. Birds appeared to fly through the beam without deviation on clear nights, and these observations stimulated me to develop a portable ceilometer device that could be used elsewhere on moonless nights (Gauthreaux, 1969). After receiving my M.S. degree in 1965, I continued my studies of the arrival of trans-gulf migration in spring and used the WSR-57 at Lake Charles and New Orleans for my Ph.D. dissertation research at LSU. In addition to gathering data on the diel and seasonal temporal patterns of trans-gulf migration, I also measured the altitudinal distribution and flocking behavior of migrants during daylight and darkness, and quantified the relationship between the amount of reflectivity from migrating birds detected by the radar and the numbers of birds recorded during moon watching (migration traffic rate).

In addition to the quantification of migration using weather surveillance radar, two other discoveries stand out from my dissertation research. The first relates to the geographical locations where trans-gulf migrants stopover after reaching the coast. Prior to my work, Lowery (1945) had postulated that when flying conditions are favorable, trans-gulf migrants continue well inland before landing, creating a geographical zone between the coast and the landing latitude that is empty of trans-gulf migrants—a zone he called the coastal hiatus. Although it was impossible to determine the exact locations where trans-gulf migrants were putting down after flying over the coast and the coastal marshes and prairie because the input of migrants into the stopover areas was a gradual process over several hours, it was obvious from the WSR-57 radar display that the density of echoes thinned dramatically once the latitude of extensive forested land was reached and only rarely did some echoes (flocks of shorebirds?) continue well inland toward central Louisiana before landing. On dates when a trans-gulf flight had arrived in southern Louisiana and weather conditions were favorable for an exodus of migrants, the WSR-57 showed a striking pattern of sudden echo abundance as migrants departed from stopover areas to begin a nocturnal migration 30 to 45 minutes after sunset. For a brief period of time the pattern of echoes from departing migrants delimited the geographical pattern of migration stopover areas within 50 nautical miles of the Lake Charles and New Orleans WSR-57 radars.

The other noteworthy discovery from my dissertation research concerned the 3-dimensional spatial distribution of arriving trans-gulf migrants during daylight and darkness. Trans-gulf migrants generally arrived on the northern gulf coast in species-specific flocks at high altitudes (3,000–6,000 ft above ground level) during the daylight hours, and when arrivals continued into darkness the radar showed that most of the flocks disbanded and the altitude of flight lowered greatly (1,500 ft agl) after dark.

After receiving my doctorate in 1968, I accepted a 2-year post-doctoral fellowship with Eugene P. Odum at the Institute of Ecology at the University of Georgia, continued to use the WSR-57 at Athens, Ga., to study bird migration, and published three papers from my dissertation research (Gauthreaux, 1970, 1971, 1972).

The ASR-4, 5, and 7 Years (1971–1998)

After joining the faculty at Clemson University in 1970, I began to work with the ASR-4 (Airport Surveillance Radar) at the downtown airport in Greenville, South Carolina. This radar had a moving target indicator so that only moving targets were displayed, and it could detect concentrations of migrating birds out to a range of 60 nautical miles. I could not relate levels of reflectivity to density of birds aloft with the ASR-4 because it did not have variable attenuation (only two levels of sensitivity time control). Instead I compared migration traffic rates (moon-watching and ceilometer techniques) with different patterns of echo density displayed on the radar screen (Gauthreaux, 1974). I continued my work with this unit until the late 1970s when the radar was upgraded (ASR-5) and relocated to the Greenville-Spartanburg Airport in Greer, South Carolina. Several years later (from 1997 through 1998) I used the ASR-7 at Howard Air Force Base in Panama to study the raptor migration during the day and songbird migration at night over the southeastern entrance of the Panama Canal and the northern portion of the Bay of Panama.

Mobile Radar Laboratory Days (1980–1991)

In the late 1970s there was great concern about transmission lines and bird collisions, and I was asked to explore the development of a mobile laboratory with radar that could be used to gather data on the flight characteristics of birds near transmission lines during the day and especially at night. With funding from Electric Power Research Institute (EPRI), I built a mobile radar laboratory that had two configurations of 3-cm (X-band) marine radars (Gauthreaux 1985a, b). One was a commercial, off-the-Shelf, 10-kW marine surveillance radar, and the other was a marine radar with a parabolic dish antenna instead of the typical open array antenna (t-bar) of a marine radar. The stationary antenna of the latter system could be directed at any angle from 90° (horizontal) to 0° (vertical). The horizontal beam configuration was able to monitor a corridor similar to that of the transmission line, and the horizontal surveillance radar could monitor movements approaching and leaving the corridor. A night-vision scope attached to a video camera and binoculars or a telescope were used to visually identify the sources of echoes in the fixed-beam radar at night and during the day, respectively. When told by the radar operator that birds were approaching the line and at what range, field observers using only image intensifiers at night saw three times the number of the birds flying toward a transmission line as did the same observers without knowledge of what the radar was detecting.

The Decline of Neotropical Migrants

In the late 1980s the North American Breeding Bird Survey indicated that populations of many species of Neotropical migrants were in a state of decline. This stimulated me to examine if spring trans-gulf migration might also have changed over a period of years. Because the WSR-57 at Lake Charles had a filmed record archived at the National Climatic Data Center in Asheville, N.C., I was able to compare the radar films from the period when I did my dissertation research (1965–67) to a 3-year period approximately 20 years later (1987–89). Because of the limitation of using the filmed record, I could only record if a trans-gulf flight occurred on a date and could not indicate the peak density of the flight. Nonetheless I was able to determine that the frequency of trans-gulf migrations arriving on the southwestern Louisiana coast had declined by approximately 40 percent over the 20-year period (Gauthreaux, 1992). Could there have been fewer flights of greater magnitude? If so, then there would have been no change in the numbers of trans-gulf migrants. To answer this question, additional WSR-57 data were gathered at Slidell, Louisiana, in the early 1990s. I examined the density of flocks on 25-nautical mile range while the radar display on 125-nautical mile range was being archived. I then related the density of flocks to the maximum range of the echo pattern from trans-gulf migration in the archived films and discovered a significant positive relationship between the two (Gauthreaux, 1994). With additional analysis I was able to reject the hypothesis of fewer flights of greater magnitude.

WSR-88D Years (1992–present)

During the 1980s a major event was underway that would have a great impact on the field of radar ornithology in the United States. In the mid-1980s, Ron Larkin began working with Doppler weather surveillance radar (CHILL) in Illinois that was the prototype for the next generation of weather radar (NEXRAD). The new weather surveillance radar called the WSR-88D (weather surveillance radar, 1988, Doppler) was first deployed and commissioned in the early 1990s, with one at Oklahoma City, Okla. (1990), and one at Melbourne, Fla. (1991). Carroll G. Belser and I began our work with the WSR-88D in the spring of 1992 when the first unit was placed on the northern coast of the Gulf of Mexico at Dickinson, Tex., south of Houston. The WSR-88D is more powerful and much more sensitive than the WSR-57. It also has a 1° beam compared with the 2° beam of the WSR-57, and most importantly, it is a Doppler radar. The radar has three fundamental moments: reflectivity, radial velocity, and spectrum width.

