Received: 6 February 2024 | Revised: 12 December 2024 | Accepted: 18 December 2024

DOI: 10.1111/cobi.70194

Conservation Biology

PRACTICE AND POLICY

The collective application of shorebird tracking data to conservation

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Article impact statement: Big data insights enhance shorebird conservation through data sharing, analytical services, and scientist–practitioner collaborations.

Funding information
Knobloch Family Foundation

Abstract
Addressing urgent conservation issues, such as the drastic declines of North American migratory birds, requires creative, evidence-based, efficient, and collaborative approaches. The abundance of over 50% of monitored North American shorebird populations has declined by over 50% since 1980. To address these declines, we developed a partnership of scientists and practitioners called the Shorebird Science and Conservation Collective (hereafter *the collective*). The collective was founded to translate the combined findings of shorebird tracking data into on-the-ground conservation action. With advice from an advisory group, the collective acts as an intermediary whereby dedicated staff collate and analyze data contributions from scientists to support knowledge requests from conservation practitioners. In its first three years, data contributions from 75 organizations include over 7.1 million shorebird observations forming movement paths of 3420 individuals representing 36 species tracked across the Americas and have informed 18 conservation projects spanning education, land and species management, land conservation, and policy requests. Others engaged in translational science from big data could consider similar knowledge-sharing models that prioritize usable data products, foster collaborative engagement between science experts and practitioners, build focused communities around topics or taxonomic groups, and employ a proof-of-concept phase to develop scalable solutions while making progress toward long-term funding to sustain impact. As the volume of scientific data continues to grow, intermediaries, such as the collective, can be vital liaisons to rapidly integrate and interpret research to support conservation action. Dedicated to the memory of Shiloh Schulte and his conservation achievements for shorebirds.

KEYWORDS
Charadriiformes, conservation planning, habitat management, migratory species, movement ecology, satellite telemetry, wildlife tracking

INTRODUCTION

Conservation efforts are often location specific (Stewart et al., 2013), presenting challenges for managing migratory species that traverse vast distances. Shorebirds (Charadriiformes, suborder Charadrii) exemplify these challenges; many travel thousands of kilometers biannually across continents and oceans (e.g., Gill et al., 2009). The flocking behavior of shorebirds gives the illusion of abundance, leading to shifting baselines (Pauly, 1995) and masking major population declines. Relative to landbirds, waterbirds, and waterfowl, shorebirds have exhibited the largest declines (net and percent loss in abundance; greatest proportion of species in decline), of nearly 3 billion birds lost in North America since 1970 (Rosenberg et al., 2019). Declines are not abating (Smith et al., 2020), emphasizing the urgent need for effective conservation action for shorebirds. We created a partnership between scientists and practitioners (defined as those directly guiding conservation) that has responded to this need for action by linking a growing scientific resource—shorebird tracking data—with conservation practice.

Scientists worldwide use electronic tracking devices attached to animals (hereafter *tags*) (reviewed by Robinson et al. [2010]) to record movements, physiological data, and environmental parameters. These data have many applications. They can be used to identify important habitats, infer animal behavior, understand population connectivity, and monitor the environment (Hussey et al., 2015; Kays et al., 2015). Long-standing initiatives have compiled tracking data for collaborative science (Urbano et al., 2021 [European mammals since 2007]) and conservation (Carneiro et al., 2024 [Seabird Tracking Database since 2004]), and new initiatives are emerging (Kauffman et al., 2021; Nightingale 2023; Smith et al., 2022). Aggregating tracking data has led to significant insights into, for example, influences of climate on terrestrial animal movement patterns in the Arctic (Davidson et al., 2020), design of marine protected areas, and how to reduce fisheries bycatch and vessel strikes (Hays et al., 2019).

Significant growth in shorebird tracking studies over the last 20 years offers opportunity for these tracking data to contribute to conservation. Shorebirds and songbirds constitute <1% of studies before 2006, but in subsequent years, these groups constituted 30–75% of tracking studies (Scarpignato et al., 2023). The conservation potential of these increasingly abundant data is evident in recent examples (Chan et al., 2019; Sanders et al., 2021; Verhoeven, 2021), but scaling up is limited by 4 major analytical and conservation challenges (Table 1): limits to data availability; limits to data usability; lack of management focus on shorebirds in many of their important habitats; and the need for strategic integration across organizations and habitats. Although the first 2 challenges apply to many types of occurrence data, they may be particularly relevant to animal tracking

TABLE 1 Factors limiting the application of shorebird tracking data to conservation include limitations to science accessibility and analysis, and limitations to conservation implementation.

Science limitations	
Data access	**Data integration and analyses**
Finding and securing access to relevant data is time-consuming.	Analyzing tracking data for applications is not straightforward.
Despite increasing use of data repositories (e.g., Movebank [Kays et al., 2022]), many tracking datasets are not open access (Scarpignato et al., 2023). Within repositories, data are spread across hundreds of studies led by many scientists. Obtaining private data involves asking permission from many owners.	Preparing, integrating, and analyzing tracking data require specialized statistical and software knowledge (Gupte et al., 2022; Joo et al., 2020; O'Toole et al., 2021). Data integration challenges are common in ecology and limit the use of datasets for the public good (Reichman et al., 2011). Practitioners typically do not have data analyses as a primary job function (Blickley et al., 2013).
Implementation limitations	
Competing priorities	**Need for strategic integration**
Shorebirds are not the priority in many of their important habitats.	Diverse groups undertake shorebird conservation.
Although interior wetland management in North America has moved from a waterfowl focus to an all-birds approach, the extent to which shorebirds are integrated into wetland planning still varies (Doherty et al., 2018). Many shorebirds rely on working lands where management may focus on food commodities production or on game or economically important species. Some management programs need updating to reflect changing conservation circumstances (Sutherland et al., 2012). Practitioners come from diverse professional backgrounds (Ciuzio et al., 2013; Fernández, 2016) that may not include a background in shorebird ecology or how to manage for them alongside primary objectives.	Groups work at all geographic scales (Table 2), have varied funding mechanisms, operate under a variety of legal frameworks, and use varied approaches to science-based conservation implementation. Within groups, distinct individuals can be responsible for research, regulations, program development, or technical assistance. Lack of a central scientific resource focused on shorebirds limits the ability to integrate knowledge across groups to help target local actions to support hemispheric priorities (Brown et al., 2001).

data (Table 1), and special effort may be required to link these data with conservation.

To overcome challenges limiting science translation for conservation, both linear loading dock and interactive (translational or coproduction) approaches are used (Beier et al., 2017; Saunders et al., 2021; Toomey et al., 2017). Each offers benefits under different scenarios. Linear methods involve creating scientific products to be accessed by practitioners (e.g., tracking data repositories, online decision-support tools, publications, and manuals). Despite having conservation benefits (Seavy & Howell, 2010; Sullivan et al., 2017), these products may not be practical due to formatting or language incompatibilities, incomplete data, or mismatched questions, and they can be time-consuming to find and combine into the needed format (Vogel et al., 2007). Interactive approaches range from focused workshops to long-term coproduction in which research and products are collaboratively designed, planned, and implemented by practitioners and scientists (Roux et al., 2006; Saunders et al., 2021; Young et al., 2014). These approaches allow participants to ask clarifying questions (Gerber et al., 2020), build and maintain relationships (Lindell & Dayer, 2022), and engage in active collaborations (Young et al., 2014). Interactive approaches are generally more successful (Cooke et al., 2020), but there are sometimes participation barriers (Oliver et al., 2019; Seavy & Howell, 2010).

We combined elements of linear and interactive knowledge-sharing approaches to form the Shorebird Science and Conservation Collective (hereafter *the collective*).

The collective is a partnership of scientists and practitioners working to advance shorebird conservation in the Americas (Figure 1). We sought to share the origin, structure, and impact of the collective to provide a case study and lessons learned to help others increase the impact of existing science on conservation. The collective is an intermediary organization; dedicated staff collate and analyze data contributions from scientists to support conservation requests from practitioners. This engagement approach differs from many other tracking data compilation initiatives in that staff members provide translational science services (for free when possible) to practitioners to encourage data-informed on-the-ground conservation. We describe how the collective raised funds, initiated a proof of concept, requested data, established operational processes, developed a coproduction process for listening and responding to the needs of practitioners, and contributed to conservation.

ENVISIONING AND LAUNCHING THE SHOREBIRD SCIENCE AND CONSERVATION COLLECTIVE

The idea to collate shorebird tracking studies for conservation was inspired by the conservation successes of BirdLife

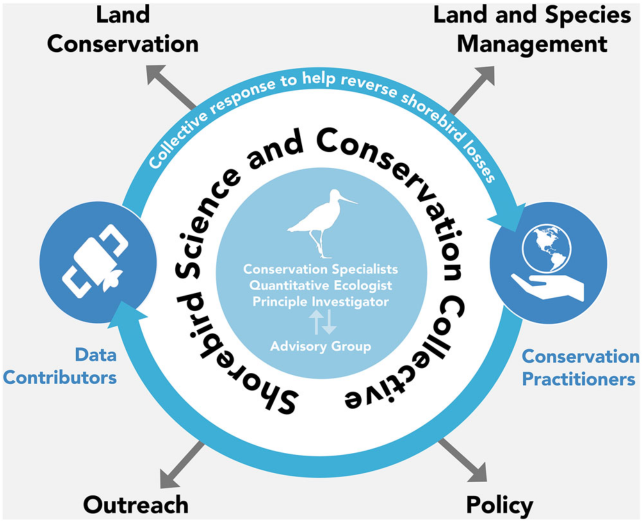

FIGURE 1 The process by which the Shorebird Science and Conservation Collective distributes knowledge generated from electronic tracking studies of shorebirds to conservation partners across the Americas to enhance land and species conservation, management, and outreach and education activities.

International's Seabird Tracking Database (BirdLife International, 2004; Carneiro et al., 2024). We envisioned transforming BirdLife's approach to match how and where shorebird conservation is implemented. This included determining a model of knowledge transfer that could overcome existing limitations (Table 1) and directly support the diverse constituency working to conserve shorebirds (Table 2).

A linear approach, for example, a database that facilitates data discovery or access but requires practitioners to find, request, and interpret complex data and literature themselves, seemed unlikely on its own to maximize knowledge transfer. Instead, we proposed a collective that would extend beyond a repository to an entity that supports knowledge requests from practitioners and provides staff to codevelop conservation products and analyses.

A funding proposal was developed between April and September 2020, and feedback was sought from researchers and conservation practitioners through open-invitation webinar discussions. Many participants were already sharing, codeveloping, or applying research to conservation. As conceived, the collective would add value by expanding conservation opportunities, rather than competing with or replacing existing partnerships.

The proposal included a 3-year proof-of-concept stage focused on the North American interior (hereafter, *Midcontinent*), which groups the Central and Mississippi flyways. In this stage, we evaluated the proposed structure and function of the collective to contribute to shorebird conservation. The Midcontinent is a conservation priority (Midcontinent Shorebird Conservation Initiative, 2024; The Central Grasslands Roadmap, 2022) that provides habitat for 42 of the 50 shorebird species that regularly breed in North America (Brown et al., 2001; Donaldson et al., 2000). The Texas Gulf Coast provides migratory and wintering habitat for more than 1 million shorebirds annually (Withers, 2002), and the Prairie Pothole Region's wetlands and grasslands (Doherty et al., 2018) support millions of migrants (Skagen, 2006; Steen et al., 2018). Wetland loss in these landscapes has been up to 90% in some states (Dahl, 1990, 2014), and these landscapes have high climatic variability, making cohesive management over time challenging (Fellows et al., 2001; Russell et al., 2016; Skagen & Thompson, 2013). Many areas are privately owned (e.g., nearly 90% of the Great Plains is not public [NRCS, 2021]), requiring coordination with landowner-focused agencies, which deliver voluntary incentive programs and provide technical assistance to manage habitat on working lands (examples in Table 1), as well as state and local governments, land trusts, and other conservation entities. The grant was awarded in October 2020, and funds were received in January 2021.

ESTABLISHING A STRUCTURE AND PROCESSES

From January to November 2021, the structure and processes of the collective were established, followed by staff hiring, data requests, and outreach to practitioners. The collective comprises 4 groups (Figure 1): operational team (principal investigator, staff, and chair of the Advisory Group), advisory group (Appendix S1), data contributors, and conservation practitioners. Staff include a quantitative ecologist, who aggregates, processes, and analyzes data, and conservation specialists, who work with practitioners to inform them of the tracking data resource, assess their information needs, and prepare conservation products. The 16-person Advisory Group advises on maximizing the collective's conservation benefit and promotes the collective's value to potential data contributors and conservation practitioner partners. Data contributors typically are researchers from public, private, or nonprofit organizations. Practitioners directly guide conservation actions in management agencies, trusts, and nonprofit groups (Table 2). Some data contributors are also practitioners.

