Migration **I**ntegration **G**roup: **R**esearch **A**pplied **T**oward **E**ducation (MIGRATE)

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Intellectual Merit—Many advances in our understanding of animal physiology, behavior, population ecology, and life history evolution are strongly tied to innovations in our ability to quantify animal movement. Recent innovations make it is clear that using new technologies will be a primary means of gaining new insights into patterns of animal movement. We argue that long-distance landbird migration is an ideal system for applying new technologies in ways that advance our understanding of the ecological and evolutionary implications of movement strategies. MIGRATE has four primary objectives: (1) focus research techniques and questions on a small suite of model species to make rapid progress in understanding the ecological and evolutionary implications of long-distance movement; (2) foster cross-disciplinary collaborations among researchers throughout the Americas and Europe; (3) encourage standardized collection and sharing of collected tissues, technological advances, and data; (4) Create a platform for interdisciplinary training of students and the public, particularly underrepresented minorities. By working at the nexus of emerging technologies (e.g., molecular, electrical, remote-sensing) and ecology, this network will successfully allow currently active researchers to engage students from under-represented groups in novel research projects.

Broader Impacts—Application of emerging intrinsic and extrinsic tracking technologies to novel problems in ecology will improve the technologies themselves. The rigorous research fostered by MIGRATE will increase our ability to infer sources of DNA, stable isotope ratios, and trace elements. Advances in use of molecular markers will have applications across a broad range of disciplines such as identifying sources of bio-terrorism, commercial testing of ingredient purity, and locating origins of introduced exotic species. MIGRATE will allow students to access the newest developments, make field scientists aware of state-of-the-art technology advancements, and provide an interface between industry and field ecologist in diverse countries. In areas of health and economics, the results of MIGRATE can be applied to understanding and controlling the spread of disease through animal movement. Moreover, the ability to track individual migrant birds and identify populations will have immediate applications for conservation planning. A complete and integrated understanding of migration ecology will allow for more effective use of limited conservation resources and provide scientists with the ability to use migratory birds to monitor ecological responses to global climate change. This network will bring together a diverse set of approaches, facilitating communication among researchers on a multinational, continental scale. Finally, the project will provide broad multidisciplinary training for minority students in both the laboratory and the field.

NETWORK THEME AND OBJECTIVES

Movement is a ubiquitous characteristic among animals that reflects the ecological, behavioral, and physiological trade-offs faced by each individual. Across diverse spatial and temporal scales, movement may be quantified in units of rate and directionality (Crist et al. 1992). Movement behavior may be shaped by natural selection, evolve when heritable (Berthhold and Querner 1981, Berthhold 1991, Helbig, 1991, Berthold et al. 1992), and be constrained by phylogeny (Cox 1985, Levey and Stiles1992, Chesser and Levey 1998). Yet, quantifying fitness consequences of animal movements is often difficult because movement itself is difficult to quantify. Our ability to study movement is limited in space and time by the tools available for observation (Adams 1965). Consequently, much of what we understand about animal movements has come from research involving taxa that are relatively large, slow moving, or sedentary. Recent technological advances are expanding the spatial and temporal range and precision of our observations and increasing the variety of taxa whose movement can be studied. Development of both intrinsic and extrinsic markers is leading to an explosion of useful approaches for precisely measuring movements over vast distances. For example, development of satellite transmitters has allowed birds to be tracked continuously across continents (Clausen et al. 2003), molecular genetic and isotopes analyses allow breeding and over wintering localities to be identified and populations to be connected (Kelly et al. *In Press*), and harmonic radar is used to track flights of individual invertebrates (Cant et al. 2005). While these technologies and associated analytical methods have been developing rapidly, they have been doing so in isolation from one another. There has been little attempt to integrate movement data, cross-validate different techniques, or apply multiple tracking technologies to single species. The strength of integrating methods that can track both populations and individuals would be especially valuable for the study of medium to small-bodied animals that regularly move quickly over vast distances.

We propose to create the MIGRATE Research Coordination Network to advance our understanding of movement ecology by focusing research efforts on several model species of landbird migrants. Once selected by network participants, these model species will provide the nexus through which advances in technological and analytical approaches can be integrated and used to understand the ecology of long-distance movement. Mirroring the vast geographic scope and phylogenetic diversity of landbird migration, the MIGRATE network includes researchers from across the western hemisphere and links to efforts already underway in Europe (Optimality in Bird Migration, http://www.esf.org/bird).

The MIGRATE network will build personal connections and the virtual infrastructure needed for collaborative research on intercontinental movements and introduce a cadre of young scientists to the interdisciplinary foundation necessary to study animals moving between hemispheres. MIGRATE will pursue four specific objectives:

1. Advance the study of long-distance animal movement through the integrated use of novel and existing intrinsic and extrinsic markers, cross-validation of technologies, and development of innovative quantitative approaches.
2. Foster cross-disciplinary collaborations (e.g., ecology and engineering) among researchers throughout the Americas to understand *in situ* migratory movements of individuals and track physiology, behavior, and population dynamics across space and time.
3. Encourage data sharing by developing common standards for movement-related data, tissue collection protocols, and identification of central repositories for data and samples.

4. Create a platform to promote collaborative research and training of students, particularly from underrepresented minorities in the US and from countries across Latin America.

BACKGROUND AND JUSTIFICATION

Few attributes of animals are more fundamental than movement. Movement is a primary means by which most animals interact with their biotic and abiotic environment. Animals move to eat, reproduce, avoid predators and find a tolerable physiological environment. Movement is an important mechanism for negotiating trade-offs between competing demands that influence individual fitness. Moreover, resolution of these trade-offs must factor in the energetic costs and risks of movement itself (sensu Werner and Hall 1988, Dingle 1996). As an informative measure of how animals adjust to environmental change, minimize constraints, and exploit opportunities, movement is a central interest in fields of physiology, behavior, population ecology, and evolutionary biology.