For the next few years, we (Belser and I) validated the WSR-88D with respect to bird movements and quantified the base reflectivity displays of bird migration on the WSR-88D radar by comparing bird density data gathered by moon watching with data on maximum relative reflectivity (dBZ) and reflectivity values (Z) in base reflectivity scans at 0.5° antenna tilt (Gauthreaux and Belser, 1998, 1999a, 2003a). In addition to our work on the arrival of trans-gulf migration (Gauthreaux and Belser, 1999b; Gauthreaux and others, 2006), we have used the WSR-88D to quantify and map the post-breeding roosts of purple martins (*Progne subis*) in the Eastern United States (Russell and Gauthreaux, 1998, 1999; Russell and others, 1998). Although much of our work involves migration studies using data from individual WSR-88 stations, we also monitor nocturnal bird migration nationwide with the national network of 154 WSR-66D radars (Gauthreaux and others, 2003). Because the reflectivity resolution cells of the WSR-88D are 1° x 1 km and smaller than those of the WSR-57 (2° x 1.2 km), the process of using the WSR-88D to delimit migration stopover areas is greatly facilitated. Several studies are underway to identify important migration stopover areas and characterize the habitat so that these resting and refueling areas can be protected (Gauthreaux and Belser, 2003b).

High-Resolution Marine Radar (1998–present)

Although I used a 12-kW marine radar in a mobile laboratory for studies of bird movements near transmission lines in the 1980s, in 1998 I developed a mobile unit based on a 50-kW marine radar with a 1-m-diameter parabolic antenna (2.5° conical beam). This unit was flown by the U.S. Air Force to Howard Air Force Base in Panama where I assessed its capabilities for detecting birds and for helping base operations in their bird/aircraft strike hazard program. The unit readily detected flocks of migrating raptors (broad-winged hawks [*Buteo platypterus*]; Swainson's hawks [*Buteo swainsoni*]; and turkey vultures [*Cathartes aura*]) out to a range of 14 km and individual migrating songbirds at night out to a range of 4–5 km. On the northern coast of the Gulf of Mexico, the unit enabled the detection of flocks of arriving trans-gulf migrants in spring at altitudes up to 12,000–15,000 ft (3,657.6–4,572 m) above ground level. It has also been used to monitor raptor migration through the Rio Grande Basin in south Texas in spring. The echo-trail feature of this radar clearly indicates moving targets, and it is possible to measure the ground speeds of individual targets using the target tracking feature. When the antenna is tilted 30° above the horizontal, the altitude of a target in the radar beam is ½ its range; so with this unit it is possible to measure the altitude, flight direction, and ground speed of a target.

Thermal Imaging and Vertically Pointing Fixed-beam Radar (1996–present)

When using an image intensifier, there is always the possibility that the vertically pointing light beam used to illuminate the underside of the migrants aloft might influence their flight direction and attract them to the light beam. To circumvent this possibility we explored the use of a thermal imaging camera. The camera detects the thermal signature of a bird as it flies over, so no source of illumination is needed. For observing migrants aloft we used the thermal camera with a telephoto lens (4.8° field of view in vertical dimension). To determine the altitude of the birds observed flying through the field of view, we used a 5-kW 3-cm wavelength marine radar with a fixed, vertically pointing parabolic antenna (~ 4.0° conical beam). I used a video screen splitter to combine the video image of the display of the fixed-beam radar and video from the thermal imaging camera and used a date and time generator to label the resultant display. The video was recorded on mini-DV digital video tapes. I analyzed video tapes with the aid of a device that makes time exposures (tracks) of the moving targets in the video record. By looking at the tracks it is possible to distinguish birds from insects and obtain accurate numbers and tracks of individuals within the sample volume (circle = 4.82° observation cone). The video frames with tracks can be saved and enhanced to maximize detection of weak radiance signals from high-flying birds. More details are found in Gauthreaux and Livingston (2006).

The Future

The future of radar ornithology will benefit greatly from technological developments related to digital processing and communications. Digital processing of raw radar data reflected from targets and captured with marine radar shows great promise. It is possible to obtain automatically quantitative information on the reflectivity of a target and its variation, target flight direction and velocity relative to wind direction and speed, and target track (for example, Nohara and others, 2005). The technology can also provide information on wing-beat patterns of a target passing through a fixed, narrow, conical beam, and this can be used to help identify the source of the radar echo (for example, insect, shorebird, passerine). Currently it is impossible to distinguish a migrating bat from a migrating bird of similar size, so we must be careful when reporting the identification of radar targets without visual or acoustical confirmation. The more information we can extract from raw radar signals returned from targets, the more likely we will be to narrow down target identification. We must remember to emphasize that careful validation of processors and algorithms with targets identified by some other means is critical to their application in biological research. Unless we know exactly what processing algorithms are doing, we cannot accurately evaluate their performance. There is much to be done in this area.

The application of radar technology to conservation issues has just begun. Weather surveillance radar is already being used to examine the input and output of migrants at stopover areas, and this approach has great potential for identifying the geographical locations of important stopover areas for migrating birds. Future improvements such as dual-polarization for the WSR-88D will help researchers better discriminate insect echoes from those produced by birds in the atmosphere. Studies of migrant stopover ecology with high-resolution radar will aid in assessing suitability of potential stopover habitats because these radars have the ability to detect birds departing from different habitat types. New computer and software tools will make the task of data analysis much easier. Advancements in communications (fiber optic, wireless, and satellite) already allow a researcher to sit at a desk and download data from a remote radar site. Work is underway to link multiple marine radars and fuse the data that each is generating. These are exciting developments that suggest a very bright future for radar ornithology!

Acknowledgments and Credits

For the early mobile radar laboratory, the off-the-shelf radar was a Decca 150 (COTS) and the marine radar with the parabolic antenna was an LN-66 (Canadian Marconi Company). The high-resolution marine radar developed in 1998 (BIRDRAD) was based on a Furuno 2155 marine radar. For the thermal imaging project, the thermal imaging camera used was a Radiance 1 (Raytheon-Amber, Calif.) and the marine radar used in the same study was a Pathfinder Model 3400 (Raytheon Inc., Manchester, N.H.). Our time-exposure device was a Video Peak Store (Colorado Video, Boulder).

Radar Workshop—Key Issues, Themes, and Questions

- Janet Ruth, USGS, Arid Lands Field Station, Albuquerque, N. Mex. and Dave Krueper, USFWS Region 2, Migratory Bird Office, Albuquerque, N. Mex.

