Red Knot, Yves Aubry

Motus
Wildlife Tracking System

Version 2022

Strategy to 2030

Tracking wildlife, driving science and conservation

BIRDS CANADA | OISEAUX CANADA

Contents

Cerulean Warbler, Jose Pablo Castillo

Northern Wheatear, Siebe Wiersma

Plan at a Glance

Motus is both a science, technology and outreach program managed by Motus Central at Birds Canada, and a large, vibrant, highly committed community of organizations and individuals around the world working together for the conservation of migratory animals.

Vision

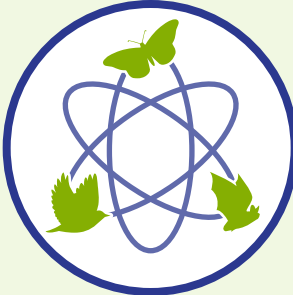Motus is a global research network delivering critical information to conserve small flying animals.

Goals

By 2030, we will achieve our vision by meeting four goals.

Enabling Conservation

Motus results widely inform conservation decision-making

Pioneering Science

The system drives fundamental advances in movement ecology

Building Community

A strong, inter-continental network built on local capacity

Innovating Technology Integration

Industry-leading standards that prioritize the user community

Objectives and Milestones

Table 1: Goals, objective and milestones

Goal	Objective	Milestones
Enabling Conservation Motus results widely inform conservation decision-making	**1.** Increase institutional partnerships	Ten agreements with national conservation organizations by 2027
	2. Cement Motus as a primary tool for conservation delivery	10 conservation initiatives/coalitions integrate Motus into decisions by 2025, 25 by 2030
	3. Engage large new audiences through outreach and story-telling	50 institutions, 0.5 million members of the public using four major tools by 2028
Pioneering Science The system drives fundamental advances in movement ecology	**4.** Create discipline-leading science opportunities	Mechanisms of population change published for 20 species by 2030
	5. Develop industry-leading data services delivered through Motus Central	New web platform launched by 2024 / 10+ Motus Central staff by 2030
	6. Advance open data frameworks	60% of Motus data are open access by 2025, 90% by 2027
Building Community A strong, inter-continental network built on local capacity	**7.** Establish an international network of regional coordination groups	15 well-resourced, networked regional coordination groups by 2026, 20 by 2030
	8. Empower collaborators and foster champions	100 champions spread across 30 countries by 2028
	9. Establish Motus intersections with Indigenous priorities	Motus projects led and staffed by Indigenous communities
Innovating Technology Integration Industry-leading standards that prioritize the user community	**10.** Foster innovation with technology partners	Collaborative development of standardized technologies and data flows by 2025
	11. Improve best practices in infrastructure and tag deployment	Tag impacts quantified, improvements implemented, and best practices published by 2025, infrastructure longevity maximized by 2026
	12. Integrate emerging technologies	Five priority tracking and environmental data types integrated by 2030

A collaborative research network tracking wildlife movement for conservation
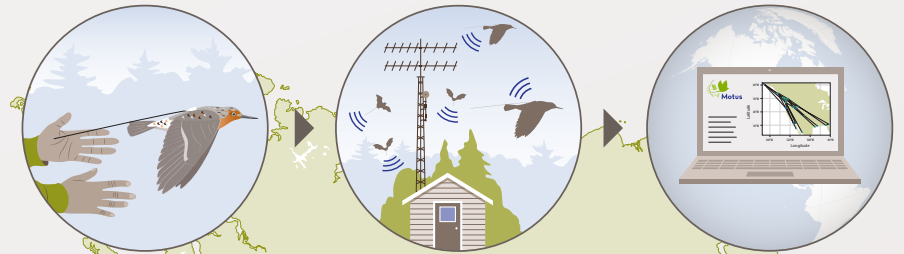
Radio tags are put on animals.

Stations collect data from tags.

Data are processed and used for research and conservation.