Quantitative measurement of animal movement has proven to be a difficult technical and analytical problem (Turchin 1998). Animal movement can be expressed in units of rate, distance, direction, and tortuosity of the path traveled (Wiens et al 1995, Turchin 1996). These parameters vary among individuals in response to environmental variation over ecological time scales (minutes to years) and are constrained by phylogeny (e.g., body size and mode of locomotion). Markers used to track animals through time and space can be divided into those that are intrinsic and those that are extrinsic to the animal (Rubenstein and Hobson 2004). On a practical level, movement can be inferred from single or limited number of multiple observations of a marker in space and time (i.e., capture/recapture) or can be empirically described by continuous observation in real time and space (i.e., tracking). Each of these practical approaches relies on intrinsic and/or extrinsic markers that provide spatial information at the individual or group/population level. The logistical, technological, and analytic barriers to quantifying movement have left significant gaps in broad areas of ecological and evolutionary inquiry.

Until very recently, the study of animal movement has been restricted to those organisms, life-stages, time periods, or habitats in which movements covered short distances, visual observation was possible, or recapture was likely. As the spatial scale and rate of movement increase, direct visual observation and recapture become less reliable and inference shifts from movement of individuals to movement of populations. For example, there have been numerous attempts to use traditional intrinsic markers of breeding and wintering geography, such as coloration and meristic traits, to assess long-distance movements of subspecies of birds (e.g., Ramos and Warner 1980, Keast 1980, Alterstam 1990). However, these traditional intrinsic markers are highly variable, difficult to measure, or qualitative and have not generally provided the degree of resolution needed to effectively address ecological or conservation questions. To overcome these challenges, extrinsic markers have always held promise. Remote-sensing devices such as radio transmitters have been in use for decades, providing high resolution spatio-temporal data (Cochran 1987). However, transmitters can weigh no more than 3 to 5% of body mass (White and Garrott 1990) and transmitter power and longevity are still determined by transmitter size. As a result there are few long-distance movement data for organisms weighing less than 100 g. This bias limits our ability to infer general patterns of animal movement and, more importantly, prevents application of rigorous experimental designs that use representative or random selection of sample units (e.g., geographic locations, populations, or species) to test questions regarding the ecology and evolution of movement behavior.

Fortunately, a surge of technological innovation in both intrinsic and extrinsic markers is rapidly creating new opportunities to quantify movement. Technological development of extrinsic markers has focused on radio telemetery, transponders, satellite tracking, RFID-2 tags, and cell phone tags and is benefiting from engineering emphasis on miniaturization. With respect to large-bodied animals (> 500g), it is now possible to use satellite-tracking to obtain near real-time migration information (e.g., Ueta et al. 2000, Ristow et al. 2000, Clausen et al. 2003). While, the ability to track small-bodied birds remains experimental, Cochran and Wikelski (2005) have shown that it is feasible to use radios to track 30 gram migrant landbirds throughout their annual cycle. This advance is poised to revolutionize our ability to track small animals in real time.

Parallel advances have been made in the use of intrinsic markers for understanding population structure and tracking long-distance movements. Molecular genetic probes (Haig et al 1997, Bensch and Hasselquist 1999, Milá et al. 2000, Milot et al. 2000, Bensch et al. 2002a, Bensch et al 2002b, Kimura et al. 2002, Irwin et al 2005, Smith et al. 2005), stable isotope ratios (Chamberlain et al 1997, Hobson and Wassenaar 1997, Kelly and Finch 1998, Hobson 1999, Wassenaar and Hobson 2000, Kelly et al. 2001, Meehan et al. 2001, Graves et al. 2002, Rubenstein et al. 2002, Pain et al. 2004, Royle and Rubenstein 2004, Bowen et al. 2005), trace element analyses (Saino et al 2005), parasite data (Rintamaki et al. 2000, Alekseev et al.2001, Ricklefs et al. 2005), and thin layer chromatography (Dockx et al. 2004) have shown promise for revealing migratory geography and population connectivity. While the ability of these markers to provide geographic information is now well established, there has been little rigorous work on the limits of resolution for each technique or the possible benefits of combining multiple markers. In fact, there is emerging concern in the literature over the utility of several markers in various contexts (Lovette et al. 2004, Wunder et al. 2005). Evaluating these limitations will be important for understanding which types of questions are best addressed with which combinations of markers. The potential to combine innovative intrinsic and extrinsic markers to track individuals and populations opens a wide array of exciting research questions that to date have been impossible to address.

A primary goal of the MIGRATE network is to foster the use of multiple tracking methods in ways that increase the accuracy and precision of tracking data. Coupling multiple traditional and technology-driven tracking methods will compensate for shortcomings of individual tracking methods. MIGRATE will work to accelerate the integration of methodologies and develop new approaches to fundamental ecological and evolutionary questions. Achieving this objective requires overcoming both technical and analytical hurdles. While the analytical challenges may be less obvious, they are, perhaps, more daunting. For example, how can population genetic markers or parasite community data be mapped in spatially meaningful ways so that they can be integrated with other spatial patterns? How can Bayesian probabilities of origin be represented for continuous landscapes (Ellison 2004, Royle and Rubenstein 2004)? Can individual movement data be amalgamated to infer patterns of population re-distribution?