Before and during the workshop, both workshop participants and speakers identified and discussed a series of key issues, themes, and questions associated with the application of radar technologies to migratory bird and bat conservation and management. Some of these questions were technical, while others were practical questions that managers need answers to before making management decisions. For ease of discussion, the issues and questions are organized under several general categories. We will present a summary of the discussions that occurred under these categories. Where there was not time or it was not appropriate to discuss an item, it is listed at the end to avoid losing the issue as something important to at least some of the workshop participants. Obviously these categories are not mutually exclusive, and issues discussed in one category may be pertinent in others as well.

Agency Needs and Challenges

This category represents the information required by management, regulatory, and other user agencies, including industry.

There are several types of issues that are currently of importance to user agencies and organizations. They center on the management, regulatory, or business issues currently facing these organizations. These issues include (1) tall structures (for example, telecommunication towers, electric utility structures, offshore oil platforms); (2) wind power; (3) habitat protection and identification of key natural and artificial habitats; (4) assessment of management activities; and (5) bird/aircraft strikes. On these subjects, agencies posed the following question: What radar tool(s) are most applicable or appropriate for providing data on these issues?

Although the needs of agencies and organizations are often very specific to their missions, there were areas of commonality that became obvious in the discussions. Many agencies (USEPA, DOD, USFWS, NPS, BLM) noted their responsibility to protect and manage habitat and their interest in knowing how radar could help them identify key natural and artificial habitats for protection and/or acquisition. Similarly, NRCS expressed their need to assess the effectiveness of their management activities on private lands. Many agencies with regulatory responsibilities (USEPA, USFWS, DOE, MMS, BLM) noted their need for information about the effects of siting facilities of various sorts on migratory birds and bats in order to make scientifically-based regulatory decisions. Agencies such as DOD, which must plan testing and training activities, and industries that build and operate structures with potential impacts, are interested in the same information. BLM was interested in knowing whether radar could help them meet particular monitoring requirements.

In addition to the identification of types of information needs, the user groups frequently expressed the need for specific information on which radar technologies are best used for answering each question. They want to know how radar can help them answer the questions listed herein, but they are overwhelmed by the multiple, complex radar technologies that appear to be available to them. This frustration was frequently expressed as a desire for fact sheets designed to provide clear, short, simplified explanations of the various radar technologies, how they can be used to address particular questions, and which technologies or applications are best used in which situations. See Action Item #4 below.

In response to questions about the applications of various types of radars, researchers offered the following guidance:

- Both large-scale weather surveillance radars (NEXRAD) and mobile radars can be used to develop better maps of bird migration. NEXRAD is better at describing broad, regional patterns, whereas mobile radar is better at addressing site-specific use and movement patterns.
- Participants questioned the applicability of NEXRAD in mountainous areas. In areas where the NEXRAD beam is obstructed by topographic relief, data from higher angles (tilts) of the radar can help determine avian use of montane habitat during migration.
- Mounting a parabolic antenna on a mobile marine radar makes the technology more applicable for biological work.
- Tracking radar units can be used to determine birds' flight paths in relation to barriers and large structures. However, it is difficult to get tracking information in relation to individual structures. Thus, thermal imaging can be more useful in tracking targets near tall structures that may draw tracking radars.
- Interference from wind turbines is NOT an issue when using non-Doppler radar technologies. However, the turbine could still physically block the beam of a marine radar.

The above list of researcher responses is rather idiosyncratic because the focus of this discussion was on the listing of agency needs. However, this information is the sort that is clearly needed by management and regulatory agencies and industry (see Action Item #4).

The user groups also want to have access to existing (especially published) information that is not now available at a single location. It was frequently emphasized that a centralized Web site, where bibliographic information and contact information could be provided, would be valuable. See Action Item #5 below. There has been very little communication between the researchers with the technical knowledge and capabilities and the managers, regulators, and industries who need to be able to use the information produced by technology applications. They frequently do not "speak the same language." In addition, workshop participants thought there was value in ongoing communication, of the sort facilitated by this workshop, to enable researchers to understand the managers' needs and for managers to become "educated consumers" who can clearly and specifically define their management questions and understand the limitations of the research community. There was some discussion about various means of addressing these needs, including the continuation and expansion of the "radar collaborative," and examples of other similar efforts.

Both regulators, and the industries being regulated, emphasized the importance of clear, defendable scientific information on which they can base their activities. They desire certainty and want standardized and accepted protocols and methodologies applied so they know that they are not "comparing apples and oranges" when comparing different study results. See further discussion under Standardization of Protocols, as well as Action Item #1 and Action Item #2 below.

Some representatives from management agencies acknowledged that they have not always been successful at clearly describing and prioritizing their information needs in a way that is useful for researchers. It was suggested that agencies with common management issues work together to improve communication and coordination in this regard. Researchers confirmed the critical importance of very specific questions from managers so that they can design and conduct the required research. See Action Item #3 below.

The user groups also expressed a wish for additional information from researchers about research funding needs and budgets (for example, how much does it cost to conduct various kinds of radar-related research?), funding sources, and partners. They felt that this information was crucial as they determined what projects and approaches were feasible. There were also questions about the pros and cons of acquiring radar equipment and training (developing "in house" expertise) as opposed to developing partnerships with entities that already have these capabilities. Researchers recognized the need for information about costs but emphasized that it was difficult to provide "ballpark" figures because there are many variables to consider (for example, availability of existing data and equipment, researcher time, duration of data collection). Although some project examples and associated costs were mentioned during the discussions, it is not within the scope of these proceedings to provide a sufficiently comprehensive description of the range of cost estimates.

One important clarification that arose from workshop discussions was that, for the most part, researchers do not feel that most user groups need to acquire radar units, nor do they feel that user groups need to acquire the training to operate units or access and analyze radar data. Rather, it is suggested that most user groups (managers, regulators, industry) consider using opportunities such as this workshop as a means to become "educated consumers." This means becoming familiar with the different technologies and applications so that they can communicate with potential collaborating scientists. Researchers would design and conduct studies that provide answers to management questions.

Radar Technology and Applications—Technical Questions and Issues

Workshop participants and speakers identified a series of technical questions and issues that they felt were important to address. Although all of the issues are listed here, some topics were not discussed at the workshop due to time limitations.

Target Identity—"Target" is the term used for any item (meteorological, biological, structural, other) that is recorded by the radar. Therefore, "target identity" means issues related to the ability to identify those targets and "target validation" is identifying the type and number of birds in a radar echo. Target identity questions included the following:

- What radar technologies can help identify individuals, species, or groups of species?
- What are our biological targets?
- At what resolution are we trying to identify targets?
- What is the validity of our identity determinations?