Motus station

B. Europe

North Sea
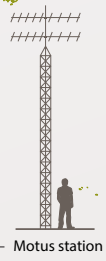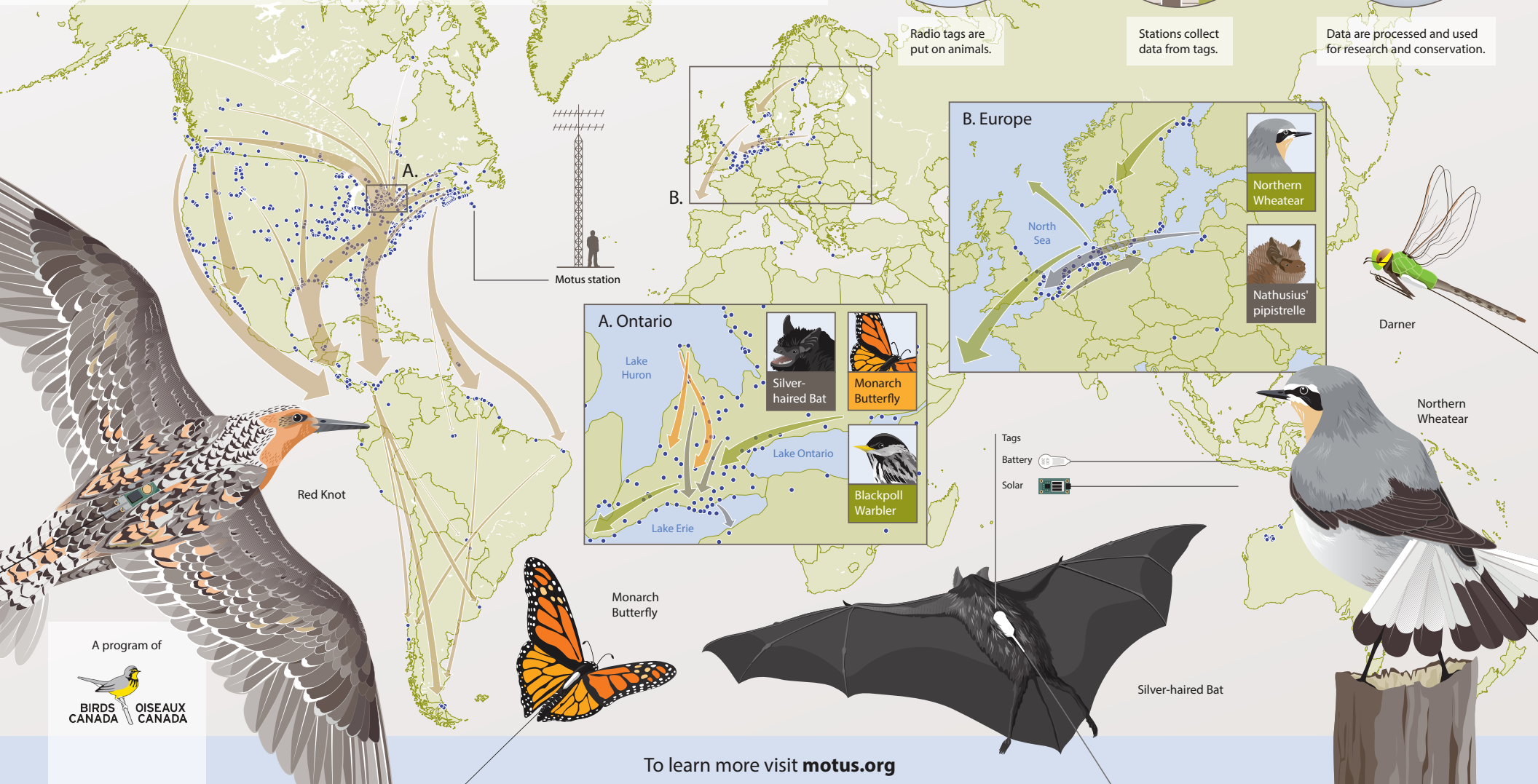
Northern Wheatear

Nathusius' pipistrelle

A. Ontario

Lake Huron

Lake Ontario

Lake Erie

Silver-haired Bat

Monarch Butterfly

Blackpoll Warbler

Tags

Battery

Solar

Red Knot

Monarch Butterfly
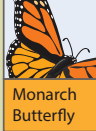
Silver-haired Bat

Darner

Northern Wheatear

A program of

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To learn more visit **motus.org**

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Motus: What it is, and How it Works

The Motus Wildlife Tracking System (hereafter Motus: Latin for movement or motion) is a collaborative global network using automated radio telemetry to track small flying organisms (birds, bats, and insects). Motus answers fundamental research questions underpinning conservation and provides novel education on animal movement and behaviour, from local to global scales. Motus is a program of Birds Canada in close collaboration with a diverse network of organizations, businesses and individuals.

The Motus system has four unique characteristics:

1. lightweight tracking devices can be safely fitted to the smallest birds, bats and larger insects;

2. it enables high resolution tracking in time and space;

3. the infrastructure, technology and data are affordable and accessible, increasing equity among researchers; and

4. individual contributions are magnified through a diverse, networked community of people working cooperatively toward shared science and conservation objectives.

Motus uses digitally-coded radio tags that emit signals on a single frequency, detectable at ranges of up to 20km by an open-source network of receiving stations, unlike traditional VHF radio telemetry, where tags emit pulses on different frequencies. This enables thousands of animals of hundreds of species to be tracked simultaneously. Irrespective of where an animal has been tagged, be it northern Europe or southern Chile, all data are processed centrally and returned to the user. Participants in the network set up receivers and deploy registered

Monarch Butterfly, Grace Pitman

Ana Gonzalez

Tiana Burke

Red Knot, Julian Garcia Walther

tags for their own purposes, and in doing so leverage the time and effort of other users, with mutually reciprocal benefits. This coordinated coalition expands the scale and amplifies the impact of everyone's work, and optimizes scarce research and conservation funds.

The growth trajectory of Motus has been impressive (Figure 1); between 2016 and 2022, the number of receiver stations annually active increased almost 300%, from 430 to >1,426 in 31 countries; the number of projects increased six-fold from ~75 to 510, deploying 33,259 tags on more than 285 species of birds, bats, and insects (including >80 species of conservation concern in the western hemisphere), from which 149 peer-reviewed journal papers and scientific documents have been published.

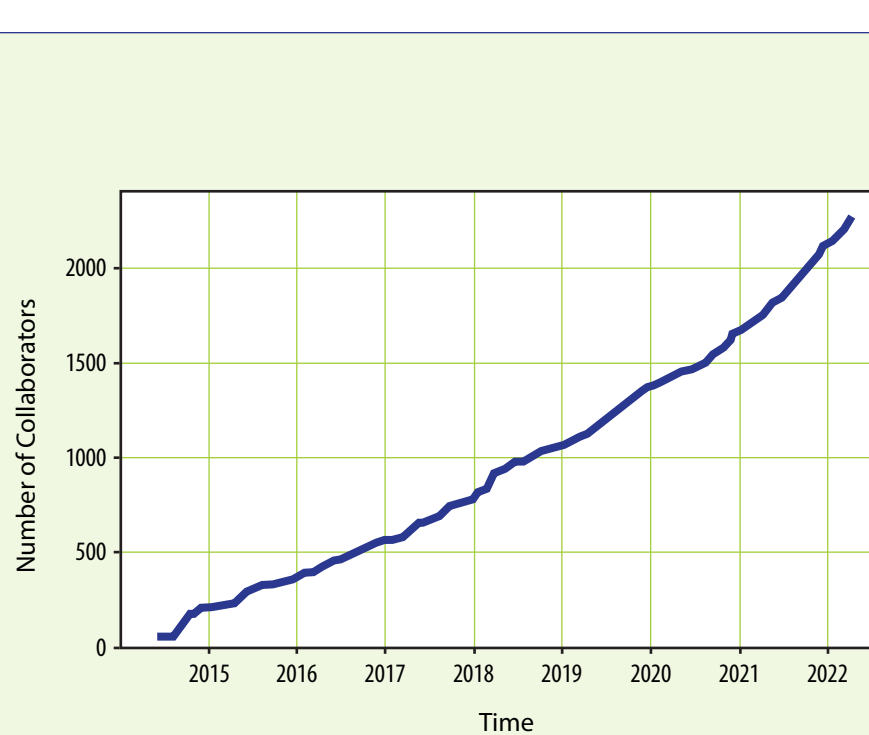**Figure 1:** Growth in Motus collaborators 2015-2022 (left), and Motus metrics 2022 (right)