With guidance from all involved, the core team developed operational processes, including a data sharing agreement (DSA) (SNZCBI, 2024a), a conservation use request form (SNZCBI, 2024b), and a reporting system (Anderson et al., 2024) to uphold data privacy agreements and increase accountability to data contributors and practitioners.

Crafting a DSA

Feedback indicated that careful crafting of a DSA would ensure maximum trust and participation by the scientific community. Many factors influence data sharing (e.g., Roche et al., 2020); some policies mandate public sharing (e.g., Wildlife Tracking Data Collection [U.S. Geological Survey Alaska Science Center, 2019]). Conversely, recent data or those restricted by endangered status of a species may require embargo. We thus drafted a flexible agreement to facilitate maximum data

TABLE 2 Examples of organizations, initiatives, and individuals engaged in shorebird conservation and management and the geographic scale at which these organizations operate.

Scale	Entity	Description
Hemispheric or continental	Western Hemisphere Shorebird Reserve Network	Science-based, partnership-driven initiative dedicated to protecting shorebirds through a network of key sites; executive office of the network housed by Manomet, Inc., a nongovernmental organization
Hemispheric or continental	Shorebird flyway conservation initiatives	Network of governmental and nongovernmental partners working to protect shorebirds and their habitats along 3 shorebird flyways (Boere & Stroud, 2006) of the Americas (Pacific, Midcontinent [combining the Central and Mississippi Flyways], Atlantic); each initiative has a conservation strategy to address threats and opportunities respective to that flyway; Arctic Migratory Bird Initiative is an initiative of the Conservation of Flora and Fauna working group of the Arctic Council and operates at a pan-Arctic level
Hemispheric or continental	Flyway councils	Partnership of representatives from states, provinces, and territories that facilitates the management of migratory birds and their habitats in each of 4 administrative migratory bird flyways in North America (Pacific, Central, Mississippi, Atlantic); flyway councils can establish priorities and coordinate collaborative conservation efforts to benefit shorebirds and their habitats
Country	Federal wildlife and environmental agencies	Federal agencies focused on protecting and managing migratory birds, species at risk, and other wildlife; such agencies can target efforts toward shorebirds and their habitat (e.g., enforce policies, write management and recovery plans, monitor, conduct research); examples include U.S. Fish and Wildlife Service and Environment and Climate Change Canada
Region	Migratory bird joint ventures (JVs)	Cooperative, regional partnerships that work to conserve habitat for birds, people, and other wildlife; many JVs have wetland and grassland programs that could affect or create shorebird habitat; there are 22 JVs spread across North America
Region	Collaborative alliances	Central Grasslands Roadmap (multicountry, North America) and the Southern Cone Grassland Alliance (multicountry, South America) focus on the private land management and conservation interface with potential to strengthen commitments to manage grasslands for shorebirds and to sustain human livelihoods
State or province	State and provincial environmental agencies	State and provincial agencies focused on the protection and management of habitats and wildlife have potential to target efforts toward shorebirds and their habitats (e.g., enforce policies, create and protect habitat, monitor species, conduct research); examples include state departments of fish and game or natural resources and provincial ministries of the environment, which often also have local assistance programs
County/local	Soil and water conservation districts	U.S. county-level programs that conserve soil and water resources, many of which could affect or create shorebird habitat if targeted appropriately
County/local	Private landowners	Owners of lands associated with shorebird use, including agricultural lands (particularly rice fields), aquaculture (e.g., crayfish, shrimp), salt ponds, and rangelands; these landscapes have potential to affect or create shorebird habitat if managed appropriately
County/local	Local nonprofit groups	Nonprofit organizations engaged in shorebird conservation locally (sometimes connected to international initiatives); examples from major flyways include Corbidi (Peru, Pacific Flyway), Coastal Bend Bays & Estuaries Coastal Bird Program (Texas, USA, Midcontinent), and SAVE Brasil (Atlantic)
Multilevel	Public land managers	Managers of protected areas can operate at local, state, or even regional and transnational levels; protected areas are sometimes created specifically for birds, sometimes mixed recreational or human use, and sometimes strictly protected
Multilevel	Natural Resources Conservation Service (NRCS)	U.S. Department of Agriculture branch that provides technical and financial assistance to farmers, ranchers, and other private landowners and managers; hosts a variety of conservation programs, typically delivered at the county level, intended to help landowners and other partners protect, conserve, and sustainably manage their private lands; many programs have potential to support shorebirds or create habitat if managed and targeted appropriately
Multilevel	U.S. Fish and Wildlife Service Partners for Fish and Wildlife Program	Provides free technical and financial assistance to landowners, managers, tribes, corporations, schools, and nonprofit organizations interested in improving wildlife habitat on their lands; projects are voluntary and customized to meet landowners' needs; participating landowners continue to own and manage their land while they improve conditions for wildlife; staff plan, design, supervise, and monitor customized habitat restoration projects with a focus on habitats of concern, such as wetlands and native grasslands; every U.S. state and territory has a coordinator who helps deliver the program
Multilevel	Land trusts	Nongovernmental organizations that place easements on or take ownership of private lands at the request of the landowner; private lands with wetland, grassland, or working agricultural habitats have potential to support shorebirds and create habitat if managed appropriately; can operate at local, regional, and national levels
Multi-level	Nonprofit and nongovernmental conservation organizations	Any nonprofit or nongovernmental program or organization not mentioned above that may operate at multiple levels from local to hemispheric; examples include Birds Canada, Birds Caribbean, BirdLife International, Ducks Unlimited, National Audubon Society, Point Blue, Wetlands International, and Wildlife Conservation Society; through programs to create or manage wetland, grassland, or agricultural habitat, these groups are (or could be) providing shorebird habitat

availability for conservation (SNZCBI, 2024a). All contributors allow the collective's core team to explore data for applicability to a conservation request and to show summary products (e.g., density grids) to conservation partners. Contributors customize permissions (either providing preapproval or requiring a permission request before each use) within use categories: conservation, education, funder reports, or collective-led scientific publications. Contributors also indicate whether their contact information can be shared for scholarly requests, for example, a data request for a thesis or peer-reviewed publication that is not directly tied to conservation.