From workshop discussions, it became clear that at the present time we do not have the ability to distinguish targets more finely than to groups of species at best. Both large-scale (for example, NEXRAD) and small-scale (mobile marine) radars are capable of distinguishing birds from insects and from "weather" such as precipitation. There remain problems in distinguishing birds from bats. When bats are foraging locally, they can be identified at times by their erratic flight patterns. But some bats do migrate, and they may do this in a manner much more similar to bird movements, making them difficult to distinguish. At some point in the future, it may be possible to identify smaller groups of birds (for example, waterfowl from shorebirds from passerines) by using flight type, target size and flapping rates, but this capability is still being developed and tested. For example, fixed-beam portable radars do allow for wing-beat analysis to help in target identity.

This discussion included mention of several other issues related to target identity that were not discussed in detail. To summarize:

- There are problems posed by multiple targets. They can create ambiguous signals (several individuals overlap in the radar beam) making individual identification difficult;
- Beam characteristics are important to understand in dealing with target identity;

- The differences in the characteristics of S-band and X-band radar are important in dealing with target identity; and
- There may be an opportunity to take advantage of existing natural history data (range, seasonal distribution, behavior) to help in target identity. At least it might be useful in eliminating some possibilities.

There was also some discussion about the usefulness of gathering a group of experts to talk collectively about difficult radar signals and how to interpret them. Experts would analyze each others' datasets and compare results. The goal would be to refine and perfect interpretations under the scrutiny of experts and in a controlled setting.

<u>Ground-truthing</u>—Ground-truthing is a bit of a misnomer because we may be talking about assessing what is on the ground (during migration stopover) or we may be talking about assessing what is in the air (during takeoff, flight, or landing). What we mean by "ground-truthing" is relating the density of birds leaving a habitat, as detected by radar, to the number of birds observed or netted in the habitat by other means. Regardless of the term used, it will require a multifaceted approach to understand and ground-truth radar signals. Ground-truthing often uses field-based studies to corroborate or provide additional information about radar data analyses results. This may involve a team approach, with targeted people and equipment assigned to ground-truth site-specific data as part of a radar data analyses project. Alternatively, it could involve accessing existing resources and databases of complementary or supplementary "on-the-ground" or "in-the-air" data.

A short brain-storming session identified the following potential sources of "ground-truthing" information, presented in no particular order:

- Point count survey data
- Migration monitoring station data – this might include passerine mist netting and banding or hawk migration surveys
- Wind turbine and tall tower kill survey data
- Acoustic monitoring data
- Radio and satellite transmitter data
- Annual waterfowl, shorebird, and colonial waterbird survey data
- Nontraditional sources such as the new Avian Knowledge Network (Cornell Lab of Ornithology) or information on arrival and departure dates for migrants

<u>Linking Migrants to Habitat</u>—This subject focuses on the challenges of determining migratory bird-stopover habitat relations by coupling radar data with landcover data. Traditionally, this has involved detecting migrants with radar as they take off to begin migration flight and attempting to make linkages, through use of information like GIS and land-cover data, with the habitat from which they have just taken off. This has been successful in identifying important stopover habitats and roosting sites. However, there remain problems and questions associated with how to make these linkages between satellite imagery and radar data. Perhaps the main ongoing problem is that by the time the birds are detected by the radar beam, they are displaced (have moved away) from the source stopover habitat (that is, they do not take off in a totally vertical fashion and therefore are not directly over their habitat by the time they pass into the radar beam). It was also suggested that the location from which birds are departing may not represent the highest quality or actual foraging habitat used during stopover.

Radar Resources Outside the United States—The question raised here had to do with whether there were opportunities to expand collaborations with Mexico, Canada, and Europe to focus on the weather surveillance capabilities there. Obviously the other radar technologies would apply as well. The following information was provided:

- The coverage of weather radars in Mexico is limited. Currently they are not useful in detecting migrating birds, and there are limited opportunities for collaboration. However, there are Mexican scientists who are interested in collaboration and have voiced concern about wind turbine development (example – a project in the Isthmus of Tehuantepec in Chiapas) and expressed interest in the applicability of radar to address this issue.
- The quality of Canadian weather radar in some places, particularly near Toronto, is quite good, and there are opportunities to collaborate.
- In Europe there are three scientific groups that regularly use radar technologies. One emerging group is focusing on the use of radar in applied research contexts. Several contractors are using "off-the-shelf" ship radars in very interesting ways.

Several additional issues were initially identified but never discussed further during the workshop. These included the following: (1) synergistic use of tools; (2) future and new applications of radar—this included interest in the next version of NEXRAD, dual polarization radar, and the new developments of automobile radars (the first two specifically addressed in research presentations and the third mentioned—see Abstracts, this volume); (3) radar systems that could fill in gaps—this included interest in military radars, airport radars, border-region aerostats, commercial Doppler radars; and (4) data processing and management.

Tools and Resources for Managers and Researchers

Software Tools—Most of the software-related questions came from researchers or others who were actually working with radar output data. The general interest among workshop participants was to gain the benefit of the experiences of experts to help them make decisions about what software to use. There are many weather-related or radar-related software packages developed by various sources that can lead to confusion. Some questions were general, and others were more technical. The questions included the following:

- What are the existing software tools and resources that are being used by experienced researchers using radar data?
- What are the most applicable programs for specific problem sets?
- Is there public domain software or open sourcing?
- What do the software packages do (from the manager's perspective and at a level that they can understand)?
- Is there a way to develop a platform for combining and synthesizing multiple platforms?
- The following observations were made about this subject:
- Software programs are often tailored to specific needs and therefore do not lend themselves well to broader or more generic applications.
- Proprietary issues are often a concern, and for the most part software of this sort is not public domain or open sourced.

- NEXRAD Viewer is a free software package that exports data in user-friendly formats. The exported data can be analyzed in GIS and statistical software packages.
- Some people use the Indrisi file format and like it, particularly because it is so stable.
- There are problems related to the software associated with marine radars. It is idiosyncratic and may not be used seamlessly between two different marine radar units.
- The observation was made that most managers do not need to gain a detailed knowledge of how software packages work or what analyses are conducted. Instead, they need to understand in a basic way what the software can do and what its limitations are.

Tools and Resources for Managers—This discussion centered on the recurrent theme of the need for a fact sheet or fact sheets that address different situations or questions with which a manager is faced. It should answer questions about the appropriate methodology for general situations, how the methodology should be used, the contacts for additional information, and first steps to take. See Action Item #4 below. The need for decision support tools was also emphasized. Public land managers do not have the time or the expertise to do the research or analyses themselves.

In addition to the discussion about the need for basic fact sheets, there was another level of discussion about a different kind of document that was needed. There were some who felt the need for a more detailed policy guidance document with specific recommendations and examples. It was suggested that the output from the working subgroups (see Action Items #1 and #2 below) could be used as a source for this larger document. There was not agreement on this suggestion, with some concerns about all the implications of generating and getting approval for such a policy-related document.