4 Continents

31 Countries with Motus receiver stations

1,426 Receiver stations

285 Species tagged

33,259 Animals tagged
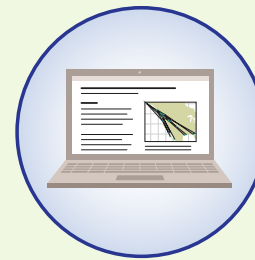
510 Projects to date

2,000 Partners and collaborators

149 Publications based on Motus data

Motus is designed as a positive feedback loop (Figure 2). Core elements of the work are conducted under a common framework, and central data portal maximizes access and use. These aspects drive increased research impact, which in turn drives greater participation. The value of the Motus network grows as the number of stations and collaborators increases. The growth rate to date shows how the conservation science community has rallied behind and adopted Motus, which underscores its future potential. Motus now provides a framework for global collaboration, integration of multiple technologies, and a coordinated approach to solving some of the most complex problems in movement ecology, including some of the major challenges in the conservation of migratory animals (Annex 1).

1 Strategic deployment of shared receiver networks

2 Animal tagging to answer specific research questions

3 Central data processing and management portal maximizes access and use

4 Highly collaborative system drives innovation and develops more highly qualified personnel

5 Increased research, conservation and outreach impacts drive greater participation and investment

Motus

Figure 2: The positive feedback framework of Motus (and adapted from Crewe et al. 2020)

Motus Ambition and Strategy

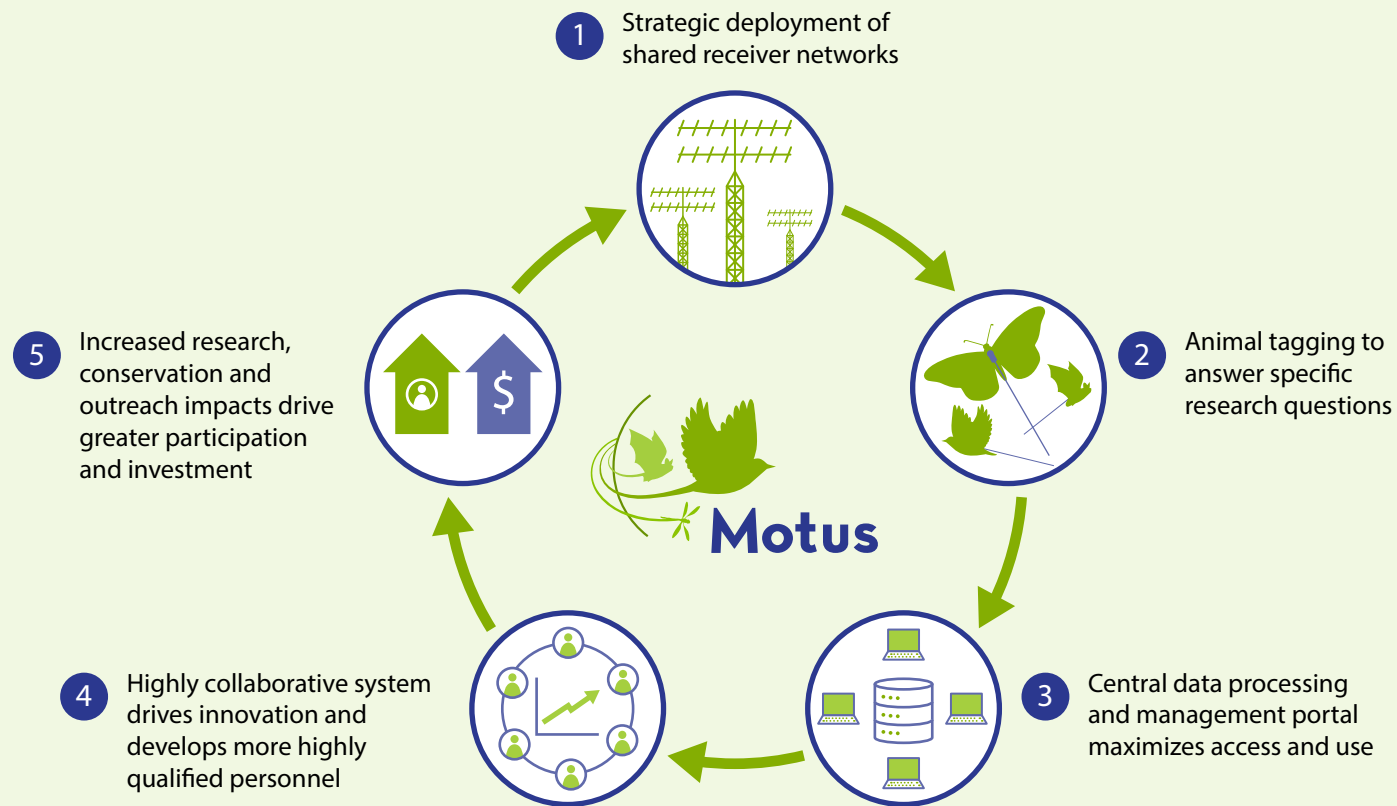This plan – the result of a two-year consultation process engaging the full spectrum of Motus collaborators, investors, and other stakeholders – sets Motus on a course to maximize the strengths of the system, making it an indispensable tool for scientists and agencies responsible for the conservation of smaller flying animals.

