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Community-engaged research enhances the scientific quality and societal impact of a long-term avian monitoring program in northwest Ecuador

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Introduction: There has been a growing realization that a more inclusive approach to research can provide both ethical and practical benefits. Long-term avian monitoring programs, and indeed the academic and research community as a whole, are still learning how best to implement these methodologies effectively.

Methods: This paper provides information on a twenty-plus-year effort to conduct community-engaged avian monitoring in northwest Ecuador, with a focus on how this approach has impacted the quality and scope of the project's science and broader societal impacts. We focus on three case studies that have been proceeding for varying lengths of time to highlight various stages of project development and maturity.

Results: A community-engaged approach has improved the quality of our scientific research by adding traditional ecological knowledge (TEK), technical capacity, and intellectual contributions to our monitoring efforts. Community-engaged research has also enhanced the breadth and quality of societal impacts, in terms of education, capacity building, and conservation, particularly in the formation of an ecological reserve that protects threatened species and habitat. We also discuss systemic and local challenges, and potential strategies to overcome these challenges

Discussion: We conclude that community-engaged research can improve the intellectual merit and broader societal impacts of long-term avian monitoring, and we advocate for continued investment, efforts, and careful reflection on best practices in this space.

KEYWORDS

avian monitoring, broader impacts, Chocó biogeographic zone, community-engaged scholarship, conservation, traditional ecological knowledge TEK, research methods

1 Introduction

Long-term monitoring of bird populations is a core element of the ornithologist's toolbox that underlies many key advances in the field. These studies provide unique insights into the demography, movement, and response of avian communities to changing environmental conditions. This information is crucial to our understanding of basic ecological, behavioral, and evolutionary processes and theories. It is also of fundamental importance for conservation, as it enables scientists and managers to monitor the trajectories of populations, species, and communities. In today's rapidly changing world, long-term monitoring provides important insight into how climate change, habitat transformation, disease, and other factors may be affecting bird populations (Pollock et al., 2022). Without this information, our collective ability to detect trends, manage populations, and influence policy would be significantly diminished.

Meaningful inclusion of local residents in avian monitoring projects can benefit both the quality of the science and the translation of research into conservation policy and action (Figure 1). Participation of locals in research, decision-making, and action that influences their surrounding environment leads to the development of grassroots leadership (Baptista et al., 2024). Several names have been given to this basic methodological approach, including community-engaged research (Hale, 2008), participatory-action research (Fals-Borda, 1991), and activist research (James and Gordon, 2008), but all share a similar goal: involving community members as active collaborators in the research process via co-design, co-implementation, and co-dissemination of results. Much of the conceptual framework and

FIGURE 1
Key principles of FCAT's approach to long-term, community-engaged research. **(A)** FCAT researcher (white shirt) draws upon traditional ecological knowledge (TEK) to teach a visiting researcher about a key ecological process, in this case seed dispersal of the palm *Oenocarpus bataua* by the long-wattled umbrellabird; **(B)** FCAT researcher and visiting researcher collaborating on research they co-designed on seed dispersal in this system; the research benefits from a series of technical advances developed by the FCAT researcher including pulley systems to place mist nets and motion-activated cameras high in the canopy; **(C)** FCAT researcher shares uses the research as a catalyst for broader dialog about ecology and conservation with local audiences, in this case members of the *Nueva Generación* Environmental Youth Club; **(D)** an alumnus of the *Nueva Generación* Environmental Youth Club goes on to become an FCAT researcher; she is shown here observing a long-wattled umbrellabird dispersing seeds from intact forest to a 'tree island' planted by FCAT in an abandoned pasture, hastening the recovery of the pasture back to intact forest indicated in panel **(A)**. The arrows are meant to indicate that each four stages of this community-engaged research model feeds into the next.

application of community-engaged research has taken place within the social sciences, with relatively little representation from STEM (i.e., Science, Technology, