Data-driven Wildlife Ecology, Habitat Management and Environmental Sensing

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Background & Proposed Research: Two large-scale NSF-funded environmental monitoring programs, the National Ecological Observatory Network (NEON) and Ocean Observatories Initiative (OOI), have recently moved from planning to implementation. These projects integrate sensing, communication, control, and data analytics to create large-scale environmental sensing networks. However, their sensors are predominantly fixed in space, limiting their application to intensively monitoring a limited number of locations. I propose a system that could leverage some of the data-transport infrastructure of these existing networks, but would depart radically in design. <u>A Distributed Dynamic Biological Sensor Network (DDBSN) would utilize animals as mobile environmental sensing platforms by applying inexpensive long-lived wireless sensor nodes (tags) to them, and linking those nodes with data aggregation and analysis tools.</u> The geographic coverage of a particular subset of tags could be prescribed by opportunistically selecting species with known spatial usage. The sensors that these animals carry will sample diverse environmental signals. The DDBSN will build on emerging embedded sensing modalities, like subcutaneous uric acid sensors [1], viral detection [2], and nanobiosensors [3], to allow rapid detection of environmental contaminants and viral outbreaks. Large-scale data of this type, coupled with environmental and geographic location information, could enable powerful epidemiological studies. Physiological sensors on these tags will also enable unprecedented study of animals in their environment.

Movement Ecology, the study of how and why organisms move within their ecosystems, is a rapidly growing field with a new journal (Movement Ecology, BioMed Central) devoted specifically to it [4]. New research tools have begun to allow an unprecedented volume and breadth of data to be gathered, revealing subtle environmental impacts (for example the impact of local weather conditions on stork migrations [5]). Other studies have shown that birds have altered their migration timing in response to global climate change [6]. New sensor networks are also being used to automatically map the social networks of wild animals [7]. These and other successes are occurring within individual research groups, with funding sources that are often specific to a particular ecological niche and that do not emphasize recurring efforts or prioritize sharing of research tools and data. Efforts have been made to create enduring data repositories (MoveBank [8]) of position data, and tools (Movemine [9]) to extract it. Though these projects are designed around position data only, they serve as a template. New programs, similar to NEON and OOI in scope, will be necessary to promote the development of hardware and software tools that will be cost-effective, scalable and enduring.

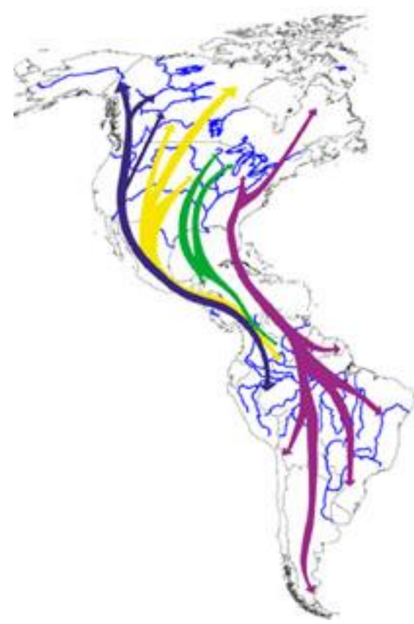

Figure 1 - Major flyways of the Americas, showing the large spatial extent of migrants and narrow migration corridors where short-range communications are tractable

Building and maintaining this network will leverage existing technology but will also require innovations in sensors, communication systems, and data processing. The effort and cost required by current data-gathering methods preclude scaling up these approaches. New communications networks that exploit natural chokepoints (Figure 1) in migratory pathways will allow short range RF communication between tags and routers. Space-based communications systems specifically designed for low-energy tags could provide global coverage [10]. Additionally, ultra low energy positioning systems based on signal arrival time [11, 12, 13], will allow lightweight tags (with small batteries) to provide large volumes of tracking information. Mass is of particular concern since only half of bird species are large enough to carry a 1 gram tag. This constrains the available on-tag energy storage, and will require research into extremely efficient computation, data storage, and communication since even the very smallest existing wireless nodes, motivated by Internet-of-things concepts, are too large and inefficient for this application. The deployment of large numbers of wireless sensors will also drive the development of scalable data archival and mining systems, by necessity. For example, a system that we recently deployed delivers eight bytes of position data once per second for 40 different birds, requiring 27 GB of storage per day for this sensing modality alone.

Impact: New sensors, communications networks and data dissemination and analysis frameworks will radically improve the tools that scientists and conservation managers use to study animals in the natural environment. When they are performed, labor-intensive ecological studies often reveal systemic disruptions [6, 14, 15] from anthropogenic forces. However, human impacts on the environment usually outstrip our current ability to assess those impacts. The large-scale data-gathering capabilities of this system could improve this scenario. Though ecological research and conservation efforts are important in their own right, the data gathered by these new tools will be far-reaching. Migratory species traverse multiple ecosystems out of necessity, and therefore serve as ideal distributed sensor platforms from which to sample diverse environmental variables including position, temperature, humidity, specific pathogens, gas concentrations, and radioactive decay. New sensors and communications networks will allow salient physiological signals from tens of thousands of migratory animals to be monitored in near real time. These data, in conjunction with location information, will provide rapid updates on relevant environmental conditions and could allow detection of emerging zoonotic disease outbreaks. Designing mobile sensor platforms and communication networks for birds and wildlife to be long-lived, small, rugged and inexpensive will require surmounting many engineering challenges. This application domain presents unique physical challenges to developing cyber-physical systems, and the opportunity for a CPS with true global reach.

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