Motus originated, and has grown most prolifically, in the western hemisphere, but is now an important scientific tool in Europe, and beginning to fledge in other regions. This plan is designed for Motus practitioners in any region. Ambition naturally centres on the western hemisphere, where lead organization Birds Canada is based, however, Birds Canada is committed to working with partners in Europe and other regions to help realize the potential and ambition underlined by early results and passion for the system in those places.

Governance and delivery will be achieved by strengthening the core "Motus Central" group (led by Birds Canada), strengthening and expanding Motus Regional Coordination Groups (managed by partners and collaborators with support from Birds Canada), and mobilizing a vibrant and diverse, networked community, including technology partners, educators and an engaged public (managed through responsibilities shared between Birds Canada, partners and collaborators).
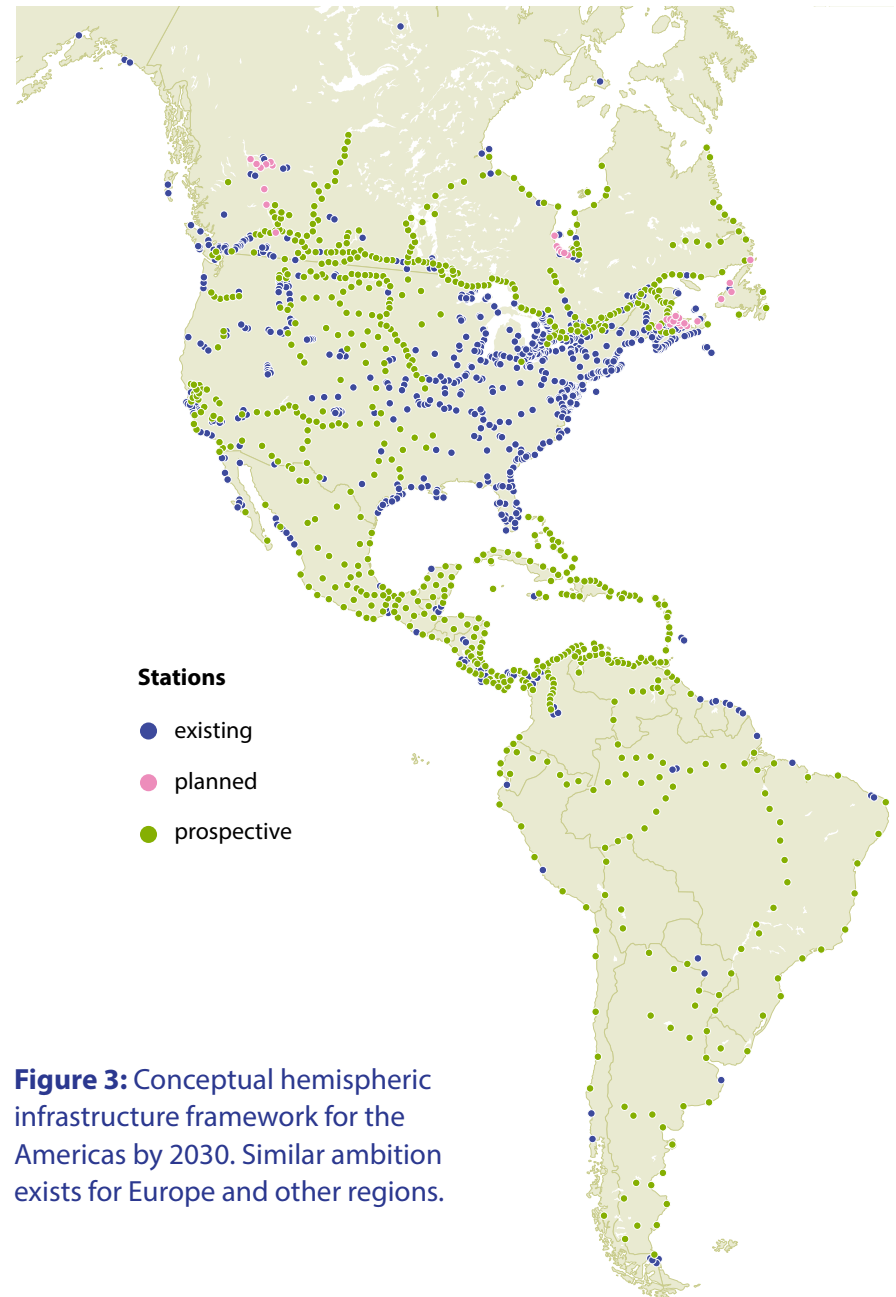

Stations

- existing
- planned
- prospective

Figure 3: Conceptual hemispheric infrastructure framework for the Americas by 2030. Similar ambition exists for Europe and other regions.

Principles for Growth

Growth of the Motus system will be guided by the following principles:

Capacity
Motus data growth is limited by the capacity of Motus Central to provide high data service standards to the community of users. Motus infrastructure growth must be matched by aligned investment to grow the regional coordination hubs that maintain the core infrastructure.

