The collective application of shorebird tracking data to conservation

Abstract

Addressing urgent conservation issues, like the drastic declines of North American migratory birds, requires creative, efficient, and collaborative approaches. Over 50% of monitored North American shorebird populations have lost over 50% of their abundance since 1980. To address these declines, we developed a partnership of scientists and practitioners called the Shorebird Science and Conservation Collective (hereinafter "the Collective"). Here, we describe the Collective's founding, structure, conservation contributions, and lessons learned to assist others engaged in translational science. The Collective acts as an intermediary whereby dedicated staff collate and analyze data contributions from scientists to support knowledge requests from conservation practitioners. Data contributions from 75 organizations include over 7.1 million shorebird locations forming movement paths of 3,420 individuals representing 36 species tracked across the Americas and have informed 13 conservation projects. As the volume of scientific data continues to grow, groups like the Collective can be vital liaisons to rapidly integrate and interpret research to support conservation action.

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Abstract

Addressing urgent conservation issues, like the drastic declines of North American migratory birds, requires creative, efficient, and collaborative approaches. Over 50% of monitored North American shorebird populations have lost over 50% of their abundance since 1980. To address these declines, we developed a partnership of scientists and practitioners called the Shorebird Science and Conservation Collective (hereinafter "the Collective"). Here, we describe the Collective's founding, structure, conservation contributions, and lessons learned to assist others engaged in translational science. The Collective acts as an intermediary whereby dedicated staff collate and analyze data contributions from scientists to support knowledge requests from conservation practitioners. Data contributions from 75 organizations include over 7.1 million shorebird locations forming movement paths of 3,420 individuals representing 36 species tracked across the Americas and have informed 13 conservation projects. As the volume of scientific data continues to grow, groups like the Collective can be vital liaisons to rapidly integrate and interpret research to support conservation action.

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 as 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 (*sensu* Pauly 1995) and masking major declines. Shorebirds have the largest declines (net and % loss in abundance; greatest proportion of species in decline) of nearly 3 billion birds lost in North America since 1970 (compared to landbirds, waterbirds, and waterfowl, Rosenberg et al., 2019). Declines are not abating (Smith et al., 2020), emphasizing the urgent need for conservation action for shorebirds. Here we present a partnership of scientists and practitioners (defined here as those directly guiding conservation) responding 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 (hereinafter "tags", reviewed by Robinson et al., 2010) to record movements, identify important habitats, infer animal behavior, understand population connectivity, and monitor the environment (Kays et al., 2015; Hussey et al., 2015). Aggregating tracking data across species has led to significant insights, for example documenting climatic influences on animal movement patterns in the Arctic (Davidson et al., 2020). Insights from tracking data have also yielded significant conservation achievements. For example, tracking data collected from marine animals were used to designate marine protected areas, reduce fisheries bycatch and vessel strikes, and minimize impacts of extractive industries (Hays et al., 2019). Tracking data are an invaluable resource to integrate with other occurrence datasets like local surveys and community science data.

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

To overcome challenges limiting science translation for conservation, linear and interactive approaches are used (Beier et al., 2017; Toomey et al., 2017; Saunders et al., 2021). Each offers benefits under different scenarios. Linear methods involve creating scientific products to be accessed by practitioners (e.g., data portals, online tools, publications, and manuals). Despite conservation benefits (Seavy & Howell, 2010; Sullivan et al., 2017) these tools may not suit practical purposes due to formatting or language incompatibilities, incomplete data, or mismatched questions, and can be time-consuming to find and synthesize (Vogel et al. 2007). Interactive approaches range from focused workshops to long-term coproduction where research and products are collaboratively designed, planned, and implemented by practitioners and scientists (Young et al., 2014; Roux et al., 2006; Saunders et al., 2021). 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 (Seavy & Howell, 2010; Oliver et al., 2019).

We combined elements of both linear and interactive knowledge-sharing approaches to form the Shorebird Science and Conservation Collective (hereinafter, 'the Collective'). The Collective is a partnership of scientists and practitioners working to advance shorebird conservation in the Americas (Figure 1). Our goal in sharing the origin, structure, and impact of the Collective is to provide a case study and lessons learned to help others increase the impact of existing science on conservation. The Collective is an intermediary whereby dedicated staff collate and analyze data contributions from scientists to support the conservation needs of practitioners. We describe how the Collective a) raised funds, b) initiated a proof-of-concept, c) requested data and established operational processes, d) developed a coproduction process to listen and respond to the needs of practitioners, and e) contributes to conservation.

Forming the idea for the Shorebird Science and Conservation Collective

The idea to collate shorebird tracking studies for conservation was inspired by the conservation successes of BirdLife International's Seabird Tracking Database (BirdLife International, 2004) but adapted for unique considerations of how and where shorebird conservation is implemented (Table 1, Table 2). Given existing limitations (Table 1), a solely linear approach facilitating data discovery or access but requiring practitioners to interpret 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 include staff for data analysis and co-development of conservation products to support direct requests from practitioners.

A funding proposal was developed with feedback from researchers and conservation practitioners through open-invitation webinar discussions. Many participants were already sharing, co-developing or applying research to conservation. As conceived, the Collective would add value by expanding conservation opportunities, rather than compete with or replace existing partnerships. Webinars were instrumental for assessing support, refining ideas, and identifying existing gaps in translating science to shorebird conservation.

A proof-of-concept for the Collective

We developed a three-year proof-of-concept focused on North America's interior (hereinafter, "Midcontinent", groups the Central and Mississippi migratory bird flyways) to evaluate the proposed structure and gauge demand for shorebird tracking data. The Midcontinent has been elevated as a priority landscape by multiple conservation entities (Midcontinent Shorebird Conservation Initiative, 2021; The Central Grasslands Roadmap, 2022) and provides habitat for 42 of the 50 shorebird species that regularly breed in North America (Donaldson et al., 2000; Brown et al., 2001). The Texas Gulf Coast provides migratory and wintering habitat for more than 1 million shorebirds annually (Withers, 2002) while the Prairie Pothole Region's wetlands and grasslands (Doherty et al., 2018) support millions of migrants each spring and fall (Skagen, 2006; Steen et al., 2018). These landscapes have experienced major wetland loss (up to 90% at the U.S. state level, (Dahl, 1990; Dahl, 2014)) and have high climatic variability, making cohesive shorebird management challenging across the region and among years (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 non-public (NRCS, 2021)), requiring coordination with landowner-focused agencies which deliver voluntary incentive programs and provide technical assistance to manage habitat on working lands (e.g., U.S. Department of Agriculture Natural Resources Conservation Service, the U.S. Fish and Wildlife Service Partners for Fish and Wildlife Program), as well as state and local governments, land trusts, and other conservation entities.

The Collective's structure and systems

The Collective comprises 4 groups of people (Figure 1): a core operational team (P.I., staff, and Chair of the Advisory Group), an Advisory Group (Appendix I), 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 conservation benefit of the Collective and promotes its value to potential data contributors and conservation practitioner partners. Data contributors typically are researchers from public, private, or non-profit organizations.

Practitioners directly guide conservation actions within management agencies, trusts, and non-profit 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, Stenzel and Harrison, 2024) to uphold data privacy agreements and increase accountability to data contributors and practitioners.

Crafting a Data Sharing Agreement

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), with some policies mandating public sharing (e.g., the Wildlife Tracking Data Collection, U.S. Geological Survey Alaska Science Center, 2019). Conversely, recent data or those restricted by endangered status, may require embargo. We thus drafted a flexible agreement to facilitate maximum data available 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 pre-approval 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 data that are publicly available, 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) that we anticipated would be most relevant to conservation requests. We developed a code pipeline (Anderson, Stenzel, and Harrison, 2024) that first applies pre-filters (e.g., to determine when a tag has become stationary, indicating it has either been shed or the bird has died). Then a state-space model (Jonsen et al., 2023) estimates 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 either pre-processed, or in raw, 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. This dataset is accessible 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, to review their DSA, and to review any 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 (examples, Anderson, Stenzel, and Harrison, 2024). The notification describes the project and provides a map of associated data. For any use that the contributor did not pre-approve, the Collective requests permission before proceeding. While this step adds to the administrative work of 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 within the Midcontinent increased awareness of the Collective, and we continue to conduct outreach via email, presentations, and

word-of-mouth. Introductory emails describe the resources and analytical support the Collective provides. Outreach often leads to a 1-hr virtual knowledge-sharing session between interested practitioners and members of the Collective's core team. The team describes the Collective's approach for data-driven conservation, and practitioners describe their work, priorities, and shorebird-related questions. 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 engaged either to notify 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, and from practitioners beyond our original geographic focus.

Throughout the project, the core team communicates with practitioners and data contributors as needed. At the project's conclusion, the team presents findings to practitioners, allowing 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 any sensitive data removed) is shared online (SNZCBI, 2024c). The Collective's core team classifies conservation contributions following the IUCN Conservation Actions Classification Scheme (Salafsky et al., 2008; IUCN, 2012) to align with standard evidence reporting (Sutherland et al., 2019).

The wealth of shorebird tracking data available for conservation in the Americas

As of June 2024, data contributions include 7.1 million locations from 3,420 individual shorebirds of 36 species (Figure 2). Since January 2021 when data were first requested, contributors have 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, 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 come from the smallest (least sandpiper, *Calidris minutilla,* 19–30g, tracked with 0.67-g Motus tags; (Anderson et al., 2019))

215 to the largest (long-billed curlew, *Numenius americanus,* 490–950 g, tracked with 9.5–22-g
216 satellite tags (Page et al., 2014)) shorebirds in North America (Species list, Appendix II).
217 Data for over half of tags (56% of tags, 26 species) were shared via Movebank (Kays et
218 al. 2022, 84% of birds tracked by Argos or GPS) and 32% of these (622 tags [18% of total], 10
219 species) currently also are open access. The remainder of data were sent to the Collective
220 directly, including data from the Motus Tracking Network (Taylor et al. 2017) which are
221 viewable online, but are not currently downloadable. Thirty-seven data sharing agreements
222 (63.8%) preapproved conservation uses (1,661 [49%]) tags of 23 [64%] species). Data from
223 only 23.6% of Argos/GPS tags are pre-approved for conservation uses. Some agreements cover
224 multiple datasets.
225
226 **Contributing to conservation**
227 Since our first conservation request in November 2021 to June 2024, the Collective has
228 supported 13 conservation projects (with another 3 ongoing). We have sent 115 notifications to
229 24 contributors informing them that their data collected from 17 species were relevant to
230 conservation requests. Sixty-six notifications were for datasets pre-approved to be used for
231 conservation, and 49 were requests to contributors requiring further permission. Of the latter set,
232 93% were approved. Below, we provide examples of ways the Collective applied tracking data to
233 support: 1) land conservation, 2) land and species management, and 3) education and outreach
234 efforts. Conservation Contribution Reports are available online as they are finalized (NZCBI,
235 2024c).
236
237 **1. Private Land Conservation**
238 Public and private lands support shorebird conservation in North America, but within the
239 Midcontinent where there is high private ownership, private lands are a crucial component of
240 environmental stewardship and land protection (Merenlender et al., 2004). Trusts, foundations,
241 and government agencies can use tracking data to help guide conservation investments and
242 secure funds for voluntary land purchase or conservation. Tracking datasets are especially
243 valuable when they provide the only evidence of shorebirds using areas (for example, when
244 systematic ground surveys or community science observations are unavailable).
245

Funding and siting of conservation easements

The Texas Parks and Wildlife Foundation's Buffer Lands Incentive Program (BLIP) provides financial assistance for conservation easements on privately owned "buffer lands" bordering Texas Parks and Wildlife Department (TPWD) public 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 nine 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 data integration and facilitation by the Collective.

Purchasing land for conservation

The Conservation Fund (TCF) and The Nature Conservancy (TNC), two non-governmental conservation organizations, separately sought information to support funding efforts to acquire lands for permanent protection in the Texas coast (TCF) and the Texas panhandle (TNC). Although no shorebirds within the Collective's dataset visited the parcels under consideration, 23 individuals of four 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.

2. 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 among sites, individual arrival and departure timing at particular sites, and species population structure to inform management actions.

Informing the timing and location of freshwater deployments

The Galveston Bay Foundation, the Nature Conservancy, and Texas Water Trade, three non-governmental organizations, recently entered into multiple multiyear agreements with water authorities to purchase water for wildlife management and environmental flows. The allocated water volumes range from 200 to greater than 2,000 acre-feet 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 six shorebird species provided information on local habitat use and timing through the focal area (Figure 3a, 3b). 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.

Offshore wind energy development

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

areas of interest and highlighted places of high activity (i.e., where track lines congregated for multiple individuals/species).

3. Education and Outreach

Despite increasing public awareness of declining bird populations, many audiences may not be aware of the broad array of habitats shorebirds need during their migrations. The term "shorebird" may limit conservation efforts in the Midcontinent, as many people do not connect them to grasslands or interior wetlands. Shorebirds are sometimes wrongly assumed to have similar habitat needs as other waterbirds like 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.

School curriculum

Educators at Grays Harbor National Wildlife Refuge in Hoquiam, Washington, USA requested example geographic coordinates and track lines to support their 3rd and 4th grade education programs. Educators incorporated data from 17 individuals of five species into four lessons, allowing students to map and explore shorebird movements within the Grays Harbor estuary and across the Pacific Flyway. The activities allowed the 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 these lessons over the 2022–23 school year.

Community outreach

Nature Canada, a non-governmental conservation organization, 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 two godwit tracks and summary statistics (e.g., stopover sites and tenures, average flight speeds) for an infographic at the end of the book. Nature Canada posted the comic

339 book online (Nature Canada, 2022) and distributed paper copies in six First Nations communities
340 around James Bay.
341
342 *Connecting communities with shorebird movements*
343 The Western Hemisphere Shorebird Reserve Network, a science-based, partnership-
344 driven, conservation initiative for protecting shorebirds through a network of key sites, wanted to
345 show how shorebird movements connect "sister sites" within their reserve network. The
346 Collective created an online storytelling series in three languages using ArcGIS StoryMaps to
347 follow three tracked individuals as they migrated across the Americas (SMBC and WHSRN,
348 2024). Each StoryMap features a migratory bird flyway (Pacific, Midcontinent, Atlantic) and
349 cultural theme (food, music, crafts), highlighting the people and places each shorebird might
350 encounter along their migrations.
351
352 **Lessons Learned**
353 The Shorebird Science and Conservation Collective is advancing conservation through
354 collaborative data sharing and analysis in support of needs identified by practitioners. Such on-
355 the-ground conservation is imperative given long-term and accelerating shorebird population
356 declines (Rosenberg et al., 2019; Smith et al., 2023). During the first two years we addressed
357 limitations to data access, analysis, and practitioners use of data insights (Table 1). As templates
358 for others to use, the Collective has shared forms used to communicate with practitioners and
359 contributors and the code pipeline used to process contributed data (Anderson, Stenzel, and
360 Harrison, 2024). The Collective's development offers insights for translational science initiatives
361 globally. Five lessons emerged that are transferable to other initiatives.
362 Lesson 1: Establishing access to processed usable data is crucial to meet the urgency of
363 our crisis discipline (Soulé, 1985). In its first year, the Collective built trust and facilitated
364 agreements with data owners, compiled and standardized data, and created reproducible
365 analytical pipelines. Having data pre-processed in multiple formats (e.g., points, density grids,
366 grouped by priority region) helps quickly inform varied conservation and management
367 discussions. However, barriers to efficiency remain and we agree with the recommendations of
368 Urbano and Cagnacci (2021) to streamline data sharing and harmonization (Urbano and
369 Cagnacci, 2021) including: supporting policy measures to improve the FAIRness of data

authorized by funding and permitting agencies (Sansone et al., 2019); facilitating communication with data registries (Rutz, 2022; Nightingale, 2023); 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); and efforts to integrate multiple data types (Urbano et al., 2010; Binley et al., 2023).

Lesson 2: Science translators and subject matter experts are a valuable resource for practitioners, providing guidance on the use and interpretation of science to meet real-world needs. Collaborative engagement and co-production require significant investment in staff salary and time but provide significant benefit. Our impression from approximately 50 hours 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. The Collective's model of engaging data contributors with each conservation request also increases trust with data sharing, gives reporting benefit to contributors, and increases the network of science translators available to each conservation project. Online decision support services or artificial intelligence tools could streamline data access and science translation for some projects but also requires investment and continued maintenance and development and may lack the benefits of trust and interpretability provided by direct engagement.

Lesson 3: 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 among multiple competing priorities. While conservation initiatives vary in their prioritization of biodiversity, biomes, function, species / guilds, and human communities, guild-specific conservation efforts like those for waterfowl can be greatly successful (Anderson et al., 2018; Brasher et al., 2019). The added capacity and consistent leadership of a collective becomes a powerful incentive for agencies to prioritize group-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: Multiple years of support during an initiative's founding are critical. The Collective's core team founding budget of 1.3 million USD provided three years of salary (51%)

and benefits (16%) for 3 staff members, travel (conferences and site visits, 8%), computing equipment (1%), contract services (language translations, strategic planning, 12%), supplies and printing (2%) support plus 10% overhead. This gave time to develop the Collective's structure, attract strong candidates by guaranteeing three years of support, standardize data, and learn from diverse conservation partners. Sustainability is a challenge for any new initiative. Well-resourced stable leadership is important to maintain momentum, coordinate within and amongst scientists and practitioners, and provide accountability. As the Collective moves from a founding to a sustaining phase, we anticipate a model where some partners can contribute to the Collective's sustainability through contracts or inter-agency agreements. This would ensure the Collective can continue providing free scientific services to financially constrained groups.