Standardization of Protocols

The interest in standardization of protocols stems from concerns related to the many different ways that researchers filter, analyze, and interpret radar data. The general assumption is that these different methods result in comparable data, but this assumption has not been tested and confirmed. Researchers are interested in ensuring the scientific credibility of their results. Additionally, managers, regulators, industry, and developers are interested in standardized approaches whose results will ensure that they are not "comparing apples and oranges" and will enable decisionmaking that stands up to legal and scientific scrutiny.

Researchers recognized this need. They made a distinction between basic and applied research, acknowledging that for applied research, standardized protocols were needed and researchers should come to a consensus. Such standardized protocols are critical for conformity and repeatability. It was noted that, in most circumstances, the goal should be comparable approaches and results. It is acceptable if two researchers obtain the same results by analyzing radar data in different ways. The presentation of results should be comparable between studies so that user groups know how to interpret them. See Action Item #1 and Action Item #2 below.

Collaborative Opportunities

This was a subject that arose multiple times during all workshop discussions and as a result, opportunities for collaboration have been identified at multiple places in this summary. There were also more general discussions about ideas for possible opportunities to collaborate further, either on particular projects or on the larger "Collaborative" effort.

Action Items Endorsed by Workshop Participants

The following Action Items arose from discussions during the workshop plenary sessions. During the final plenary session, these Action Items were presented for discussion and then endorsed by unanimous consent of the workshop participants.

ACTION ITEM #1 – For Researchers (ENDORSED): Establish a Working Subgroup from the "radar collaborative" to address Large-Scale Surveillance Radar Standardization issues.

For purposes of this Action Item, Large-Scale Surveillance Radar is defined as high power, low spatial resolution radar technologies such as NEXRAD (also known as WSR- 88D). The Subgroup's assignment is to address issues related to common or ***standardized metrics*** (that is, making the analyses results comparable) to ensure quality data and output from large-scale radar analyses. The Subgroup should determine whether there is a standard or standards that can be recommended. The composition of the Working Subgroup may include representatives from interested government agencies (management and regulatory), researchers, nongovernmental organizations, and industry. It was agreed that there should be a separate and parallel working subgroup to address similar issues for small-scale radars (see Action Item #2 below).

The following workshop participants volunteered to participate on the Large-Scale Surveillance Radar Standardization working subgroup:

Working Subgroup—Large-Scale Surveillance Radars Standardization

Sid Gauthreaux	Manuel Suarez
David Mizrahi	Rick Sojda
Robb Diehl	Lori Randall
Jeff Buler	Wylie Barrow

NOTE: It is not intended that the above names represent the full membership of the working subgroup. It represents a core of members that were present at the workshop. It was noted that working groups operate best when they are not so large as to be unwieldy. It was suggested that the important thing was to have representative members and not necessarily every person who might do a good job.

ACTION ITEM #2 – For Researchers (ENDORSED): Establish a Working Subgroup from the "radar collaborative" to address Small-Scale Radar Standardization issues.

For the purposes of this Action Item, Small-Scale Radar is defined as high spatial resolution radar technologies such as marine surveillance radars, tracking radar, and so forth. The Subgroup's assignment is to address issues related to common or ***standardized metrics*** (that is, making the analyses results comparable) to guarantee quality data and output from small-scale radar analyses. The subgroup should determine whether there is a standard or standards that can be recommended. The composition of the Working Subgroup may include representatives from interested government agencies (management and regulatory), researchers, nongovernmental organizations, and industry. It was agreed that there should be a separate and parallel working subgroup to address similar issues for large-scale surveillance radars (see Action Item #1 above).

The following workshop participants volunteered to participate in the Small-Scale Radar Standardization working subgroup:

Working Subgroup—Small-Scale Radar Standardization

Ed Herricks	David Mizrahi
Sid Gauthreaux	Adam Kelly
Bruno Bruderer	Steve Pelletier
Robb Diehl	Bob Beason

NOTE: It is not intended that the above names represent the full membership of the working subgroup. It represents a core of members that were present at the workshop. Several particular people not present at the workshop were mentioned as potential subgroup members – Thomas Steuri (Bruno Bruderer's colleague); Chad Chase (graduate student associated with USGS NWRC); and other representatives from consulting firms. It was noted that working groups operate best when they are not so large as to be unwieldy. It was suggested that the important thing was to have representative members and not necessarily every person who might do a good job.

ACTION ITEM #3 – For Management and Regulatory Agencies (ENDORSED): Identify the three most important information needs for each of the following management issues as they relate to radar technologies. These management issues include, but are not limited to: (1) anthropogenic structures (communication towers, wind turbines, power transmission lines, tall bridges); (2) identification of "key" natural and artificial habitats; (3) minimization of bird/aircraft strikes; and (4) assessment of the efficacy of conservation or management actions.

The focus of such an effort will necessarily require a focus on landscape scale management issues rather than focusing on a site-specific scale and will require interagency collaboration. The finalization of this Action Item did not coalesce around defining the need for a designated working subgroup of the "radar collaborative." However, it was suggested during the discussion that the assignment might best be addressed through such a working group or workshop. It was noted that it should include people not present at the workshop and that it would be very important to identify the key managers who should be involved in such a discussion. It was also suggested that, although the majority of the effort needed to come from managers and regulators, it would be necessary to have ongoing communications with researchers to perfect the priority questions. It was noted that the availability of fact sheets (See Action Item #4 below) would be an important resource for such an effort. It was also emphasized that such an effort should maintain communications with other related activities within and outside the "radar collaborative" (for example, the Migration Committee of the Northeast Coordinated Bird Monitoring working group; State Wildlife Action Plans).

ACTION ITEM #4 – For Researchers (ENDORSED): Develop a Fact Sheet (or series of Fact Sheets), targeting management and regulatory agencies and industry audiences, to provide information about radar technology applications to migratory bird and bat conservation issues.

These Fact Sheets should provide information about the available radar technologies and answer questions such as: What radar and other technologies are best used to assess direct and indirect impacts from tall structures, to identify key natural and artificial habitats and stopover areas, to minimize effects from bird/aircraft strikes, and to assess the effectiveness of management practices? This document will be peer-reviewed by the scientific community. Although the documents will not provide a "cookbook" for all situations, the information provided from a national perspective should be able to be stepped down so that it is useful at the local and site-specific level.

ACTION ITEM #5 (ENDORSED): Create a "radar collaborative" Web site to provide information about radar biology applications, contacts, publications, and so forth.

Initially such a Web site would provide basic radar biology information, links to applicable Web sites and downloadable files, contact information, bibliography, workshop proceedings when published, and so forth. It was noted that a Web site can be an ideal vehicle for education of managers, regulators, industry, and the public. However, it was recognized that there might be challenges to be addressed (policy issues depending on who serves the Web site, the need for time and resource commitment to maintain the Web site). It was agreed that it should be done well (professionally) or not at all. There are many possibilities to explore in developing such a Web site and many models to choose from.