Data Collaborations and Sharing
Motus recognizes that an open data policy is a powerful tool to minimize barriers to data access, to maximize data value, and to ensure appropriate collaborator recognition, but balances this with the importance of respecting individual collaborators needs.

Equity
Motus will continue to promote equity in research and development, striving to lower financial barriers to using technology, maintaining non-proprietary, open-source, affordable hard- and software, and encouraging technology companies and individuals to contribute to system improvements for all.

Priority
Motus will focus on strategic infrastructure expansions and projects that enable innovative conservation science, to support animal groups at greatest risk (e.g., aerial insectivores, neo-tropical migrants, grassland and shorebirds, larger migratory insects, and bats), and to inform compatible industrial and commercial applications (renewables, contaminants, agricultural and urban landscapes).

Inclusivity
Motus is strongly supportive of all projects and collaborators using the system. A focus on regional capacity growth will ensure the network can meet the support needs of all local projects in all regions, including those that may not overlap stated priorities.

Piping Plover, Peter Paton

Northern Wheatear, Harro H. Müller

Major Milestones and 2022 Baselines

By 2030, Motus aims to comprise a network of strategically placed infrastructure arrays (2,500, 5-year resourced, permanent stations), supported and maintained by 20 regional coordination centres and 100 local champions in 30 countries. The science will contribute to identifying previously unrecognized mechanisms of population change for 20 species, and will inform conservation actions taken by 25 conservation agencies and coalitions.

By 2030

2,500 permanent stations
490 existing (●), 2,010 added by 2030 (●)

● = 10 stations

20 regional coordination centres
7 existing, 13 added by 2030

100 champions
30 existing, 70 added by 2030

30 countries*
6 existing, 24 added by 2030

* with regional coordination centres and champions

20 population impacts

25 conservation agencies and coalitions
5 existing, 20 added by 2030

Motus

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Goal: Enabling Conservation

Overview

The timely application of knowledge gained from Motus, by agencies, practitioners, and partnership initiatives responsible for conservation, is a key to success in this next phase of development. Many of these groups have well-established local to continental-scale conservation priorities, and have identified science and conservation gaps that Motus can help fill. Engaging more formally with these groups, providing enhanced data products to better integrate Motus into decision-making, and incorporating their feedback to improve the system, is how Motus will enable conservation. A primary mechanism for achieving this is for Motus to formalize partnerships with more organizations that have conservation-based missions and leadership capacity. Another mechanism is to seize outreach opportunities to grow the public constituency for evidence-based conservation, and communicating how collaborators are helping us understand, and make a difference for species, sites and landscapes.

Liza Barney

Northern Saw-whet Owl, Liam Hanks

Objectives

1. **Increase institutional partnerships**

   i. Establish national director and regional coordinator positions with organizations with shared interests and objectives.

   ii. Establish long-term collaborative agreements with government agencies.

   iii. Expand Motus Central (leadership, governance, and coordination) into an international team guiding conservation-focused science and product development, and collaborations.

   iv. Enable conservation organizations to lead in the development of local and regional Motus projects and regional coordination groups.

   Milestone and timeline

   10 multi-year agreements between Motus and government conservation agencies or national conservation organizations by 2027 (2022 baseline = 4)

2. Cement Motus as a primary tool for conservation delivery

i. Develop compelling methods for integrating Motus data into conservation and management decision-making processes through co-production and understanding stakeholder needs; publish case studies of approaches and lessons learned.

ii. Publish and promote conservation outcomes informed by Motus, and share evidence for Motus-informed conservation successes with the public and conservation organizations.

iii. Use products from i) and ii) to expand application of Motus by federal wildlife agencies, (e.g., Environment and Climate Change Canada, U.S. Department of the Interior, Federal Agency for Nature Conservation [Germany]), coalitions (e.g., Partners in Flight), State Wildlife Action Plans in the U.S., species and habitat working groups, and Conservation Investment and Business Plans

Milestone and timeline

10 conservation organizations, initiatives or coalitions integrate Motus into decision-making by 2025, expanded to 25 by 2030 (2022 baseline = 5)

## 3. Engage large new audiences through outreach and storytelling

i. Harness the potential of specific outreach initiatives to raise public awareness of the contributions of Motus (and other tracking technologies) to the conservation of migratory wildlife:

    a. Explore Motus Tools and Nature Counts 3.0, and Status of Birds in Canada web portals (Birds Canada-led);

    b. The Migratory Bird Initiative (National Audubon Society-led);

    c. Atlas of Migratory Connectivity (Smithsonian Institute/ Georgetown University-led);

    d. Movebank Platform (Max Plank Institute-led).

ii. Hire dedicated outreach capacity to coordinate and disseminate science and conservation impacts, specifically:

    a. Develop and implement communications plan aligned to launches or integrations of initiatives listed in 3i;

    b. Generate public-facing narratives and stories for how Motus advances knowledge, informs actions and decisions, and tells stories of migration.

iii. Enable schools, institutions and individuals to host stations, projects, and exhibits as science and conservation outreach tools, through:

    a. Partnering with institutes to develop live exhibits (nature and science centres, museums for children);

    b. Creating and promoting interactive online educational packages, aligned with national science, technology, engineering, arts and math (STEAM) curricula, for three primary audiences: schools (teachers and students); public education centres; university courses and departments.

Milestones and timeline

50 education and natural history-based institutions, plus 0.5 million members of the public, using the four major tools listed in 3i and packages generated under 3iiib by 2028.