Although methods involved in overcoming these problems can be complex, there are several examples that suggest that promoting work in these areas will be rewarding. Chamberlain et al. (2000) combined band recoveries and stable isotopes to infer the geography of a migratory divide in willow warblers (*Phylloscopus trochilus*). Likewise, Norris et al. (2004) also used leg bands and stable isotopes to infer molting locations in American Redstarts (*Setophaga ruticilla*). In another example, Clegg et al. (2003) integrated stable isotope data with microsatellite markers to infer the breeding origins of wintering Wilson's Warblers (*Wilsonia pusilla*). These examples suggest that integrating multiple tracking methods will be the key to understanding the ecology, physiology, and evolution of long-distance movement. The rarity of such studies reflects the degree to which technological hurdles prevent most researchers from employing this strategy. Advances in the fields of engineering, genetics, biochemistry, and spatial analysis have occurred apace over the past decade and have far surpassed any individual's ability to understand and integrate the information produced. MIGRATE will provide a community portal through which question driven research can be connected with the latest technology

We have four reasons for focusing this network narrowly on landbird migration. First, technological innovation in the study of movement has arisen from interest in organisms with poorly described movements and the greatest promise of providing insight into fundamental ecological, evolutionary, and conservation questions. Because the primary logistical challenges have been related to body size, rate of movement, and distance covered, animals that weigh < 50 g and move long distances in short time periods have driven much of this innovation. Among vertebrates, birds have been at the center of tracking innovation. Consequently, there is a broad diversity of international researchers focused on intercontinental migrant landbirds. Many members of this community are already familiar with one or more method of tracking individual migrants.

Second, there are range-wide, long-term surveys of breeding density (Sauer et al. 2004) and reproductive output (e.g., DeSante et al. 1995) of birds in many parts of the north temperate breeding range. These baseline population data make it likely that more can be learned about the ecology and evolutionary biology of these species than could be for species where population data do not exist at a broad spatial and temporal scale. In particular, the ability to link retrospective analyses of intrinsic markers (e.g., based on museum collections) to population data is a research opportunity that is not available for many taxa.

Third, rapid long-distance movement that characterizes avian migration represents the endpoint of a continuum of potential movement strategies (Alerstam and Hedenstrom 1998). Every spring and autumn billions of landbirds migrate hundreds of kilometers per night, often on successive nights. Some migrants, like blackpoll warblers, traverse enormous geographic barriers via non-stop powered flight. When considering the metabolic costs of this mode of locomotion, the rate of travel per g of body size, and the distance covered per g of body size, these migrations are extraordinary in the history of life on earth. Examination of such extreme behaviors has often been useful in developing and testing general theories of ecology and evolution as well as for assessing anthropogenic impacts at the broadest scales.

Finally, public awareness of songbird migration and fundamental interest in bird conservation makes this topic a valuable venue for public education. MIGRATE's theme provides an accessible window on numerous scientific fields. The integration of technology and ecology around the spectacular natural phenomenon of bird migration will enhance our ability to recruit students from diverse populations and cross-train students from diverse disciplines. For example, through connections available in the MIGRATE network, a student originally attracted to bird biology could receive training in electronics and satellite technology while a geneticists could receive training in landscape ecology.

Implications for Basic Ecology and Evolutionary Biology — Truly innovative and risky science is not often rewarded in the short term (Metzger and Zare 1999). That is, narrow disciplinary studies with predictable results are more likely to be funded than trans-disciplinary studies that that lead to less certain paths. This cultural bias reduces the rate and dimensions of progress in most fields of science. Overcoming this cultural inertia is an important component of training young scientists to take risks that will produce novel understanding. Toward this end the MIGRATE network will be structured to reward high-risk training programs in which scientists with disparate backgrounds are encouraged to collaborate in training students to attack novel problems in innovative ways. The network will be comprised primarily of geneticists, physiologists, behavioral ecologists, and population biologists with quantitative scientists from applied mathematics, statistics, and spatial modeling. We anticipate that trans-disciplinary work in these areas will forge new understanding of the evolution of animal movement strategies and their importance in the life histories of animals.

The rate of improvement in our ability to quantify animal movement has particular impact on physiological, behavioral, and population ecology. The heavy dependence of these disciplines on movement data is reflected in the number of core members of MIGRATE who are using movement data to examine basic ecological relationships among genotype, phenotype, development, physiological condition, survival, and reproduction, life-history variation, population density, dispersal, connectivity, landscape configuration, and changes in distribution; all of which require the ability to either track or relocate animals. Most of these basic ecological relationships also bear upon applied problems, which include declines of rare species, spread of diseases and exotic organisms, effects of landscape alteration on individuals and populations, and effects of climate changes on distribution and abundance. This diversity of topics reflects the fact that animal movement lies at the intersection of many avenues of basic and applied inquiry. We argue that advancing our ability to quantify animal movement through a network of interdisciplinary scientists will enable rapid advancement of ecological and evolutionary understanding across many disciplines.

Some questions being asked by Core Participants of MIGRATE using recent innovations in tracking techniques include: How are physiology, metabolism or morphology of animals constrained by the need to migrate (e.g., M. Wikelski)? What is the role of migratory behavior in maintaining reproductive isolation among divergent populations of birds (e.g., D. Irwin). What are the relationships between strength of connectivity, population dynamics, land use, and climate change (e.g., T. Smith, J. Kelly)? Can predictive models of population dynamics be developed that apply to a diversity of long-distance migratory animals (e.g., R. Norris)? Can dispersal distances from natal sites to breeding locations be quantified and what are the implications for population structure and dynamics (e.g., P. Marra)? What is the role of migratory movement in disease transmission (e.g., F. Moore, Owen et al. in review)? Such questions will provide critical clues for understanding the evolution of animal movement strategies and their implications for ecological responses of animals to recent environmental variation. MIGRATE will expedite this progress by facilitating connections among disparate research programs and by training students to search across disciplinary boundaries for the key questions that will move science forward.