For publicly available data, a DSA is not required for the collective (or any individual) to use the data and should not be viewed as restrictive. However, the collective requests a DSA be completed to help guide the values shaping the collaboration, provide fair attribution, enable reporting of conservation uses to data creators, and provide engagement opportunities to assist with analytical interpretation.

Compiling data

We invited data contributions through email, a webinar, social networks, and word of mouth. Data were received either through repositories, such as Movebank (Kays et al., 2022), or were sent directly to the collective's staff. We prioritized processing data with higher spatial accuracy (e.g., Argos and GPS) (Table 3), which we anticipated would be most relevant to conservation requests. We developed a code pipeline (Anderson et al., 2024) to process and standardize data. First, a series of prefilters are applied to identify common problems in the data to, for example, identify data gaps or data collected after a tag has become stationary, which indicates the tag was shed or the bird died. Then, a state-space model (Jonsen et al., 2023) is used to estimate the most probable movement path accounting for spatial error and irregular sampling across individuals and species. The collective is currently integrating data from the Motus Wildlife Tracking System (Taylor et al., 2017) and light-level geolocators (Table 3) that were contributed in preprocessed or unprocessed form, requiring additional processing or standardization to ensure appropriate interpretation (Lisovski et al., 2018).

Shared data are harmonized from their sources and stored in a private, password-protected database accessible only to the collective's core team. Data are linked to their associated DSAs to ensure that permissions and attributions are followed. Contributors are invited annually to share new data and review their DSA and proposed amendments to the agreement. Outreach to new contributors occurs via presentations, email invitations to authors of new publications or new Movebank studies, or conversations as a part of professional collaborations. The collective's database is updated approximately biannually to incorporate new contributions and to ingest new data from active tags in repositories associated with existing DSAs.

Reporting conservation uses to contributors

Contributors are notified when their data are relevant to a conservation request (notification examples in Anderson et al. [2024]). The notification describes the project and provides a map of associated data. For uses the contributor did not preapprove, the collective requests permission before proceeding. Although this step adds administrative work to the collective's staff, it incentivizes and rewards data contribution, increases accountability, safeguards privacy settings, and promotes dialogue to prevent misinterpretations of contributed data.

Engaging conservation partners

An initial email campaign to practitioner organizations in the Midcontinent increased awareness of the collective. Outreach via email, presentations, and word of mouth is ongoing. Introductory emails describe the resources and analytical support the collective provides. Outreach often leads to a 1-h virtual knowledge-sharing session between interested practitioners and members of the collective's core team. If there is opportunity to inform a project, further conversations refine questions, information needs, and preferred formats of data products. After questions are refined, practitioners submit a formal Conservation Use Request Form (SNZCBI, 2024b). Data contributors are then notified by the collective that their data are relevant to a conservation request or to request further permission. Increasingly, the collective receives unsolicited requests via our online form or through emails. As of June 2024, 43% of requests were from practitioners beyond our original geographic focus.

Throughout a project, the core team communicates with practitioners and data contributors as needed. At the project's conclusion, the team presents findings to practitioners and allows questions and feedback regarding the delivery format, analyses, and recommendations. A conservation contribution report summarizes findings, acknowledges data contributors, and provides information about shorebird ecology and best management practices. A public version (with sensitive data removed) is placed online (SNZCBI, 2024c). The collective's core team classifies conservation contributions following the International Union for Conservation of Nature Conservation Actions Classification Scheme (IUCN, 2012; Salafsky et al., 2008) to align with standard evidence reporting (Sutherland et al., 2019).

SHOREBIRD TRACKING DATA AVAILABLE FOR CONSERVATION IN THE AMERICAS

As of June 2024, contributions include 7.1 million observations from 3420 individual shorebirds of 36 species (Figure 2).

TABLE 3 Description and sample size of data types submitted to the Shorebird Science and Conservation Collective as of June 2024.

Technology	Description	Data format[a]	Spatial accuracy	Sampling frequency	Monitoring duration	Number of individuals contributed (%)	Number of species contributed (%)
GPS	Electronic tags attached to individual birds; locations estimated from GPS satellites and obtained either by retrieving the device and downloading stored data (i.e., archival tags) or transmitting the data to satellites	Latitude and longitude coordinates	Typically 10–100 m (Noonan et al., 2019)	Minutes to days or preprogrammed schedules, such as every 2 weeks during overwintering and 2 days during migration, depending on study goal and tag battery life	Months to years depending on tag type and attachment method	1213[b] (35.5)	16 (44.4)
Argos Doppler Shift	Electronic satellite tags (called platform terminal transmitters or PTTS) attached to individual birds; tags send signals to orbiting satellites that retransmit location data to a receiving station on Earth for processing	Latitude and longitude coordinates with location class codes or error ellipses that indicate accuracy of the estimated location	Generally 250–1500 m (CLS America, 2016); individual locations can have errors larger than 25 km (Jonsen et al., 2020)	Minutes to days often irregular; tags may use preprogramed on–off schedules to allow for charging (solar models) or to conserve energy (battery models)	>1 year depending on tag type and attachment method	938[b] (27.4)	15 (41.7)
Motus	Electronic VHF radio tags attached to individual birds detected by a network of receiving stations; detection data stored on receivers, synched over the internet, or sent via satellite or cellular network	Raw detection data (e.g., time stamp, signal strength) associated with the location of each receiving station	Typically 15–20 km from receiving stations (Taylor et al., 2017) but up to 180 km (Anderson et al., 2019); ∼500 m if omnidirectional antennas are used (Taylor et al., 2017)	3–30 s when tag nears receiving station, generally; gaps can be minutes to days	Days to months	1091 (31.9)	4 (11.1)
Light-level geolocator	Electronic devices attached to individual birds that record ambient light levels, which can be related to global light patterns to estimate the animal's location; must be retrieved to download the data	Raw ambient light levels that require substantial processing and analyses to estimate locations (Lisovski et al., 2020)	50–200 km with much greater error in latitude during spring and fall equinox (Lisovski et al., 2012; Rakhimberdiev et al., 2016)	1–2 locations per day	>1 year	362 (10.6)	15 (41.7)
Resight	Observations of individual birds marked with unique color band, flag combinations, or alphanumeric bands or flags	Latitude and longitude coordinates provided by observer	Depends on observer proximity, usually <100 m	Limited to where and when observers search for birds, marker retention, and animal lifespan	Limited to observer effort, marker retention, and animal lifespan	Submitted data currently not integrated into the Shorebird Science and Conservation Collective dataset	15 (41.7%)

[a]Tags also collected barometric pressure (0.5% of individuals, 1 species), external temperature (1.4%, 5 species), altitude (12.3%, 5 species, generally of limited accuracy), acceleration (0.7%, 1 species), magnetic field values (0.6%, 1 species), gyroscope data (0.5% of individuals, 1 species), an indication that the tag was wet or dry (0.2%, 1 species), or whether the tag became immobile (17.3%, 4 species).
[b]Includes 184 individuals tracked with both GPS and Argos technologies.

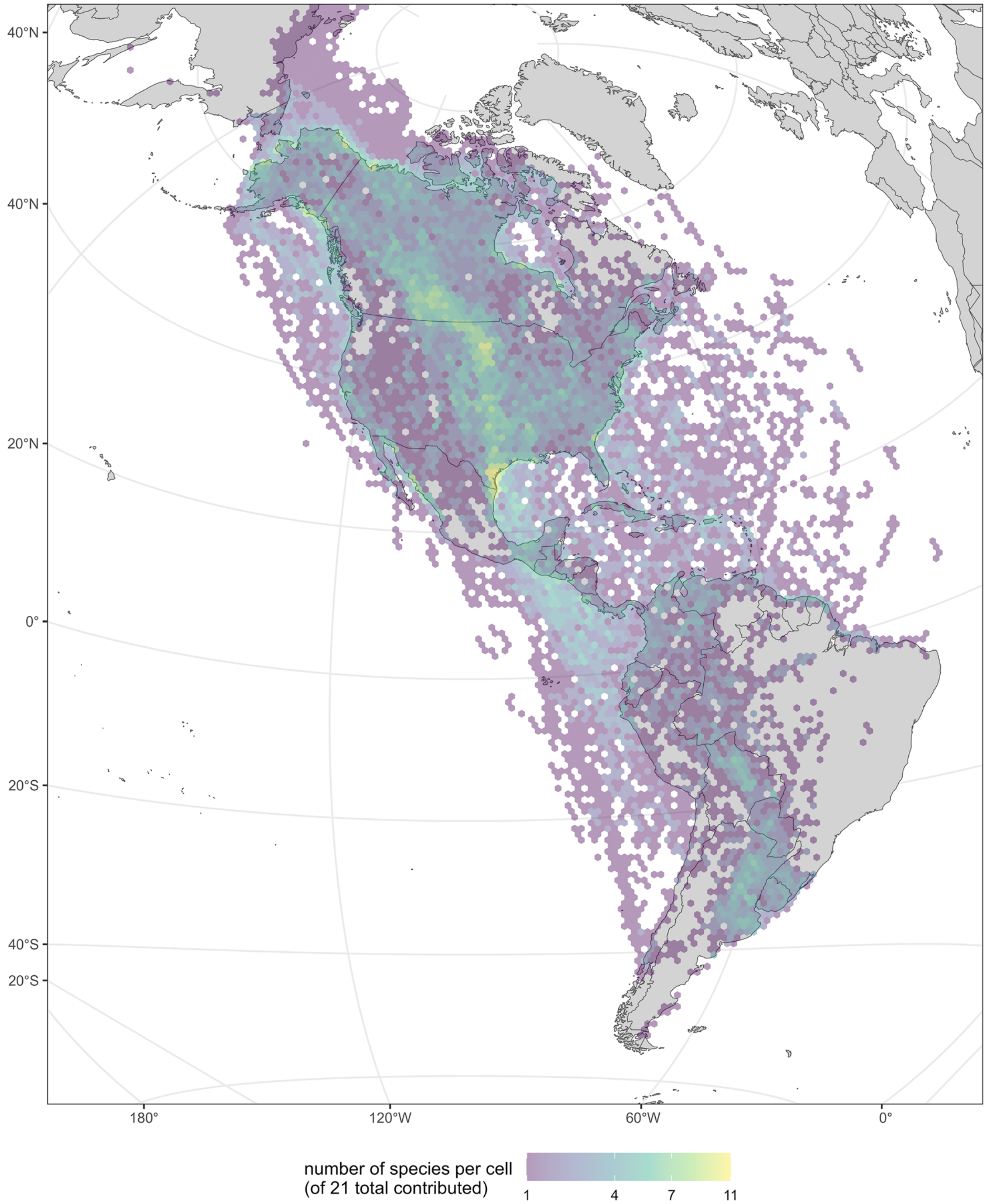

FIGURE 2 Distribution and density of species with Argos and GPS tracking data from tags deployed in the Americas (Table 3; $n = 1883$ individuals of 22 species) contributed to the Shorebird Science and Conservation Collective as of June 2024 (shading, number of species with tracking locations in 100 × 100 km diameter hexagonal cells [8660 km^2]).

Since January 2021, when data were first requested, contributors signed 58 agreements for data originating from 75 organizations and 137 data co-owners. Data span the Americas, with areas in the Midcontinent demonstrating clear importance to multiple species (Figure 2). Shorebirds were tracked via light-level geolocator, Argos, GPS, and Motus technologies, and through visual observations of marked birds (Table 3; Figure 2). A portion of tags (17% of tracked species and 22% of tracked individuals) also provided environmental or behavioral measures (Table 3). Data are from the smallest (least sandpiper [*Calidris minutilla*], 19–30 g, tracked with 0.67-g Motus tags [Anderson et al., 2019]) to the largest (long-billed curlew [*Numenius americanus*], 490–950 g, tracked with 9.5- to 22-g satellite tags [Page et al., 2014]) shorebirds in North America (species list, Appendix S2).

Data for over half of the tags (56% of all tag types, 84% of birds tracked by Argos or GPS, 26 species) were shared via

Movebank (Kays et al., 2022). Of these, 32% (622 tags, 18% of total, 10 species) were open access. The remainder of data were sent to the collective directly, including data from the Motus Tracking Network (Taylor et al., 2017), which are viewable online but are not currently downloadable. Thirty-seven DSAs (63.8%) preapproved conservation uses (1661 tags [49%] of 23 species [64%]). Data from 23.6% of Argos or GPS tags were preapproved for conservation uses. Some agreements covered multiple datasets.

CONTRIBUTING TO CONSERVATION

From November 2021 (when the first conservation request was received) to June 2024, the collective supported 15 conservation projects (with another 3 requested). We sent 115 notifications to 23 contributors from 17 organizations informing them that their data collected from 638 individuals of 17 species were relevant to conservation requests. Sixty-eight notifications were for datasets preapproved to be used for conservation, and 47 were requests to contributors requiring further permission. Of the latter set, 93% were approved. The collective applied tracking data to support conservation decision-making and outreach across 4 categories (Figure 1): land conservation, land and species management, education and outreach efforts, and policy (in progress). Conservation contribution reports are available online as they are finalized (SNZCBI, 2024c).

Private land conservation

Public and private lands support shorebird conservation in North America, but in the Midcontinent, where there is high private ownership, private lands are a crucial component of environmental stewardship and land protection (Merenlender et al., 2004). Trusts, foundations, and government agencies can use tracking data to help guide conservation investments and secure funds for voluntary land purchase or conservation. Tracking datasets are especially valuable when they provide the only evidence of shorebirds using areas (e.g., when surveys or community science observations are unavailable).

The Texas Parks and Wildlife Foundation's Buffer Lands Incentive Program (BLIP) provides financial assistance for conservation easements on privately owned lands bordering Texas Parks and Wildlife Department (TPWD) public lands (called "buffer lands"). The BLIP requested evidence for shorebird use of buffer lands bordering 12 priority TPWD lands as one metric in their rubric to prioritize applications for conservation easement funding. Half of BLIP funds are allocated for shorebird and grassland bird projects. Fifty-two individuals of 9 species in the collective's dataset stopped or overwintered on buffer lands (83% of tags were deployed outside Texas). In a report to BLIP, the collective summarized when birds used buffer lands, the habitats used, global migration links ranging from Russia to Argentina, a list of all TPWD lands visited by tracked shorebirds, and state-wide density maps of individuals and species tracked. Because many parcels under consideration are inaccessible to the public, direct evidence of shorebird use comes almost exclusively from tracking data. This information would have likely been unattainable by BLIP without collaborative support from the collective.

The Conservation Fund (TCF) and The Nature Conservancy (TNC) (conservation nongovernmental organizations [NGOs]) separately sought information to support funding efforts to acquire lands for permanent protection along the Texas coast (TCF) and in the panhandle (TNC). Although no shorebirds in the collective's dataset visited the parcels under consideration, 23 individuals of 4 species were tracked nearby (within 3–18 km). We used habitat layers and standardized eBird relative abundance (Fink et al., 2022) to provide additional context about the potential value of the parcels to shorebirds. Some habitats in the parcels seemed promising, suggesting that on-the-ground surveys could be used to confirm shorebird use. Both organizations shared these data with funders to demonstrate the potential value of the lands for shorebirds.

Land and species management

Many shorebird conservation actions manage for habitat or species of concern (Iglecia & Winn, 2021). Land management includes activities like deploying water to create habitat, alternating wetting and drying of rice fields timed with shorebird usage, and prescribed grazing and burning of grasslands or rangelands. Species management includes activities like species recovery planning and status assessments, harvest management, and beach closures. Tracking data can reveal important sites, connectivity, stopover duration and timing, and population structure to inform management actions.

The Galveston Bay Foundation, TNC, and Texas Water Trade (NGOs) entered into multiyear agreements with water authorities to purchase water for wildlife management and environmental flows (such agreements are called water transactions). The allocated water volumes range from 200 to over 2000 acre-feet (2.5×10^8 L to 2.5×10^9 L) transacted annually. They wanted to know when and where to deploy water on private and public lands along the Texas coast to benefit shorebirds. Water transactions offer many benefits, including habitat creation and restoration, salinity management, and continued crop yields during drought (Culp et al., 2014; Garmany, 2020). Tracking data from 6 shorebird species provided information on local habitat use and timing through the focal area (Figure 3a,b). Standardized relative abundance data from eBird (Fink et al., 2022) added insights for species with limited tracking data and provided peaks of occurrence across multiple species (Figure 3b). The collective provided partners with recommendations for when to deploy water (preferred and alternate times [Figure 3c]) and shorebird habitat management best practices.

Wind energy is important for reducing carbon emissions but may have negative effects on birds through collisions or displacement (Fox & Petersen, 2019; Goodale & Milman, 2016). Tracking data can provide valuable insight about routes and passage timing in proposed and active offshore wind areas to