Lesson 5: 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 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 now 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 are transferrable to groups with similar conservation aims. Translational models of data sharing simplify complex datasets in efficient, understandable, trusted, co-developed, and actionable ways. This lowers the activation energy for practitioners and policymakers to use science. For migratory species, innovations in tracking technology continue to enhance our understanding of behaviors and habitat use—patterns that are changing with persistent habitat loss and climate change (Sutherland et al., 2012; Galbraith et al., 2014). Ongoing data collection and sharing are vital for liaisons like the Collective to rapidly integrate and interpret research for conservation in a changing world.

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

Science Limitations	**Data Access** Finding and securing access to relevant data is time-consuming • Despite increasing use of data repositories (e.g., Movebank, Kays et al., 2022), many tracking datasets are not open access (reviewed by Scarpignato et al., 2023). • Within repositories, data are spread across hundreds of unique studies led by many scientists. • Obtaining private data involves asking permission from many owners.	**Data Integration and Analysis** Analyzing tracking data for applications is not straight-forward • Preparing, integrating, and analyzing tracking data requires specialized statistical and software knowledge (O'Toole et al., 2021; Joo et al., 2020; Gupte et al., 2022). • 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 analysis as a primary job function (Blickley et al., 2013).
Implementation Limitations	**Competing Priorities** Shorebirds are not the priority within many of their important habitats • 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 (Fernández, 2016; Ciuzio et al., 2013) that may not include a background in shorebird ecology, or how to manage for them alongside primary objectives.	**Need for Strategic Integration** Diverse groups undertake shorebird conservation • 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. • The 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).

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802 Table 2. Examples of organizations, initiatives, and individuals engaged in shorebird
803 conservation and management and the geographic scale (hemispheric to local) at which these
804 organizations operate.
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Hemispheric / Continental	
Western Hemisphere Shorebird Reserve Network	A science-based, partnership-driven initiative dedicated to protecting shorebirds through a network of key sites. The Executive Office of the network is housed by Manomet, Inc., a non-governmental organization.
Shorebird Flyway Conservation Initiatives	A network of governmental and non-governmental partners working to protect shorebirds and their habitats along three 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. The 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.
Flyway Councils	A partnership of representatives from states, provinces, and territories that facilitates the management of migratory birds and their habitats in each of four 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 have the potential to target efforts towards shorebirds and their habitat (e.g., enforce policies, write management/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.
Collaborative Alliances	The Central Grasslands Roadmap (multi-country, North America), and the Southern Cone Grassland Alliance (multi-country, South America) focus on the private land management/conservation interface with potential to strengthen commitments to manage grasslands for shorebirds and to sustain human livelihoods.
State or Province	
State/Provincial Environmental Agencies	State and provincial agencies focused on the protection and management of habitats and wildlife have potential to target efforts towards shorebirds and their habitats (e.g., enforce policies, create/protect habitat, monitor species, conduct research). Examples include State Departments of Fish and Game or Natural Resources and Provincial Ministries of the Environment. Often also have local assistance programs.
County / Local	

Soil & 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.
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.
Local Non-profit Groups	Non-profits that are 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), SAVE Brasil (Atlantic), and many more.
Multi-level	
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.
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. NRCS 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 NRCS programs have potential to support shorebirds and/or create habitat if managed and targeted appropriately.
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 nonprofits 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 like wetlands and native grasslands. Every U.S. State and Territory has a coordinator who helps deliver the program.
Land Trusts	Non-governmental 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/or create habitat if managed appropriately. They can operate at local, regional, and national levels.
Non-profit / Non-governmental Conservation Organizations	Any non-profit / non-governmental 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, Wildlife Conservation Society, and more. Through programs to create or manage wetland, grassland, or agricultural habitat, these groups are (or could be) providing shorebird habitat.