Implications for Conservation — Short-term ecological responses of migrants are of particular relevance for gauging human impacts on global ecology. Individual migrant landbirds require adequate habitat in two hemispheres within the temporal scale of days to weeks. Because this trait is rare among animals, migratory birds are among the few organisms that have physiological, behavioral, and population attributes that are likely to yield valid indications of how continent-wide land-use changes are affecting natural systems over short time scales. The temporal and spatial scales involved in landbird migration make it ideal for monitoring physiological, behavioral, and population responses of biodiversity to global effects of anthropogenic change. The MIGRATE network will bring together specialists applying multiple disparate approaches to the study of animal movement to foster cross-disciplinary advances in the accuracy and precision with which long-distance movement data can be collected and analyzed. It is clear that innovations in our understanding of long-distance animal movement will derive primarily from advances in these technologies and our ability to extract information from the multiple types of data available. We view these innovations as critical tools in our ability to use movement behavior to assess the ecological consequences of continent-scale changes in climate and land use. Such analyses will be critical to implementing management and conservation plans such as the trinational (U.S.A., Canada, Mexico) North American Bird Conservation Initiative (NABCI 2005) and the North American Landbird Conservation Plan (Rich et al. 2004).

COORDINATED ACTIVITIES AND NETWORK PRODUCTS

***Model Species* —** The process of selecting study organisms often inadvertently leads to a wealth of information on a limited number of species . This is true in the field of migration ecology and synthesis of the large body of existing data for a few species will be a significant first step in understanding the complexity of migratory behavior, physiology, ecology, and evolution. This foundation of knowledge can then help identify the most pressing information needs and shape a productive direction for future research. The MIGRATE network will debate and select a small number of model species (<5) for intensive study. By doing so we hope to focus the research community on species for which study will allow the greatest advancement in our understanding of rapid long-distance animal movements. For example, the *Catharus* thrushes include good candidates for model species designation. Within this group, there are multiple recent studies on mtDNA (Ruegg and Smith 2000), stable isotopes (Wassenaar and Hobson 2001, Hobson et al. 2001), radio telemetry (Cochran 1987), stopover and winter ecology (Wang and Moore 1993, 1994, 1997, 2005, Stouffer and Dwyer 2003), and orientation (Sandberg et al. 2002, Cochran et al. 2004). Each of these studies presents important fundamental knowledge about migratory biology. Additionally, within this genus, there has been some effort placed on integrating intrinsic markers of movement (Kelly et al. *in press*).

Our first goal as a coordinated network of researchers will be to select model species for which we can develop a comprehensive picture of migration. In order to allow for input from scientists with diverse interests and backgrounds, we will proceed with model species selection in two steps. As a first step, we will gather information on *Catharus* thrushes to determine which species ought to be our initial model species for the study of migration. The PIs are currently engaged in intensive studies of migration ecology, behavior and physiology in this genus using a variety of approaches that include molecular genetics, stable isotopes, and radios. In addition there is a wealth of background information waiting to be synthesized on morphology, abundance, and productivity. Once the relevant data are assembled we will select the single, best-studied species, so that we can show the rapid progress that can be made by channeling efforts of this research network into a model species. Prior to our first annual conference, we will solicit additional model species nominations from MIGRATE's initial Core Participants and design sessions within the first annual conference to discuss the merits of a model species approach and reach consensus on additional model species. These model species will then form the basis of network interactions, data sharing, and cross-disciplinary proposal development. This process for selecting model species will fully leverage the expertise of the network participants and focus participants on integrating their research in ways that improve the accuracy and precision of data on long-distance movements of animals.

***Data and Tissue Collection Standards* —** Progress towards a comprehensive understanding of landbird migration in particular, and animal movement in general, hinges on uniting data sets from numerous researchers collecting information across widely disparate locations. However, the logistical challenges to joining and analyzing multiple data sets can be so great as to be prohibitive (Cook et al. 2001). The success of the MIGRATE network's efforts to coordinate research and integrated analysis on even a small number of model species will depend on development and adoption of data collection standards. Moreover, all attempts to cross-validate tracking methodologies also will require standardization of tissue and specimen collection and access to tissue samples through a central tissue library/archive. Although establishing a physical tissue archive is beyond the scope of this proposal, some core members have already initiated substantial collections of tissues such as the Conservation Genetics Resource Center at UCLA (e.g., Smith et al. 2003) and blood parasite samples from Central America (R. Ricklefs). To facilitate such collections, the MIGRATE network will work toward developing data and tissue collection standards as well as provide a central node for disseminating those standards and sharing information about data and tissue availability. MIGRATE will establish working groups from network participants to develop guidance on data and tissue collection standards which will be posted at the MIGRATE website (http://faculty-staff.ou.edu/K/Jeffrey.F.Kelly-1/migrate.htm) for open review. Revision and adoption will occur through a consensus-based process. Finalized standards will be published online and taught in student training activities. Ideally, these standards will apply to all new network-related research projects. Through the MIGRATE website and interactive activities, we will establish data-sharing mechanisms to facilitate integrated use of multiple data types and development of new quantitative spatial methods to improve inference regarding animal migration.

Citizen Science — The MIGRATE network will develop and implement a citizen science effort to collect data on migration phenology of our model species. The goal of the citizen science effort will be to record the time and place of observations of model species during the migratory period. We expect this public involvement to fulfill at least two network objectives. The first objective is education. Our focus on a limited number of model species and the simplicity of data collection ensure that avocational ornithologists and K-12 student groups will be able to collect valuable data with limited guidance and training. In turn we can offer citizen scientists information distilled from primary research that puts their observations in context. By involving a broad spectrum of the public in this effort, we will expand the science education and outreach potential of the MIGRATE network. This effort also contributes to our scientific objectives by providing baseline data on long-distance animal movements. Surprisingly, data on phenology of migratory movements across North America are not available in any comprehensive form. Published accounts of passage and arrival dates tend to be discontinuous, scattered among geographic regions, and collected from single, disjunctive years (e.g., BNA accounts, Poole and Gill 1992-2003). Although some relevant data are publicly available (e.g. www.eBird.org), they, too, tend to be discontinuous in space and time. We propose to overcome these problems by focusing public-interest on a few species that will provide insight into migration.