Goal: Pioneering Science
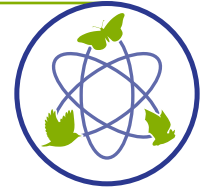
Motus data have contributed to more than 150 peer-reviewed publications, theses, and related works, averaging >25/year by 2022. New migration discoveries, animal behaviors, survival and vital rates, ecological methods, development risks and conservation planning recommendations have all been documented (e.g., Taylor et al. 2017, Motus publications). To advance the scientific impacts of Motus over the coming decade, we propose to: scale up and integrate thematic studies that Motus is best-suited to; strategically expand and maintain arrays that enable fundamental science questions to be answered; focus on user-friendly analytical tools and visualizations; build trust in open data practices and facilitate re-use and collaboration with other open data portals; and grow capacity of the Motus Central core team to deliver services to the highest standards.

Eastern Towhee, Michelle Eshleman

Objectives

4. Create discipline-leading science opportunities

i.   Partner with leading research teams to conduct cutting-edge studies in:

    a.   migration (flight/stopover) and dispersal science

    b.   full life cycle ecology and migratory connectivity

    c.   vital rates and population level tracking

    d.   animal physiology and contaminant impacts

    e.   development risk and environmental assessment

    f.   urban applications

    g.   data science applications

ii.   Develop a hemispheric infrastructure management plan to fully resource maintenance of robust arrays to 2030 for scientific studies at local, regional and hemispheric / flyway scales.

iii.   Facilitate and support leading academic users to address fundamental conservation science questions at broad geographic and population level scales, to guide development of analytics to accelerate research, and integrate with relevant parallel disciplines (e.g., stable isotopes, genetics, banding).

iv.   Leverage the contribution of Motus to research science equity through a Motus dataset identifier and data index metric that enables principal investigators to assess data impact, in a complementary way to citation indices.

Milestones and timeline

Motus data define mechanisms of population dynamics and recommend solutions to threats in high impact journals for at least 20 species by 2029.

5. Develop industry-leading data services through Motus Central

i. Double the core staff of programmers and analysts at Motus Central, to develop state-of-the-art automated data analyses, visualizations and decision support tools, with and for the conservation science community and public audiences.

ii. Publish, and promote advances in data science (data/signal processing, database management techniques and processes) made by the Motus Central team, building on the strengths of the standardized metadata.

iii. Grow the community of altruistic science collaborators innovating new analytical resources and making them available through the Motus R Package.

iv. Support establishment of Motus as a standard monitoring and evaluation tool for industries, building on the applications of Motus to wind energy development.

v. Align resourcing for database capacity to remain ahead of the growing data volume curve.

Milestones and timeline

Web platform featuring sophisticated new tools for exploring Motus data and applications launched by 2024, and continually improved thereafter.

Motus Central team comprises 10 programmers, analysts and data managers by 2030 (2022 baseline = 4)

6. Advance Open Data Frameworks

i. Provide leadership and guidance on open data frameworks.

ii. Generate collaborative opportunities to maximize use of existing/archival Motus data.

iii. Integrate Motus data into other open data repositories.

iv. Pursue avenues to promote the role of Motus in advancing open-access code and tools, communicating science, mentorship, and informing open data related policies.

Milestones and timeline

60% of Motus data are open access by 2025, and 90% by 2027 (2022 baseline = 30%).

Erin Strasser

Goal: Building Community

Motus is made possible by a diverse, inclusive community of people. Motus promotes an open and collaborative environment where individuals, agencies, organizations, academic institutions, and corporations all work together to support the system and achieve common objectives. Collaborators agree to contribute their infrastructure, knowledge, technology, and data to Motus, and share with other collaborators to maximize the efficacy of everyone's contributions. Maintaining the fabric of this network requires strong communication, coordination, and support to enable dedicated champions, long-term commitments, and leadership from many collaborators and partners, at all tiers of system use, from individual projects to large institutions operating many projects.

Motus is a western science program that operates on the traditional territories of many Indigenous communities. Motus is being used by some Indigenous nations as a complement to traditional knowledge, and some nations are leading and collaborating on projects, or hosting receiver stations. Motus collaborators will learn from these experiences and develop an ethical framework for engagement with Indigenous nations, in the context of Indigenous rights and reconciliation.

Objectives

7. Establish an international network of regional coordination groups

i.   Formalize, replicate and adapt the regional coordination group model established in North America and extend to focal regions of Central and South America, Europe and Australasia.

ii. Seek and support regional coordination leaders, typically individuals working for NGOs, government departments,

Julian Garcia Walther

Philip Taylor

and universities, with strong regional project design and/or fundraising expertise, well-connected to conservation partnerships like Partners in Flight and the Joint Ventures, and technical expertise on infrastructure and tag deployment.

iii. Develop a grant or cost-sharing program to support equity in capacity and network growth in Latin America and the Caribbean.

iv. Increase profile and support for role of regional coordination groups as focal points for new and local Motus collaborators.

Milestones and timeline

15 fully-resourced, networked regional coordination groups active in the Americas by 2026, and five more in other global regions by 2030 (2022 baseline = 7)

Woodcock, Nick Flanik

8. Empower collaborators and foster champions

i. Redevelop the motus.org web platform to strengthen the community fabric and further improve service to the wider network

ii. Develop and promote a feedback loop of products, services, and communication to reward station owner/host/landowner infrastructure maintenance and project participation, and drive development and cohesion of regional groups.

iii. Develop a pool of well-trained Motus biologists/technicians within each regional coordination group to a) procure, set up, trouble-shoot and take responsibility for arrays in their region, b) help design, implement and coordinate between regional projects, and c) develop and promote regional best practices.

iv. Deliver and support Motus workshops as a primary training mechanism including best practices in safety when building stations.

v. Promote the many early career development opportunities presented through Motus.

vi. Maximize exposure, acknowledgement and recognition of Motus collaborators in Motus communications, website, and data products and services.