ACTION ITEM #6 (ENDORSED): Formalize and expand the USGS-USFWS "radar collaborative."

There was a clear consensus among workshop participants that a continuation and expansion of the "radar collaborative" was needed to facilitate these Action Items and move forward with the momentum generated by this workshop. There was unanimous agreement that the "radar collaborative" served a useful purpose in facilitating the interaction between these disparate interest groups and in directing our discussions and focus. It was generally agreed that the "radar collaborative" would serve an even more useful purpose in the future. There was clear evidence of interest from many workshop participants from the research community, Federal and State agencies, nongovernmental organizations, and industry in being included in an expanded collaborative effort beyond the original USGS–USFWS "radar collaborative." The workshop participants reached a level of agreement represented by the Action Item language above and agreed that it would provide some sort of organizational umbrella for the two Working Subgroups identified in Action Items #1 and #2 above, facilitate the implementation of the other Action Items, and possibly serve as a peer review body for publications as needed.

Substantial differences of opinion were expressed regarding what the future "radar collaborative" should look like and how formalized or "official" the entity should be. Some of these discussions were complicated by discussions about possible means of actually funding such a collaborative effort and how that could be accomplished. A variety of models for organization were discussed including a formal consortium, a nonprofit organization, or an informal coalition. Therefore, the exact nature of this "radar collaborative" (by whatever name) was left undefined at this time, to be revisited as seems necessary as these Action Items are implemented.

It was also suggested that the nomination of a Steering Committee or Coordinating Committee to provide guidance to the coalition would be extremely important. However, it was noted that a Steering Committee can be unwieldy and inefficient if it becomes too large. It should include representatives from USGS, researchers, interested management and regulatory agencies, nongovernmental organizations, and private consulting firms, not necessarily someone or everyone from all organizations who might be interested (for example, perhaps a single person from the Department of the Interior could represent several agencies at once). It should not be forgotten that such a Steering Committee serves to guide the large coalition in which a broader range of representatives can participate.

ACTION ITEM #7 (ENDORSED): Advance basic research, such as target identity and validation that will support and improve our abilities to apply radar technologies to conservation objectives.

This Action Item represents a consensus among the workshop participants that, although we tend to focus on applied research in discussing applications to bird and bat conservation and management, the distinction between basic and applied research is rather artificial. Without the basic research needed to provide answers to many remaining questions, our abilities to apply radar technologies to our management and conservation questions will remain restricted. All partners are encouraged to recognize this fact and to seek ways to support basic research within the scope of their missions. In addition, it was noted that support for basic research is a necessary component of the activities of our proposed working subgroups.

Summary Observations from the Workshop

A Research Perspective of the 2006 Radar Biology Workshop

- Robb Diehl, University of Southern Mississippi, Hattiesburg, Miss.

Radars commonly used by biologists fall into two general categories. Small, portable radars can take many forms from so-called “marine radars”—cost-effective units with limited modes of operation—to more costly and less available tracking radars that, while highly flexible, are more difficult to use and maintain. Despite large differences in the operational characteristics of each, they share the common property of providing information on the behavior of individual targets, usually birds, insects, or bats. Large weather radars generally comprise the other category. Unlike their portable cousins, weather radars are usually stationary (or at best, challenging to move) and quantify large volumes of airspace that may capture the movements of hundreds of thousands of birds, insects, or bats over tens of thousands of square kilometers. Portable and weather radars complement each other and together offer insight into diverse behaviors that range from the wing-beat rate of an individual bird to the habitat preferences of millions of migrants across much of North America.

Use of each type of radar comes with its own set of challenges. A paper presented at the 3d International Partners In Flight conference in 2002 (Diehl and Larkin, 2005) identified issues confronting the use of weather radar for ornithological work. A number of these have been addressed or accommodated over the last few years (table 1).

One of the most visible applications of weather radar in migratory biology is its ability to associate birds with their stopover habitats over large areas (fig. 9). Biologists applying radar this way can identify habitats that concentrate birds in highest densities, measure how these patterns of habitat use vary within and across seasons, study how landscape features influence the use of habitats, and so on. Such data have directed conservation efforts on the ground to protect habitats important to birds during migration.

Table 1. Some challenges in the application of weather surveillance radar for biological research and how those challenges are being met by the biological community.

Challenge	Solution
Improve ability to associate birds with stopover habitats	Modeling (AIC, IBM); merging sweeps
Range bias	Vertical profiles of reflectivity (VPR)
Sunset bias	Correct through longitudinal adjustment
Migratory exodus undersampled	Combining sweeps, interpolation from exodus models
Ground clutter	Improved clutter rejection algorithms
Target identification	Airspeed-based target discrimination, development of intelligent algorithms

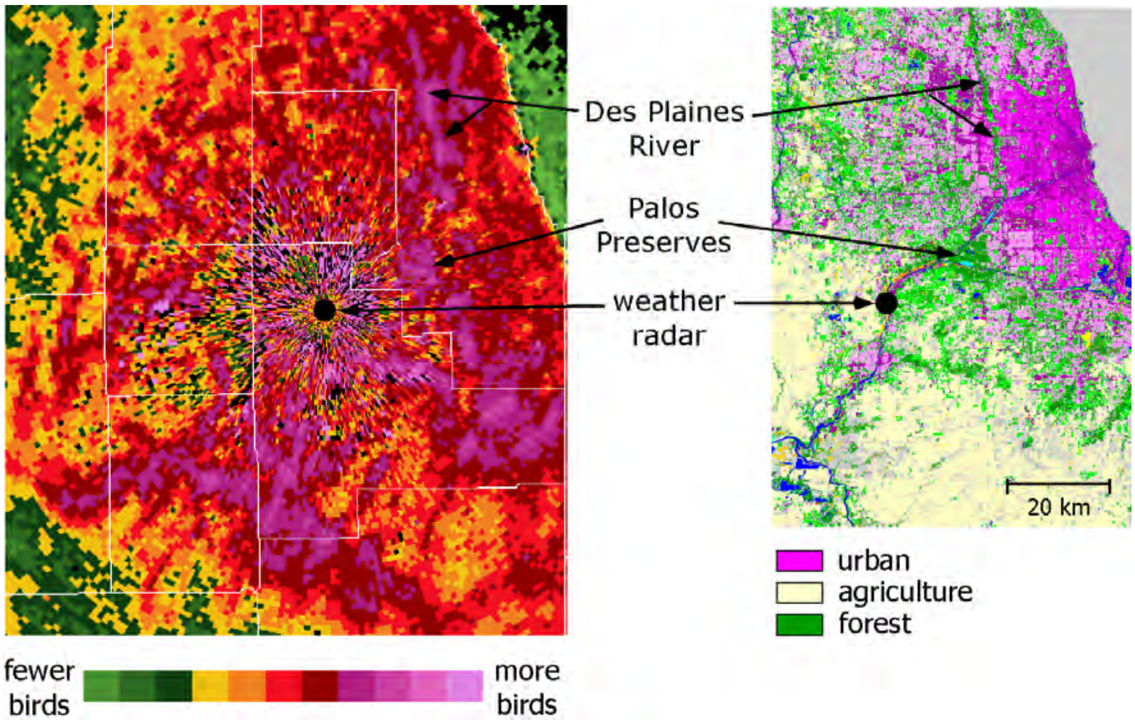

Figure 9. Radar echoes caused by landbirds departing habitats around Chicago, Ill. are shown shortly after the onset of migration. Birds spatially associated with source stopover habitats early in migration yield patterns of echoes that reflect their distribution in the landscape prior to migration. Strongest echoes indicate birds emanating from forest-dominated habitats. In time, this structure is lost as birds disperse in the airspace.