Citizen scientists will be recruited in targeted regions. Focus sites will be chosen based on accessibility, habitat and landscape features, and expected species distributions. Data will be collected on first and last observation of each season, number of days present and absent during the migratory phase, and peak number counted. We will establish a working group of Core Participants during our first annual conference to develop specific protocols for data collection, submission, and posting to the Internet. The PIs and Network Coordinator will implement mechanisms for recruiting citizen scientists including contact with K-12 teachers through groups such as the National Association of Science Teachers with the advice of the steering committee and seek formal collaborations with public-oriented groups (e.g., National Audubon, Gulf Coast Bird Observatory) as necessary. Beyond the life of this proposal we envision MIGRATE's citizen science initiative will be linked to a Citizen Science Gateway as proposed by the

Education Committee of the National Ecological Observation Network (NEON, P. 8, http://neoninc.org/documents/EDU_Boston_Report.pdf).

***Collaboration and Exchange* —** Given the international and inter-disciplinary nature of MIGRATE's theme, a critical element in achieving our objectives will be bringing researchers together to share research results, methods, technological innovations, and ideas. We propose three activities that will facilitate this valuable exchange: annual meetings, laboratory exchange visits, and annual student field and techniques training courses.

Conferences: We will sponsor five annual conferences, each with its own theme but sharing a common focus on the application of intrinsic and extrinsic markers to migration ecology. At each conference there will be a strong emphasis on inclusion of students, groups underrepresented in science, and international researchers.

Year 1: A Model Species Approach to Migration Biology (Organized by J. Kelly). The initial conference will be pivotal to future evolution of the MIGRATE network. This workshop will have four goals: (1) foster initial collaboration among researchers attacking similar questions with disparate methods; (2) engage the future of current approaches by exploring the fringe of what is possible now; (3) debate the concept of model species for migration biology and select model species; and (4) develop integrated strategies for public outreach, education, and increasing network diversity centered on technological applications for understanding migration.

Prior to the conference, attendees will be asked to submit brief proposals for model species. These suggestions will be accompanied by brief position papers that explain the merits of the proposed species as models. These proposals will be made available to all attendees prior to the conference. The conference will begin with current practitioners providing their vision of the future. Less emphasis will be placed on review than on what comes next. Presenters will be encouraged to focus on what might be possible over the next ten years and what would be the first steps in realizing these possibilities. Many of the attendees will be students from labs of Core Participants. Subsets of participants will be asked to form rotating committees that will be responsible for recruiting new members and maintaining openness and diversity; developing data and tissue collection standards; and developing protocols for the citizen science effort. A draft agenda for this conference can be found at the MIGRATE website (http://faculty-staff.ou.edu/K/Jeffrey.F.Kelly-1/migrate.htm).

Year 2: **Tracking Individuals: Insights into Migration Physiology and Optimal Migration** (Organized by M. Wikelski). Long distance movement over short time periods requires unique physiological adaptations. To date there has been limited success in understanding these adaptations because in-flight physiology of migrants requires real time tracking of both bird location and key physiological parameters. Integrating these metrics for free-ranging birds during migrations has proven a difficult technical problem. Nonetheless, much progress has been made toward measuring physiological parameters through the European Optimality in Bird Migration initiative lead by F. Bairlein (http://www.esf.org/bird) as well as through the NSF funded E-Bird RCN (http://depts.washington.edu/ebirdusa/) and its parallel networks in Canada and Europe. This conference will focus on three issues (1) identifying extrinsic markers that are best for each model species; (2) determining what physiological markers can tell us about in-flight physiology; and (3) seeking agreement on a set of physiological parameters and measurement methods that can be applied across research groups.

These discussions will be informed by reports from ongoing research in Old World and New World migration systems.

Year 3: **Migration Stopover Ecology** (organized by F. Moore). – Although many landbird migrants are capable of making spectacular, non-stop flights over ecological barriers, few actually engage in nonstop flights between points of origin and destination. Rather, they stopover periodically, resting for a few hours or a few days before resuming migratory flights. In fact, the cumulative amount of time spent at stopover sites far exceeds time spent in flight and largely determines the total duration of migration. The least understood aspect of long-distance migration arguably is the suite of factors that influence where and when migrants stop to refuel and the behavioral decisions made during these stopover periods, including when to depart. While a great deal of progress has been made in this area over the past decade, the difficulty of tracking individuals within a stopover period, much less between stopover periods, continues to hamper understanding of interactions between periods of migratory flight and the intervening stopovers. Population models (e.g., Sillett and Holmes 2002) suggest that mortality in the migratory phases of a songbirds' life cycle can be substantial. However, there are no data available for passerine migrants to assess how much of this mortality occurs as a result of events during actual migratory flight relative to how much mortality occurs at stopover sites (Newton 2004). Moreover, questions about basic spatiotemporal patterns of mortality during migration are simply unexplored. This conference will focus on (1) assembling and reviewing data on stopover biology of MIGRATE's model species; (2) applications of intrinsic and extrinsic tracking methods specifically targeted for studying sources, locations, and timing of mortality during the en route migration and stopover periods for these model species; and (3) how tracking techniques can be used to link en route biology to reproductive success and winter mortality.

Year 4: **Migration and Population Processes**. (Organized by S. Mabey). A primary reason for improving our ability to measure animal movement is to better understand population dynamics. In fact Turchin (1996:2086) contends that "movement is the glue that connects local population dynamics in time and space, and it is now widely appreciated that quantitative studies of population redistribution in the field are a necessary component of any research program aiming to understand spatial population dynamics." More impetus for quantifying movement comes from studies indicating that the degree to which breeding and winter sites are connected (i.e., share the same individuals) can matter a great deal to the dynamics and evolution of populations (Webster et al. 2002, Webster and Marra 2005, Runge and Marra 2005). Despite these conceptual advances, there remain no true estimates of survival of small-bodied migrants during the migratory phase. Nor is there a good example of an empirically driven analysis of the relationship between connectivity and dynamics of populations. There is, however, tantalizing evidence suggesting that effects that carry-over among phases of the life cycle can strongly impact vital rates of populations (Marra et al 1998, Norris et al 2003, Smith and Moore 2005).