Milestones and timeline

100 Motus champions active across 30 countries by 2028, mentoring biologists, technicians, and public engagement, nurturing regional coordination centres, leading development of discipline-leading science opportunities, and institutional champions (2022 baseline = ~20 in 5 countries).

9. Establish support for Indigenous priorities

i. Explore how Indigenous communities can benefit from the application of Motus in their communities, to support Indigenous Protected and Conserved Areas, monitoring, stewardship, governance, and storytelling, including through the Indigenous Guardians network.

ii. Co-develop fully-resourced, Indigenous-led and Indigenous-staffed Motus projects

iii. Share case studies and lessons learned, including barriers to engagement and how tracking may complement traditional knowledge, to facilitate wider application of the technology where it can be useful to Indigenous goals.

iv. Establish mutual respect and understanding between Indigenous principles of data ownership, control, access and permission, and the open data framework principles of Motus.

Milestones and timeline

Motus projects led and staffed by Indigenous communities, including Indigenous coordinators in Artic, sub-Arctic and Boreal regions (2022 baseline = 0).

Julian Garcia Walther

Dunlin, Amie MacDonald

Goal: Innovating Technology Integration

Motus technology comprises both the physical (e.g. receivers, stations, tags, power systems, modems), and computational infrastructures (e.g. servers, software, processes, presentation and analytical tools, and the database). Motus must continue to solve problems that other technologies do not yet address, and at the same time remain flexible, modular, accessible and affordable. This requires striking an optimal balance between maintaining and advancing the best of existing technologies, enhancing inter-operability between manufacturers, and integrating additional existing and emerging new technologies.

Objectives

10. Foster innovation with technology partners

i.   Establish an open and collaborative working group framework with technology partners around the following design principles:

- *Simplicity* – lowering real or perceived technological barriers to entry, creating "plug and play" options for participants, which require a basic working knowledge only;

- *Accessibility* – wide-scale use of internet or cellular networks streaming data directly to servers and remote updates to software at receiver stations:

- *Affordability* – greater equitability in research, lowering financial entry barriers enabling more people and organizations to participate and large numbers of receiver stations to be deployed Adaptability – to changing technologies with capability to integrate new tag, sensor, and data types as these evolve;
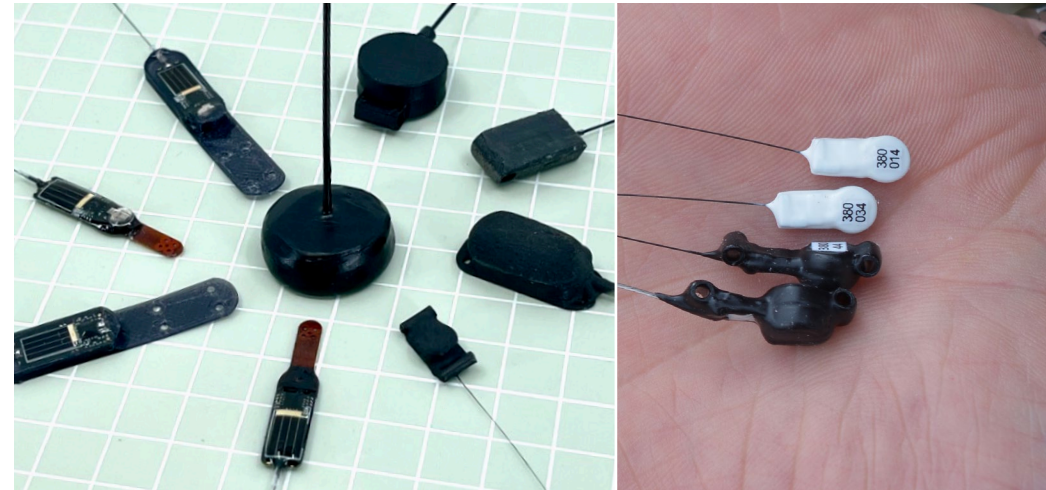
- *Accuracy* – maximizing tag detection range and spatial resolution, and minimizing false detections.

For Tags

- Develop and promote the use of universal tag codesets to be used by multiple manufacturers, and coordinated by Motus Central.

- Support research and development that minimizes tag sizes, and maximizes tag longevity and detection ranges.

For Receivers

- Develop and promote open-source, multi-platform, and interoperable software and hardware, so the system can support multiple manufacturers, tag and receiver-types.

- Maintain legacy support for existing technology for as long as appropriate.

ii. Encourage and incentivize technology partners to invest in, promote and normalize participation in the network

Milestones and timeline

Collaborative development of standardized data flows from all tag, receiver and other sensor types by 2025, significantly reduced from 2022 baseline, and continually improving to 2030.

11. Improve best practices in infrastructure and tag deployment

i. Demonstrate leadership in developing methods and promoting best practice in responsibly and safely catching and tagging animals, and understanding long-term impacts of tags.

ii. Continue to improve and recommend higher standardization infrastructure designs related to site conditions that withstand environmental extremes, minimize maintenance costs, and upgrade all stations as appropriate prioritizing remote stations.

iii. Develop and promote improvements and advances in core technological and methodological aspects of the system that optimize station ability to maximize detections, increase robustness (re. 12ii), and minimize maintenance costs.

iv. Minimize environmental impact of infrastructure and develop and promote procedures and policies that ensure the health and safety of Motus collaborators.

Milestones and timeline

Tag impacts quantified, improvements implemented, and best practices published by 2025, infrastructure longevity maximized by 2026.

12. Integrate emerging technologies

i. Conduct annual horizon-scan with an inter-disciplinary group including technology partners to identify and evaluate emerging opportunities and potentially compatible technologies, tag and data types (e.g. ICARUS, GPS, bio-logging).

ii. In a rapidly changing technological landscape, act as a leader in anticipating technological challenges that may arise, and work with the technology sector to overcome those challenges.

iii. Continue engaging the research and conservation communities to evaluate and prioritize the integration of relevant new technologies and data types of greatest relevance to the Motus community.