The value of this application of weather radars is too great to overlook some of the research needed to advance this capability. To date, biologists have directed little effort toward corroborating patterns of habitat use determined by radar. A concerted, field-based effort would sample migrants' use of varied habitats—including the habitats birds tend not to use—across diverse landscapes. Furthermore, more work is needed to improve weather radar's ability to resolve habitat/migrant associations. Increasingly sophisticated models reveal the roles played by habitats and their landscape contexts in determining the factors that influence habitat use patterns by migratory birds. Other modeling efforts are pushing the limits of weather radar to resolve habitat preferences at finer spatial scales.

Research into target identity is arguably the most critical need in both portable and weather radar-based studies. Birds share the airspace with insects and bats, and distinguishing among these is a technically difficult but not intractable challenge. Portable tracking radars operate in ways that capture detailed records of the spatial, temporal, and "electronic" characteristics of individual targets which in turn allows discrimination among target types. However, the cost and scarcity of tracking radars requires most biologists to rely on more accessible "marine" radars. Work is progressing in both academic and commercial circles to develop target recognition algorithms for marine units.

Unlike portable radars, weather radars, by design, are not amenable to monitoring individual targets. Rather, the need for weather radars to monitor large areas requires that even the most resolute measures of echo (for example, ca. a few pixels in fig. 9, left) represent volumes of airspace large enough to include many different kinds of targets. Because these volumes can include both birds and insects (and bats), attributing radar echo to one kind of animal or another is more indefinite than with portable radar. As a result, target identification in weather radar applications tends to be a matter of identifying which target types explain most of the echo. Currently, insect-dominated movements are distinguished from those dominated by birds (and "birds" may often include some or many bats) by differences in their respective airspeeds (Gauthreaux and Belser, 1998). Unfortunately, airspeed analyses are time-consuming and rely on winds-aloft data that are temporally and spatially coarse. In response to these shortcomings, research is underway to develop "intelligent" algorithms that rely strictly on the nature of the radar's data to classify targets (Zrnic and Ryzhkov, 1999). In the next several years, the U.S. system of weather radars will undergo an extensive upgrade that will advance its target-discriminating capabilities.

Interest in biological applications of radar has grown considerably in recent years, urged in part by the efforts of radar biologists familiar with radar to present their work, free and easy access to data from the U.S. NEXRAD system (Del Greco and Hall, 2003), and the wide availability of inexpensive marine radars. Nonetheless, the lingering perception that radar is difficult to understand and apply remains a barrier to its wider use among biologists. This is a reasonable sentiment. Methods for quantification lack standardization; software aiding analysis is idiosyncratic, proprietary, or simply does not yet exist; methods of target identification are under development; important work remains unpublished (not least, this author's). That few biologists possess the technical skills to address many of these needs speaks to the value in the near term of interdisciplinary collaboration with software developers, engineers, and radar meteorologists. In the long term, graduate and undergraduate education will be critical to preparing and maintaining a user community of biologists sufficiently familiar with radar to understand when and how it should be applied.

Some Reflections on the Albuquerque Radar Ornithology Workshop

- Tom Will, U.S. Fish & Wildlife Service, Fort Snelling, Minn.

I was asked to provide some personal reflections on the radar ornithology workshop from the perspective of a biologist working in an agency charged with the trust responsibility of managing migratory bird populations. If I were to speak from a wholly personal perspective, I would speak as a poet confessing a total fascination with Al Manville's concept of airspace as bird habitat—which we as humans pollute with our carbon, waste gases, and light, and into which we insert our airplanes, wind and communications towers, and buildings. But I'll put on my manager's cap, look at the workshop landscape from a higher altitude than did Robb in his excellent summary of radar advances, and reflect instead on what I saw as some major emergent themes.

The workshop brought together two distinct communities—the research community with its radar biologists, ornithologists, meteorologists, programmers, and radar technicians; and the management agency community, with its conservation planners, habitat managers, program coordinators, and policy decisionmakers. Hopefully this dialogue between research and management will lay the foundation for the kind of research prioritization that has been so successful in other initiatives. In the Cerulean Warbler Technical Group, for example, identification of broad-front, range-wide research priorities helped provide some management focus to the often haphazard, interest-based academic project roster. The result was more successful grant writing and a suite of funded coordinated regional replicate projects focused on the fundamental answers needed for proactive conservation.

In the case of this workshop, the research community is rather nontraditional, inasmuch as it is focused on a tool (radar) rather than on a discipline or coherent set of theoretical questions. That community has done a great job summarizing recent advances in radar technologies and the kinds of questions those tools are capable of answering. The management community, for its part, has not been nearly as successful in identifying the most important questions for which radar might serve as a useful tool. I must confess to being somewhat shocked—even appalled—at hearing discussion about how much it might cost to do a “radar study” without hearing any discussion whatsoever about what questions the study proposed to answer and therefore how extensive, both spatially and temporally, it would need to be. It seems all too typical for management to be embarrassingly fuzzy about its objectives.

The workshop did consider some research questions to which radar was applied as a tool; for example: What are the relative contributions of forested upland bluff habitat and bottomland forest to migrant landbird stopover along the Upper Mississippi River? Along the Gulf Coast, where do wintering waterfowl concentrate in their daily foraging and roosting movements? What we did not see, however, was any effort on the part of the management community to identify and prioritize the research questions which might employ radar, or—perhaps more importantly—any effort to place that set of questions within a broader context of prioritized critical national or regional conservation information gaps.

Once management is successful in clarifying and prioritizing its research questions and objectives, the research community can then help management to identify which questions are best answered using radar tools. It is at this point that the value of the “radar collaborative” to management begins to emerge—as well as its inherent responsibilities. Once management asks for help from the radar community, it implicitly assumes some responsibility to help that research community meet radar biology’s own prioritized objectives for improving its tools and techniques. For example, the agency management community might step up to the plate to help fund basic research on improving radar's capacity to distinguish bird targets.