This conference seeks to make progress on four fronts: (1) identifying data for model species that can be used to infer vital rates from different stages of the annual cycle; (2) incorporating migration data into existing or new models of population dynamics to generate predictions regarding population trajectories; (3) identifying key parameters to be tested or measured in the field to bolster models on population dynamics; and (4) exploring which methods of tracking movement will contribute most to improving measurements of population parameters. This conference is planned for year four because we anticipate that much data synthesis will be required on model species before such an effort can be most productive.

Year 5: **MIGRATE - The next five years** (Organized by T. Smith) – This conference will summarize activities of MIGRATE members over the five years covered by the proposal and look toward the next steps for advancing research on migration of model species. In particular, critical evaluation of the model species approach from outside the MIGRATE network will be sought. Discussion will focus on re-evaluating the species upon which research is focused and changes in the network's priorities for the coming five-year period. Solicitation of new ideas will follow protocols used in the Year 1 conference. In particular, suggestions for changes will be solicited prior to the conference and the resulting documents will be circulated to attendees. Key questions will examine (1) what findings of MIGRATE's 1st five years have improved our general understanding of animal movement ecology and (2) how should the network re-orient to address topics that will provide the most rapid advance in our understanding of animal movement. Accomplishments regarding research productivity, education, and outreach will be evaluated by each of the Co-PIs in their area of expertise. Expected outcomes include collaborative proposals for continued funding of the core activities of the MIGRATE network.

Laboratory Exchange Visits: Laboratory exchange visits will contribute substantively to the success of the MIGRATE network by providing researchers and students with the opportunity to share techniques and ideas in depth. Each year, we will support a limited number (6-12) of extended exchange visits for MIGRATE participants granted through a proposal process. Ideally, exchange visits will provide opportunities for cross-disciplinary training and collaboration as well as provide a basis for developing international connections. Proposals will be evaluated on their scientific merit, their contribution to the objectives and goals of the MIGRATE network, and their contribution to forging new collaborations, particularly those involving researchers and students from under-represented minorities. We anticipate exchange visits will support the following types of activities: (1) dissemination of novel laboratory, field, or quantitative techniques; (2) integrated analysis, review or synthesis leading to publication; and (3) development of new interdisciplinary research proposals.

Student Field Training Course: The MIGRATE network will create a unique platform for attracting student scientists to the complex, interdisciplinary area of movement ecology. We propose to host a rigorous training program for students that will provide an opportunity to develop technical field, lab, and quantitative skills. The course will be an intensive two-week field-based experience hosted at sites associated with the long-term migration research of MIGRATE PIs. For example, F. R. Moore has operated a fall migration banding and research station on the Bon Secour National Wildlife Refuge at Fort Morgan, AL for almost 20 years. This site fulfills both the ecological (e.g., accessible and abundant migrants; high migrant and habitat diversity) and the logistical (e.g., available housing; near major airport) requirements of a course location. Students will learn and practice core field skills including mist-netting and bird banding (e.g., net extraction, ageing and sexing, measurement protocols); field tissue collection (e.g., proper feather and blood collection and storage); survey techniques (e.g., transect and point counts); and data collection and management. In addition to this central curriculum, we will establish a working group to develop modules focusing on quantitative analysis and application of intrinsic and extrinsic markers. We will recruit students through announcements posted on the MIGRATE website as well as through professional societies, related networks and organizations, and Alliance for Graduate Education and the Professoriate (AGEP) programs. Prospective students will submit applications and will be selected according to publicly available criteria established by the Training Working Group and Steering Committee. Course instructors will be solicited from the pool of active MIGRATE participants. The field training course is not only an efficient way to train students new to the practice of migration ecology; it provides an important opportunity for students to develop close connections within their academic cohort that can lead to career-long associations and collaborations.

MANAGEMENT PLAN

General Operation of the Network — The MIGRATE network will be organized to promote growth, evolution, openness, and equitable allocation of resources. The University of Oklahoma will be the lead institution for funding and management purposes. To consolidate management and ensure consistency, PI Kelly will be the lead Network Coordinator and have managerial oversight of network activities, scheduling, and progress toward network goals with support from a funded assistant coordinator and a computer technician/webmaster. The five additional co-PIs will each spend one year in the position of co-Network Coordinator working with Kelly to achieve network success. In addition to this foundation of leadership, we will establish a Steering Committee to work together with the PIs and assistant Network Coordinator on matters related to recruiting and selecting participants for training activities and reviewing proposals for exchange visits and conference and workshop submissions. The Steering Committee will include the six co-PIs with an elected membership of 4-6 core network participants to ensure broader representation. The elected members of the Steering Committee will be nominated and selected at our first conference and membership will change annually. After the first year, at least one member of the elected steering committee will be a student. We expect the Steering Committee to reflect the diversity of MIGRATE's Core Participants but we will make an additional effort to maintain representation from both North America and Latin America. Working groups will be established to deal with specific tasks as needed. Each working group will chaired by a co-PI.

The co-Network Coordinators will have primary responsibility for (1) overseeing and hosting the annual network meetings; (2) coordinating student training, laboratory exchange visits, and citizen science activities; (3) acting as primary contacts for communication with the Steering Committee, working groups, and sister networks; (4) scheduling and chairing bi-monthly phone conferences with the Steering Committee; (5) maintaining current content on the MIGRATE website; and (6) coordinating review and publication of conference proceedings. The Steering Committee will be tasked with ensuring that the network becomes increasingly inclusive and the resources are distributed equitably among the participants. Annual turnover of the elected membership of the Steering Committee will guard against partiality for particular research groups or institutions. The MIGRATE Steering Committee will be responsible for expanding mechanisms for widely recruiting participants for training activities, laboratory exchange visits, and conferences. Participation in training activities will be based on a simple application process whereas exchange visits will require a short proposal. Each year the Steering Committee will review applications for all MIGRATE activities and select the top candidates. Open calls for applications for student training will be posted through newsletters of professional societies and linked to minority student development programs (e.g., AGEP-sponsored programs like Alliance for Graduate Education in Mississippi (AGEM)).