809 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**	SPATIAL ACCURACY	SAMPLING FREQUENCY	MONITORING DURATION	NUMBER OF INDIVIDUALS CONTRIBUTED (% of individuals)	NUMBER OF SPECIES CONTRIBUTED (% of species)
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 pre-programmed 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	1,213* (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 re-transmit location data back to a receiving station on Earth for processing.	Latitude and longitude coordinates with "location class" codes or error ellipses that indicate the accuracy of the estimated location	Generally 250—1,500 m (CLS America, 2016) but individual locations can have errors larger than 25km (Jonsen et al., 2020)	Minutes to days, often irregular; tags may use pre-programmed on/off schedules to allow for charging (solar models), or to conserve energy (battery models)	1+ years depending on tag type and attachment method	938* (27.4 %)	15 (41.7%)
Motus	Electronic VHF radio tags attached to individual birds that are detected by a	Raw detection data (e.g., timestamp, signal strength)	Typically 15 – 20 km from receiving stations (Taylor et al., 2017) but up to	3 - 30 seconds when tag nears receiving station, generally, though	Days to months	1,091 (31.9 %)	4 (11.1%)

	network of receiving stations. Detection data are stored on receivers, synched over the internet, or sent via satellite or cellular network.	associated with the location of each receiving station	180 km (Anderson et al., 2019); ~500 m if omnidirectional antennas are used (Taylor et al., 2017)	gaps can be minutes to days			
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. Devices must be retrieved to download the data.	Raw ambient light levels which require substantial processing and analysis 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+ years	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 the observer	Depends on observer proximity but 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 Collective dataset	15 (41.7%)

* Includes 184 individuals tracked with both GPS and Argos technologies

** 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 that the tag became immobile (17.3%, 4 species).

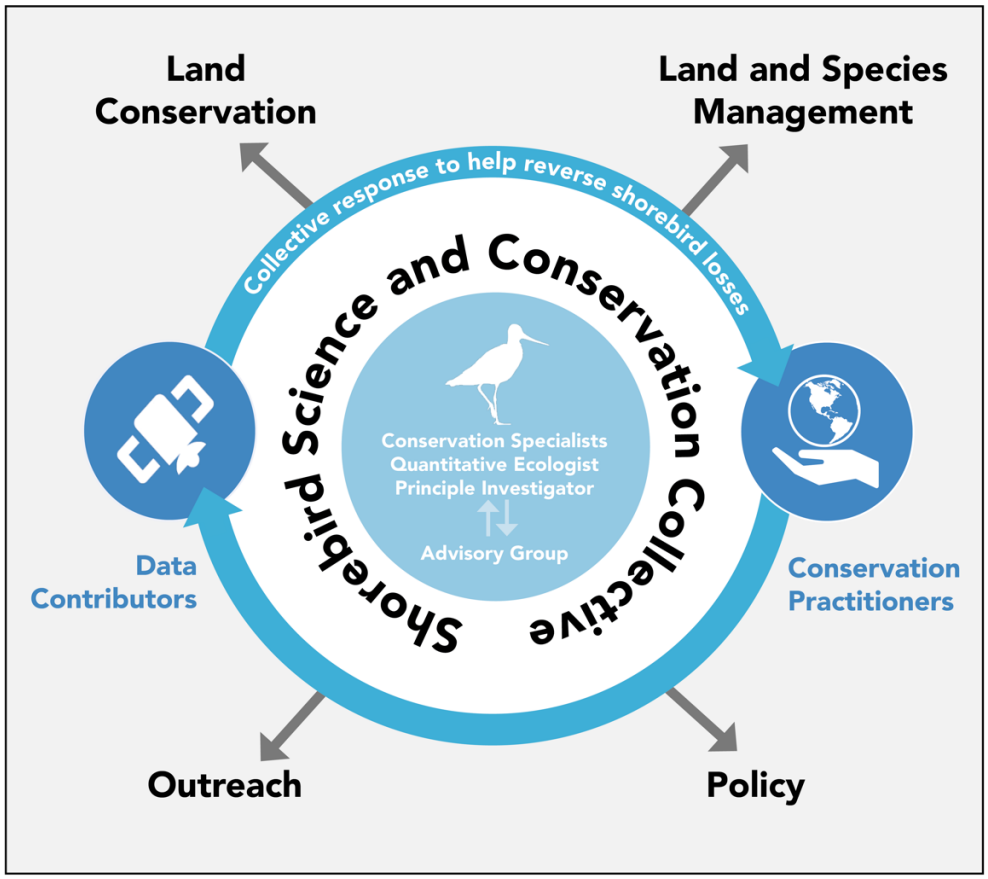

Figure 1. The process by which the Shorebird Science and Conservation Collective distributes knowledge generated from electronic tracking studies of shorebirds to conservation partners across the Americas to enhance land and species conservation, management, and outreach and education activities. In the future, this resource also has potential to inform conservation policy. The Collective engages with practitioners in service to community-driven management and conservation needs, with the ultimate goal of reversing population declines.