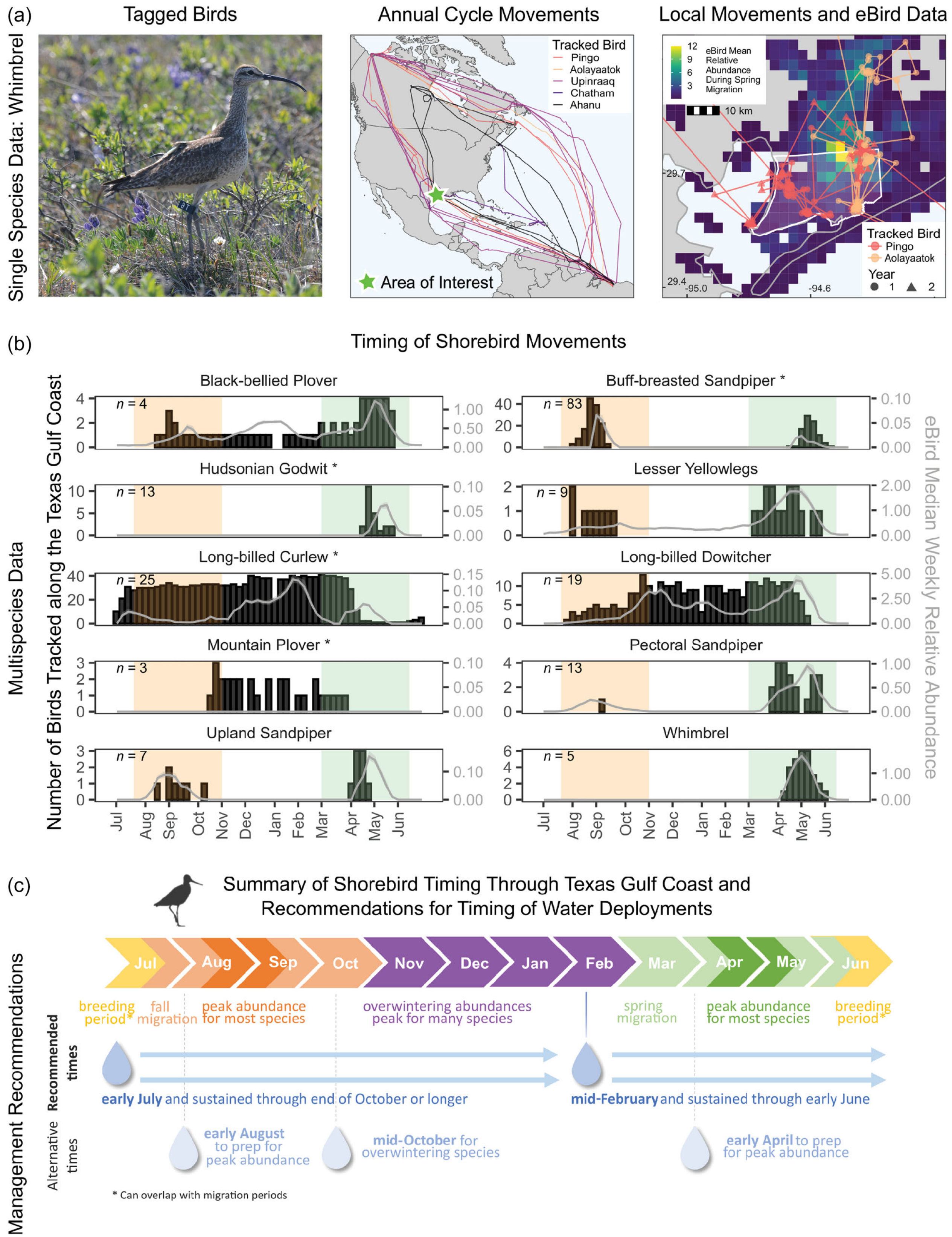

FIGURE 3 Example figure from a conservation project report informing the timing of freshwater deployments to provide habitat for migratory and wintering shorebirds in Texas (USA): (a) annual cycle movements from 5 tracked whimbrel (*Numenius phaeopus*) (Jennie Rausch, Environment and Climate Change Canada) (middle) and local movement data from 2 individuals overlaid on a focal area of interest in Texas (right), (b) time series of when tracked birds traveled through the Texas Gulf Coast (black bars) and median weekly relative abundance (gray lines) in the area of interest predicted by eBird community science data (Fink et al., 2022) (orange, fall migration; green, spring migration; asterisks, Texas "species of greatest conservation need" [Texas Parks & Wildlife Department, 2023]; individuals

(Continues)

FIGURE 3 (Continued)
tracked in more than 1 year contributed to counts more than once because timing varied for individuals between years), and (c) recommendation to conservation partners for deploying water to benefit migrating and overwintering shorebirds under recommended and alternate scenarios. Information from (a) and (b) was used to determine periods during which water deployments could benefit peak diversity and abundances of migratory shorebirds and led to the recommendations (c).

help determine shorebird vulnerability, inform siting decisions, or encourage "smart curtailment" strategies during high-risk migratory periods (Loring et al., 2021; Schwemmer et al., 2023). The Canadian Wildlife Service requested information for 2 rapid (18-month) assessments offshore Nova Scotia and Newfoundland and Labrador to understand the temporal and spatial distribution of shorebirds moving through the focal areas. The collective provided maps of 41 individuals of 8 species that migrated through the offshore focal areas and highlighted places of high activity (i.e., where track lines congregated for multiple individuals and species).

Education and outreach

Despite increasing public awareness of declining bird populations, many people may not be aware of the broad array of habitats shorebirds need during their migrations. The name shorebird may limit conservation efforts because many people do not connect them with grasslands or interior wetlands. Shorebirds are sometimes wrongly assumed to have similar habitat needs as other waterbirds, such as gulls, egrets, rails, or waterfowl. Environmental education has indirect and direct conservation outcomes (Ardoin et al., 2020), and, as an outreach tool, tracking data offer strong visual and hands-on learning opportunities to gain support for shorebird conservation efforts.

Educators at Grays Harbor National Wildlife Refuge in Hoquiam, Washington (USA), requested example geographic coordinates and track lines to support their third- and fourth-grade education programs. Educators incorporated data from 17 individuals of 5 species into 4 lessons, allowing students to map and explore shorebird movements within the Grays Harbor estuary and across the Pacific Flyway. The activities allowed students to enhance skills in geography and ecology while learning how small actions in their communities can affect a shorebird's entire migration. Refuge educators visited multiple classrooms every month, reaching a total of 870 students across 14 schools with the lessons over the 2022–23 school year.

Nature Canada, a conservation NGO, requested tracking data for a comic book following Bico, a fictional Hudsonian godwit (*Limosa haemastica*), as she travels from Canada to Chile. The book's goal is to raise awareness and generate excitement about shorebirds that visit James Bay, Canada, a globally important stopover area. The collective provided 2 godwit tracks and summary statistics for an infographic at the end of the book. Nature Canada posted the comic book online (Nature Canada, 2022) and distributed paper copies in 6 First Nations communities around James Bay.

The Western Hemisphere Shorebird Reserve Network, a science-based, partnership-driven conservation initiative for protecting shorebirds through a network of key sites, wanted to show how shorebird movements connect sister sites within their reserve network. The collective created an online storytelling series in 3 languages with ArcGIS StoryMaps that followed 3 tracked individuals as they migrated across the Americas (SMBC & WHSRN, 2024). Each StoryMap features a migratory bird flyway (Pacific, Midcontinent, Atlantic) and cultural theme (food, music, crafts), highlighting the people and places each shorebird might encounter during migration.

LESSONS LEARNED

The Shorebird Science and Conservation Collective is advancing conservation through collaborative data sharing and analyses in support of needs identified by practitioners. Such on-the-ground conservation is imperative given long-term and accelerating shorebird population declines (Rosenberg et al., 2019; Smith et al., 2023). The collective offers insights for translational science initiatives globally. During the first 2 years, we addressed limitations to data access, analyses, and practitioners' use of data insights (Table 1). As templates for others, the collective has shared forms used to communicate with practitioners and contributors and the code pipeline used to process contributed data (Anderson et al., 2024). Five lessons emerged that are transferable to other initiatives.