We anticipate an initial need for four working groups to be established at the first annual meeting. These working groups will focus on (1) data standards; (2) tissue/specimen collection, archiving, and sharing; (3) citizen science and outreach; and (4) hands-on student training. Membership in working groups will be open to Core Participants and recommended and willing colleagues and students.

We have selected initial Core Participants to closely reflect our scientific and programmatic goals and provide representation from the key fields of ecology, genetics, biochemistry, parasitology/epidemiology, engineering, mathematics, statistics, and conservation. This group includes internationally recognized leaders in the field of migration ecology and innovators in the application of intrinsic and extrinsic markers to the problem of movement. The spatial scale of avian migration mandates that coordinated research on migratory movement occur across continents. To facilitate our primary objectives, the Core Participants are broadly distributed across all geographic regions of the United States and include scientists from Canada and Latin America. Additionally, we have garnered support and participation from internationally-recognized European migration ecologists as a basis for broadening our approach to movement ecology and establishing a formal point of contact for pursuing comparative research and synthesis across migration systems. The MIGRATE network concept has attracted scientists from a wide variety of academic institutions including Tier I and II universities, Masters-granting universities, and four-year colleges as well as private and government-sponsored research and conservation institutions. The geographic and institutional scope associated with this impressive group of initial Core Participants will substantially enhance our ability to reach populations of colleagues and students traditionally under-represented in the sciences.

Initial Core Participants who have provided statements describing their current activities and how they relate to the MIGRATE network or provided informal agreement to participate are: F. Bairlein (Institute of Avian Research, Germany), W. Barrow (U.S. Geological Survey, Lafayette, LA), S. Bensch (Lund University, Sweden), K. Bildstein (Hawk Mountain), G. Bowen (University of Utah), L. Clark (Bennett College for Women), R. Greenberg (Smithsonian Migratory Bird Center). Keith Hobson, (Environment Canada) S. Haig (USGS and Oregon State University, Corvallis), D. Irwin (University of British Columbia, Canada), A. Jahn (University of Florida), J. Kelly, (Univ.of Oklahoma), S. Mabey (North Carolina State Univ.), P. Marra (Smithsonian Environmental Research Center), D. Mehlman (The Nature Conservancy), F. Moore (Univ. of Southern Mississippi), S. Morris (Canisus College) R. Norris (University of British Columbia), K. Pollock (North Carolina State University), R. Ricklefs (University of Missouri St. Louis), J.P. Rodriguez (Instituto Venezolano de Investigaciones Cientificas Centro de Ecologia, Venezuela) S. Skagen (USGS, Ft. Collins), J. Smith (NASA –Goddard Space Flight Center), T. Smith (UCLA), F. Spina, (Istituto Nazionale per la Fauna Selvatica, Italy), M. Wikelski (Princeton University), M. Wunder (Colorado State University).

Interested researchers will be able to register at the MIGRATE website to receive electronic notices of events and opportunities associated with the network. The MIGRATE network and associated activities will be advertised through professional societies such as the Ornithological Societies of North America, the Neotropical Ornithological Congress, the International Ornithological Congress, the Ecological Society of America, and Society for Conservation Biology and through websites of sister networks and programs organized to cultivate minority students in the sciences (e.g., NSF AGEP programs). We will further raise the profile of the MIGRATE network by encouraging participants to organize symposia at national/international meetings.

Assessment of the proposed activity — The objectives of the network are primarily to promote science and scholarship through an integrated study of movement ecology. We will assess the success of the MIGRATE network in relation to both broad objectives and specific goals. We will solicit assessments through our website and annual meetings and will compile an annual report documenting specific accomplishments including: (1) number of cross-disciplinary proposals developed and submitted; (2) number of students trained; (3) use of network materials and protocols in publications; (4) number of new registered visitors to the MIGRATE website; (5) number of new Core Participants; and (6) publications resulting from integrated analysis, review, or synthesis emerging from exchange visits or resulting from other network activities. The annual report will be published online. At the end of the five year term of the MIGRATE network, we will also assess our success based on broader questions relating to our objectives. For example, is there significant focus on model species for which understanding of migratory biology is rapidly expanding? Is the accuracy and precision of measurements of long-distance movements significantly better using cross-disciplinary approaches than with single markers? Has the network driven better general understanding of animal movement? This assessment will develop from discussions and invited comment during our final annual conference and published within the proceedings of that conference.

COORDINATION PLAN

The MIGRATE network will coordinate research and yield insights valuable to a number of on-going scientific and conservation initiatives. MIGRATE's scientific objectives of understanding movement ecology through advances in tracking individuals and populations over space and time parallel those of the European Optimality in Migration initiative. MIGRATE and this European network will benefit from interaction and cross-communication. Comparisons of the Nearctic-Neotropical and Palearctic-African migration systems will strengthen our understanding of the evolution of migratory behavior and responses of migrants to environmental change. Several of our initial Core Participants are actively involved in Opimality in Migration initiative, including Franz Bairlein who coordinates and oversees that initiative. The MIGRATE network and the currently funded E-BIRD RCN have a natural linkage in that both networks will contribute to an integrated understanding of avian life histories. We propose to interface with E-BIRD and cross-link our websites. We will pursue further formal connections to appropriate programs and initiatives such as the Landbird Migration Monitoring Network of the Americas and the Western Hemisphere Migratory Species Initiative.