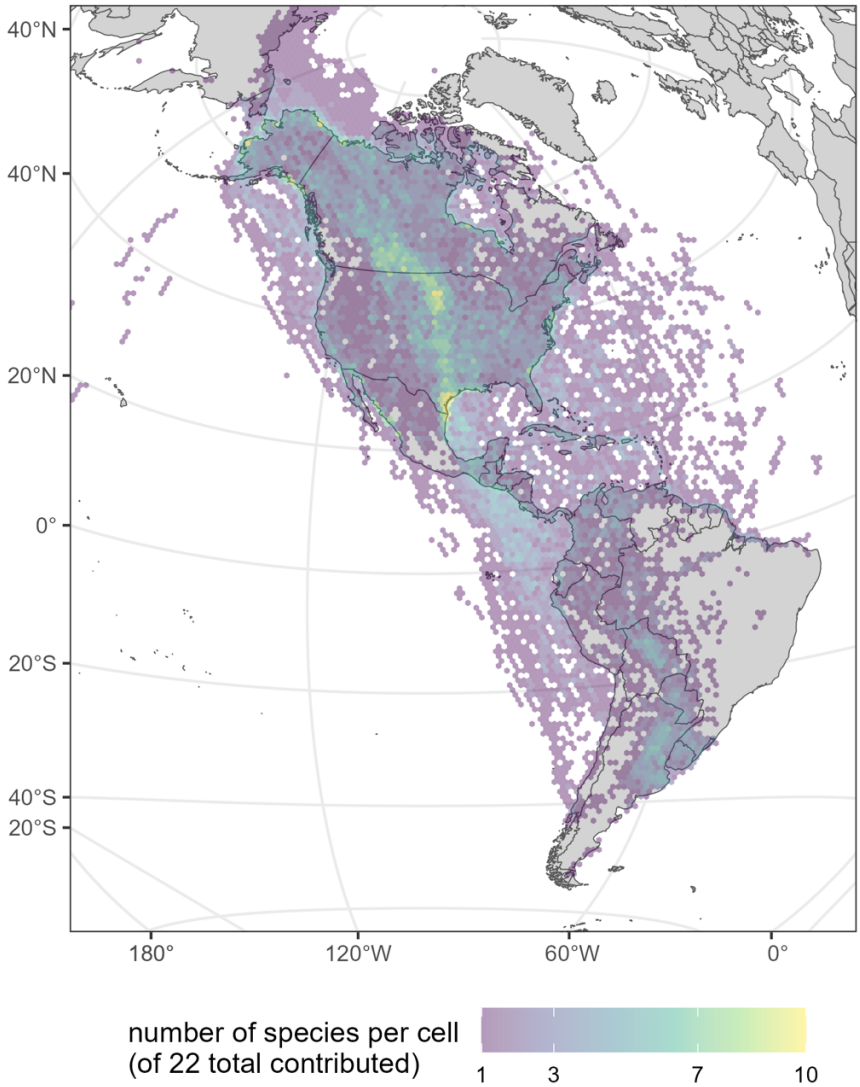

Figure 2. Distribution of Argos and GPS tracking data from tags deployed in the Americas (Table 3; n=1,883 individuals of 22 species) contributed to the Shorebird Science and Conservation Collective as of June 2024, shaded by the number of species with tracking locations in 100 km x100 km hexagonal cells.