Lesson 1 is that establishing access to processed usable data is crucial to meet the urgency of a crisis discipline (Soulé, 1985). In its first year, the collective hosted webinars, requested data, facilitated agreements with data owners, compiled and standardized data, and created reproducible analytical pipelines. Having data preprocessed in multiple formats (e.g., points, density grids, grouped by priority region) helps quickly inform varied conservation and management discussions. However, barriers to efficiency remain, and we agree with the recommendations of Urbano et al. (2021) to streamline data sharing and harmonization. Measures include policies to improve the FAIRness (i.e., findability, accessibility, interoperability, and reuse [Wilkinson et al., 2016]) of data authorized by funding and permitting agencies (Sansone et al., 2019); facilitating communication with data registries (Nightingale, 2023; Rutz, 2022); use of data and metadata standards to improve datasets and increase interoperability (Campbell et al., 2016; Sequeira et al., 2021); code sharing (Culina et al., 2020; Kölzsch et al., 2022); and efforts to integrate multiple data types (Binley et al., 2023; Urbano et al., 2010).

Lesson 2 is that collaborative engagement and coproduction require significant investment in staff salary and time but provide large benefit to practitioners, data contributors, and the conservation process. Science translators and subject matter experts are greatly valued by practitioners; they provide guidance on the use and interpretation of science to meet real-world needs. Our impression from approximately 50 h of listening sessions with practitioners from 35 organizations is that interactive knowledge sharing significantly influences whether and how deeply shorebird science is trusted and considered for their programs. In a large global survey of policy makers, practitioners, and scientists (Rose et al., 2018), the use of key intermediaries (the collective's staff in this case) was ranked highly as a solution to better link science with policy. The collective's model of engaging data contributors with each conservation request also provides a pathway for contributors to join the science translation process. This further increases trust with data sharing, ensures contributors are aware of and can report on uses of their data, and increases the network of science translators available to each conservation project. Data contributors provide context, prevent misinterpretation, and add additional knowledge. Online decision support services or artificial intelligence tools could streamline data access and science translation for some projects but require investment and continued maintenance and development and may lack the benefits of trust and interpretability provided by direct engagement.

Lesson 3 is that a focused collective can elevate a specific group (here, shorebirds) within the priorities of on-the-ground conservation while informing science strategy. Outreach to practitioners has raised awareness of opportunities to support shorebirds specifically among multiple competing priorities. Although conservation initiatives may prioritize biodiversity, biomes, function, species, or human communities, conservation efforts specific to taxonomic groups, such as those for waterfowl, can be highly successful (Anderson et al., 2018; Brasher et al., 2019). The added capacity and consistent leadership of a collective become a powerful incentive for agencies to prioritize taxa-specific conservation initiatives. The collective's synthesized dataset also leverages the partnership to identify conservation knowledge gaps and prioritize new data collection, reduces the costs to achieve robust sampling designs (by pooling smaller studies across organizations), and reduces fiscal and administrative barriers for agencies.

Lesson 4 is that long-term support is essential. The collective's core team founding budget of US$1.3 million provided 3 years of salary (51%) and benefits (16%) for 3 staff members and paid for travel (conferences and site visits, 8%), computing equipment (1%), contract services (language translations, strategic planning, 12%), supplies and printing (2%), and 10% overhead. This allowed for time to develop the collective's structure, attract strong candidates by guaranteeing 3 years of support, standardize data, and learn from diverse partners. Founding investments have been crucial for launching other integrative tracking initiatives, but sustainability can be challenging (Urbano et al. 2021). Well-resourced stable leadership is important to maintain momentum, coordinate within and among scientists and practitioners, and provide accountability. Developing a formal evaluation process to measure the collective's influence on conservation decision-making will be important for continued support. As the collective moves from a founding to a sustaining phase, we anticipate a model in which some partners contribute to the collective's sustainability through contracts or interagency agreements. This would ensure the collective can continue providing free scientific services to financially constrained groups.

Lesson 5 is that a proof-of-concept stage helps balance the need to develop efficient and scalable operations for a nascent initiative with tangible mission progress. There is enough demand for the collective's services within the proof-of-concept region to fill staff time. However, migratory species conservation demands action across boundaries (Harrison et al., 2018). Requests for the collective's support regularly come from other regions. To expand conservation impact, the collective's vision is to scale up to better support practitioners in Latin America and the Caribbean through the inclusion of tracking data from species endemic to these regions and through a conservation specialist based outside North America. We also hope to inform regional, national, and international priorities through strategic analyses designed to have the biggest effect on reversing shorebird population declines. However, the sustainability of the collective is not guaranteed (Lesson 4), creating a tension between maintenance and growth.

The lessons above indicate that translational models of data sharing require significant investment but have many strengths. They simplify complex datasets in efficient, understandable, trusted, codeveloped, and actionable ways. This lowers the activation energy for practitioners and policy makers to use science. For migratory species, innovations in tracking technology continue to enhance understanding of behaviors and habitat use—patterns that are changing with persistent habitat loss and climate change (Galbraith et al., 2014; Sutherland et al., 2012). Ongoing data collection and sharing are vital for cooperatives like the collective to rapidly integrate and interpret research for conservation in a changing world.

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ACKNOWLEDGMENTS

Support for the Shorebird Science and Conservation Collective is provided by the Knobloch Family Foundation. Additional support is provided by ConocoPhillips Charitable Investments in support of the Migratory Connectivity Project (A.-L.H.) and by the U.S. Fish and Wildlife Service (R.B.L.). We thank the advisory group (Appendix S1) and B. Ballard, B. Corey, G. Castresana, K. De Santiago, P. Erdmann, J. Pinnix, R. Summers, J. Shackelford, D. Shaw, M. Singer, M. Weegman, and L. Wright for data or conservation contributions. We also thank all who provided early feedback and funders, collaborators, volunteers, and staff who collected or supported the collection of shorebird tracking data. Any use of trade, firm, or products is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

How to cite this article: Harrison, A.-L., Stenzel, C., Anderson, A., Howell, J., Lanctot, R. B., Aikens, M., Aldabe, J., Berigan, L. A., Bêty, J., Blomberg, E., de Almeida, J. B., Boyce, A. J., Bradley, D. W., Brown, S., Carlisle, J., Cheskey, E., Christie, K., Christin, S., Clay, R., … Wunder, M. B. (2025). The collective application of shorebird tracking data to conservation. *Conservation Biology*, e70194. https://doi.org/10.1111/cobi.70194