If one takes a step back, generalizes the emerging patterns, and uses a slightly different vocabulary to describe the interactions connecting the management and research communities, one should recognize a theme that seems to recur in many of our discussions about filling information gaps—the need for basic (exploratory) research on the one side and applied (management question-driven) research on the other. This dichotomy should look familiar to those of you who have been struggling recently with coordinated bird monitoring (CBM); expressed in CBM vocabulary, it is the dichotomy between long-term trend or surveillance monitoring on the one hand and short-term, hypothesis-driven or project evaluation monitoring on the other. It is a dichotomy that has at various times perplexed, frustrated, and inhibited the development of coordinated bird-monitoring frameworks.

In order to create a productive “radar collaborative,” I submit that we first need to reframe the obfuscating dichotomy between research and management—and between the basic and applied research connections—in terms of a broader, more inclusive, more unifying concept. We need to move from a dichotomizing to a dynamic framework. As a “radar collaborative,” we need to put some thought into how best to express this unifying conceptual umbrella; for the present, let’s just call it a Radar Biology Conservation Collaborative (fig. 10). Under a unifying conservation framework, basic (long-term, surveillance) and applied (short-term, management-driven) research expresses two overlapping spheres along a single continuum of inquiry and action ranging from more proactive to more reactive approaches—all of which are essential for sustained effective conservation of biological resources and the rewarding intellectual inquiry they nurture. The enthusiasm expressed at this workshop suggests that collectively we possess the requisite intelligence, dedication, and commitment to move the unifying paradigm forward. Our choice of “collaborative” as a descriptor of our collective identity is a step in the right direction, as it tends to focus our interactions on coordination and opportunity.

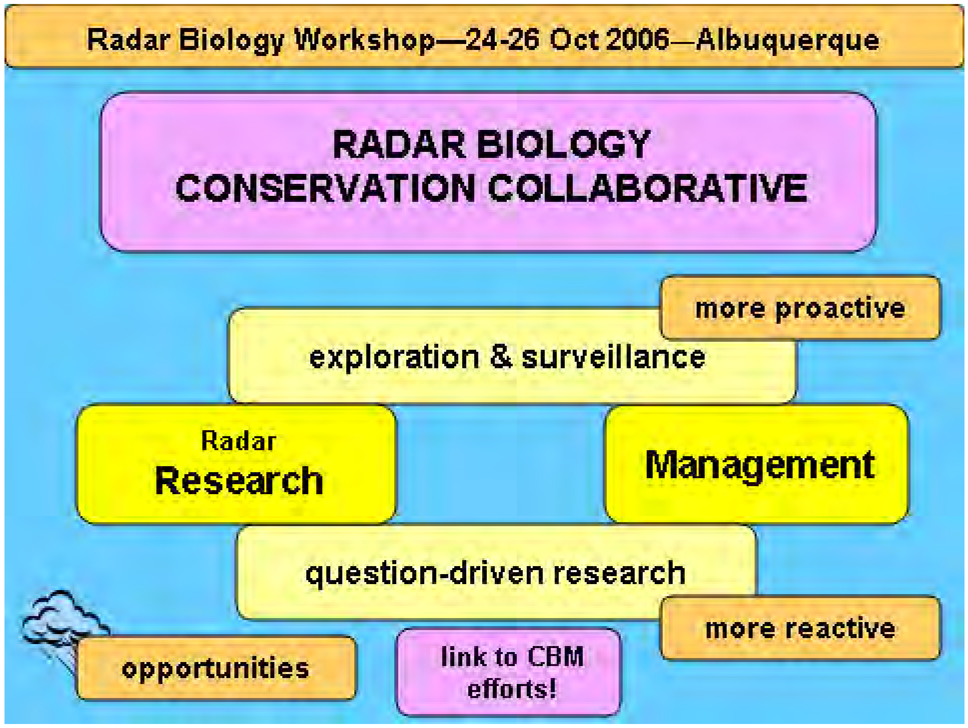

Figure 10. A conceptual diagram for a Radar Biology Conservation Collaborative.

Speaking of opportunities: We need to identify and exploit them. The stories about how the biological echoes that comprise radar biology's gold mine are nothing but noise to meteorologists—data to be filtered out and thrown in the trash—sent shivers down my spine. Obviously the technologies that meteorologists develop to filter out biological noise are the same techniques that biologists might use to capture data; the collaborative possibilities are obvious in both directions, but I have seen enough of uninformed bureaucracy to know how easily (and irrevocably) opportunity can be lost without conscious attention to establishing lines of communication across agencies. The presence of meteorologists at this workshop is encouraging, to say the least. Thinking similarly of opportunities and recalling the CBM analogy: we need to promote active linking with coordinated bird-monitoring efforts. Among other things, CBM can provide radar ornithology with the existing infrastructure needed to ground-truth radar images.

I appreciated the management community's desire for better decision support tools for both understanding the applicability of radar and guiding research decisions as well as for making radar biology's information output simpler, more directly applicable to management decisions, and more understandable and accessible to field biologists. Once again, however, management needs to clarify objectives and think more carefully about who will actually be using decision support tools and in what contexts. Radar may not be the most appropriate tool to answer some questions (for example, important stopover habitat), but radar products might be indispensable as documentation needed to defend legal challenges to management and conservation decisions.

I was encouraged by the group's desire to strengthen the "radar collaborative" by including outreach and education in the suite of activities needed to broaden support for radar ornithology—building, for example, on the recent excellent article in *Birding*. Popularizing the use of radar images in understanding bird movements helps to call attention to migration as a fundamental aspect of bird life history that requires conservation action.

Now is an especially opportune time to raise the profile of radar biology and to become proactive in focusing conservation attention on migration. Global climate change is expected to result in an increase in both the frequency and severity of weather events affecting movements within the continent and especially across the Gulf of Mexico. While radar seems most appropriate as a tool for understanding migration, we also should continue to think creatively about applying radar to breeding and non-breeding residency questions as well. This approach seems especially suited to the growing recognition that effective local and regional responsibility for bird conservation must involve stewardship across all aspects of the life cycle. Responsibility for what happens to a species that breeds in a State does not end once it crosses State or international boundaries, and tools that can assess vulnerabilities as creatures move through the vast spaces in which they evolved should become increasingly indispensable. Now is a great time for a "radar collaborative" to lead the way in bringing together researchers and managers to ask the right questions, develop clear objectives, and develop innovative tools to find the answers that will sustain the magnificent creatures whose airspace we share.

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Clemson University Radar Ornithology Laboratory Web site:
http://virtual.clemson.edu/groups/birdrad/

The Radar Entomology Web site:
http://www.pems.adfa.edu.au/~adrake/trews/ww_re_hp.htm

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