Milestones and timeline

Five user-defined, highest priority additional tracking, acoustic and environmental data types integrated into receiver stations and/or data flow by 2030.

Dunlin, Kristin Sesser and Blake Barbaree

Annex: How Motus Science Advances Conservation

Motus is revolutionizing our understanding of flying animals. Taylor et al. (2017) review how Motus is advancing knowledge of animal movement, behavior, and physiology. That science is now being applied to management and protection actions by agencies responsible for conservation. Motus can be used either as a stand-alone technique for specific studies, or in combination with other disciplines to answer questions at local, regional, and continental scales. Motus also provides a mechanism for the public to establish connections with animals and grow the constituency for their conservation through technology and real-world story-telling.

To learn more about how the system informs conservation, this article explains how the long-term survival prospects for hundreds of species are improving through Motus helping to identify where and when conservation efforts and investments are most needed. In a similar piece, Munro (2017) explores what is driving the long-term declines in shorebirds and how Motus helps pinpoint issues along their inter-continental migration routes. This Annex summarizes a few scientific publications that illustrate Motus applications to conservation planning and management at different scales. A comprehensive list of publications is available here.

Red Knots, Ron Ridout

Conservation Planning and Species at Risk Recovery

At local scales, in Atlantic Canada, Motus revealed that recovery of Bank Swallows requires conservation of wetlands, where the birds roost during the breeding season, in addition to the nesting colonies (Saldhana et al. 2019). Motus also revealed that conservation of networks of chimneys by local authorities is vital to stemming further declines in the Chimney Swift (le Roux and Nocera 2021). In Pennsylvania, tracking of Bobolinks helped reveal that delayed haying has a large positive effect on reproductive success, and, effectively engaged farmers, persuading them to switch haying timing in favour of the birds (Willistown Conservation Trust and partners). Motus studies of a nocturnal aerial insectivore, the Eastern Whip-poor-will, in Ontario, filled a breeding habitat knowledge gap, revealing how the birds use a mixed forest-rock barrens landscape, providing land managers with new information on optimal habitat management and creation (Grahame et al. 2021).

At regional scales, Motus has shown that post-fledging survival is a population limiting factor for Barn Swallows in southern Ontario agricultural landscapes, with implications for landscape conservation planning and management (Evans et al. 2019). Motus is especially helpful at identifying carryover effects from one part of a species' life cycle to another, for example drought in a major Arctic coastal wetland (Anderson et al. 2021). On the Gulf coast of Louisiana, Motus has illuminated the crucial importance of high-quality coastal wetland stopover sites to long-distance migratory shorebirds from multiple breeding and wintering areas; this finding strongly suggests conservation agencies and land-use planners prioritize protection of the limited remaining patches of this declining habitat (Herbert et al. 2022).

At continental scales, the continued recovery of Kirtland's Warbler from near-extinction is now being informed by new data from Motus, including identifying the danger of ocean-water crossings, the degree to which breeding warblers move long distances within the nesting season, and understanding their ecology on their very limited winter range (Cooper and Marra 2020). The Red Knot, an iconic shorebird, has suffered huge population losses, despite decades of study and a high public profile. Motus, in combination with other methods, showed that Red Knots in better condition, having fattened up on horseshoe crab eggs in Delaware Bay on their northbound spring migration, were more likely to be found migrating south again in fall (Duijns et al. 2017). Reducing and eventually eliminating the use of horseshoe crabs for biomedical research is the solution being pursued by conservation groups. Motus studies of long-distance migratory songbirds like Canada Warbler and Swainson's, Gray-cheeked and Bicknell's Thrushes linking North, Central and South America and the Caribbean are revealing specific habitat conservation priorities in breeding, migratory stopover, and non-breeding areas of these species annual life cycles (e.g., Begin-Marchand et al. 2022, 2020; González et al. 2021; Bayly et al. 2020, Bulluck 2019).

Environmental Assessment, Development Mitigation and Policy Implications

Motus tracking of seabirds and shorebirds along the Atlantic coast (e.g., Loring et al. 2021, 2019) has been extensively trialed and is now being used as a tool to assess and monitor offshore wind energy siting under the U.S. National Environmental Policy Act. In parallel, data from tracking threatened bats and birds moving over the Great Lakes (Canada/U.S.) and the North Sea (northwest Europe) provide recommendations to offshore wind energy siting and risk assessment (McGuire et al. 2012, Bach et al. 2022, Brust and Hüppop 2022).

Experimental work using Motus as a tool has generated important new evidence on the impacts of contaminants on migratory birds and insects, for example, how sub-lethal exposure to neonicotinoid pesticides (Eng et al. 2019), and the toxic components of oil impair migration behavior (Bianchini and Morrissey 2018), with likely carry-over effects into reproductive and key survival stages of species' life cycles.

Black Tern, Jenni Fuller

Green Darner, Grace Pitman

Red Bat, Brock and Sherri Fenton

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Birds Canada is the country's only national organization dedicated to bird conservation. Every day, our thousands of caring donors, more than 75 passionate staff, and over 74,000 outstanding volunteers are taking action to help us better understand, appreciate, and conserve birds and their habitats. Together, we are Canada's voice for birds.

Birds Canada is a partner in BirdLife International, the largest global alliance for nature conservation, made up of national organizations in more than 115 countries and territories, with a mission to conserve birds, their habitats and global biodiversity, working with people toward sustainability in the use of natural resources.

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Monarch Butterfly, Stu Mackenzie

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