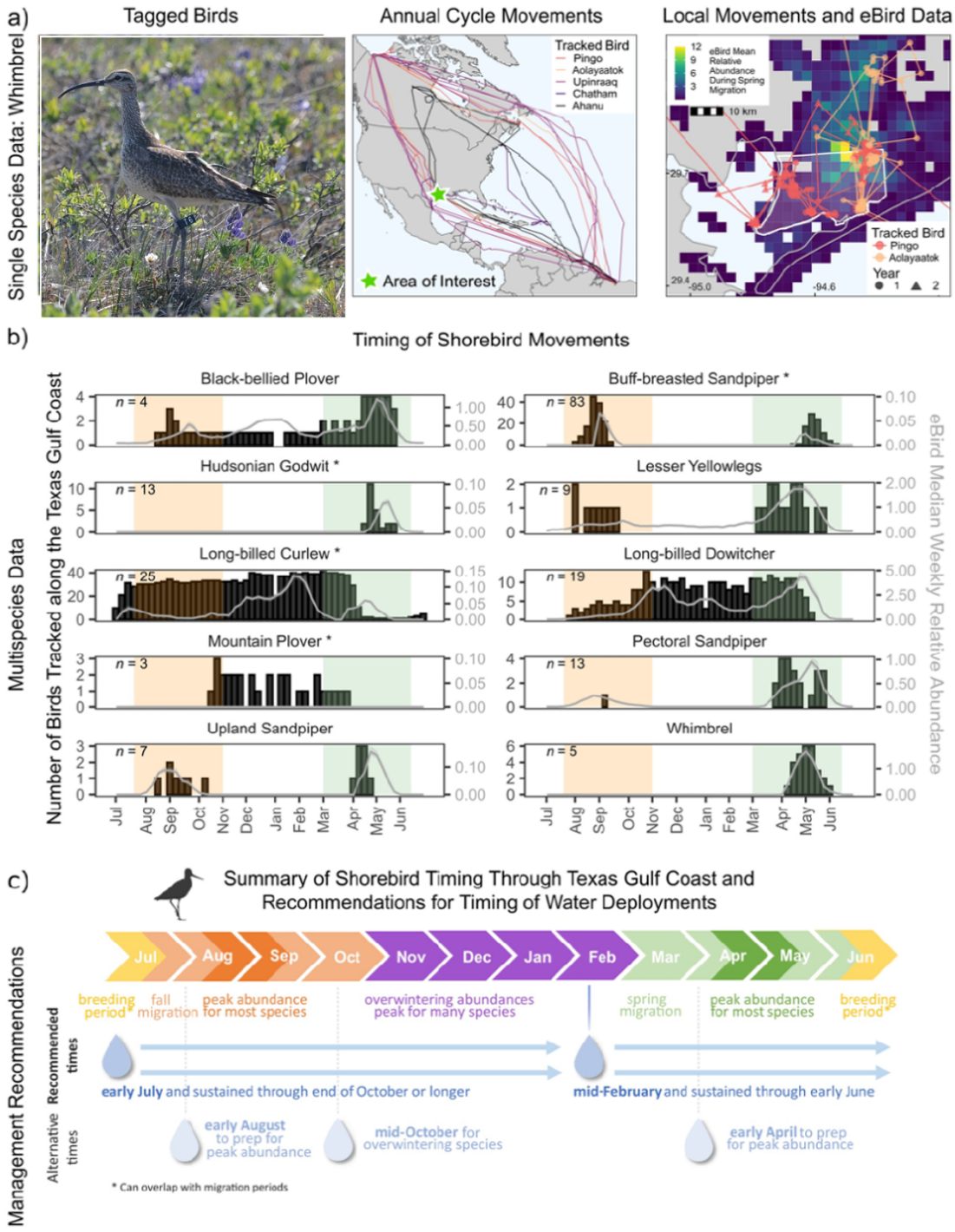

Figure 3. Example figure from a conservation project report informing the timing of freshwater deployments to provide habitat for migratory and wintering shorebirds in Texas. A) Example tracking data from whimbrel (*Numenius phaeopus)*, shared by Jennie Rausch, Environment and Climate Change Canada (middle) and overlaid on a focal area of interest in Texas (right). B)

Time series of when tracked birds traveled through the Texas Gulf Coast (black histogram bars) together with median weekly relative abundance (gray lines) in the area of interest predicted by eBird community science data (Fink et al., 2022). Individuals tracked in more than one year contributed to histogram counts more than once because timing varied for individuals between years. Fall migration is shaded orange and spring migration is shaded green. Species with asterisks are Texas State Species of Greatest Conservation Need (Texas Parks and Wildlife Department, 2012). Information from A) and B) were used to determine time periods during which water deployments could benefit peak diversity and abundances of migratory shorebirds, leading to C) Recommendation to conservation partners for deploying water to benefit migrating and overwintering shorebirds under recommended and alternate scenarios.