Our goals for cultivating scientists from traditionally under-represented minorities strongly overlap with two additional programs in which two of our principal institutions are actively involved. PI Moore (USM) has an established connection with the Alliance for Graduate Education in Mississippi (AGEM) and PI Mabey (NCSU) has an agreement from North Carolina Opportunities in Education Program (NC Opt-Ed) to maintain contact with the MIGRATE network. AGEM and NC Opt-Ed are both funded through the NSF AGEP programs designed to create and promote opportunities for minorities in the sciences. Working with AGEM and NC Opt-Ed will allow us to advertise MIGRATE activities and opportunities and recruit students as well as access AGEM and NC Opt-Ed opportunities to involve minority students in MIGRATE-related research. We will solicit the Core Participants for recommendations and connections with similar programs.

INFORMATION AND MATERIAL SHARING

The primary means for sharing information and material across the MIGRATE network will be a publicly accessible website. Through the MIGRATE website we will link to sister networks, professional societies, and other appropriate entities (e.g., Partners-In-Flight, Institute for Bird Populations) to achieve maximum openness and accessibility. Additionally, a primary objective of the PIs will be to publish and widely disseminate both conference proceedings and syntheses that emerge from this trans-disciplinary work.

By its very nature, untangling the problem of tracking individuals and populations must rely on data sharing. No single researcher can gather all the data necessary to thoroughly describe migratory movements and understand migratory connectivity. Furthermore, many scientists conducting field research on migration ecology have access to tissue samples such as feathers and blood but lack the expertise to analyze them for intrinsic markers.

For these reasons, data and material sharing will be a critical aspect of the MIGRATE network. In order for data or tissue samples to contribute to studies involving multiple sites and researchers, basic standards must be in place (Cook et al 2001). Adoption of data standards and tissue collection and storage protocols developed by MIGRATE working groups will facilitate effective data and tissue sharing (see Data Standards above). Through the MIGRATE website and interactive activities, we will establish data-sharing mechanisms to facilitate integrated use of multiple data types as well as sharing of new quantitative spatial methods to improve inference regarding animal migration.

Researchers interested in sharing data and/or specimens will be encouraged to post standardized meta-data from their relevant projects on the MIGRATE website along with contact information. Registered visitors to the website will have access to this list. Contact and negotiation of the conditions of sharing, including authorship and attribution, will be the responsibility of individual researchers. Data collected through MIGRATE's Citizen Science campaign will be available through the website to network participants and registered visitors who fill out a use agreement form specifying guidance for attribution and acknowledgement.

MIGRATE conferences, laboratory exchange visits, and student training will all allow for repeated exchange of developing technological innovations and analysis methodologies. As new protocols for technologies or methods emerge from MIGRATE activities and are incorporated into network standards for data collection and tissue handling, the network will require appropriate attribution of the protocols in the form of acknowledgement or formal citation.

PLAN TO INCREASE DIVERSITY

The international scope and inter-disciplinary basis of the MIGRATE network creates an ideal platform for attracting traditionally under-represented minorities. Capitalizing on this strength, we specifically propose to: (1) leverage and expand our existing connections to AGEP programs (e.g., AGEM, NC Opt-Ed), (2) make our website available in Spanish, (3) reserve priority placement in training courses for Latin American students and North American minority students, particularly those from technological sciences such as genetics or electrical engineering seeking cross-training in ecology. We further anticipate success in this area because the PIs and the initial group of Core Participants represent all geographic regions of the United States and the broadest array of academic institutions, with particularly strong representation from the Southeast, Southwest, and West Coast where high concentrations of minority students can be found. One of our PIs (F.R. Moore) regularly attends AGEM conferences and, as chair of the Department of Biological Sciences, has been involved in mentoring numerous AGEM students at University of Southern Mississippi. Citizen Science activities will feed K-12 science curricula and excite interest among future scientists in the potential of emerging technologies and migratory phenomena. We will actively advertise our citizen science effort and the MIGRATE network through professional societies of science educators.

SIGNIFICANCE/BROADER IMPACTS

Our proposal focuses narrowly on the ability to track individual organisms over large distances and relatively short time scales (i.e., those relevant to physiology, behavior and population dynamics). While the implications for basic ecology and evolutionary biology are significant, the products of this network will also be valuable to a host of issues relevant to the health and welfare of the general public. The application of emerging intrinsic and extrinsic tracking technologies to novel problems from the field of ecology will provide feedback for improvement of the technologies themselves. The rigorous research that results from the MIGRATE network will lead to the development of tools to infer sources of DNA, stable isotope ratios, and trace elements. Advances in use of molecular markers will have applications across a broad range of disciplines such as identifying the sources of bio-terrorism to commercial testing of ingredient purity. Successful use of external tracking devices for the study of large-bodied landbird migrants is already possible with current technology, but will be easier in the future due to improvements in miniaturization and efficiency of power supplies. The MIGRATE network will allow students to access the newest developments, make field scientists aware of state-of-the-art technology advancements, and provide an interface between industry and field ecologist in diverse countries.

In the areas of health and economics, the results of the MIGRATE network can be applied to understanding and controlling the spread of disease through animal movement. Moreover, the ability to track individual migrant birds and identify populations will have immediate applications for conservation planning and action as we develop the ability to more precisely define source and sink habitats on a hemispheric scale and identify critical resource needs for migrating birds. With a better integrated understanding of migration ecology, scientists will be poised to use migratory birds to monitor ecological responses to global climate change. The extreme popularity of birds has led to the creation of numerous government-private conservation partnerships over the past two decades (e.g., NABCI, PIF). The results of MIGRATE's efforts will help these initiatives more effectively target their limited resources and contribute significantly to the preservation of migratory birds. . This network will bring together a diverse set of approaches, facilitating communication among researchers on a multinational, continental scale. Finally, the project will provide broad multidisciplinary training for minority students in both the laboratory and the field.

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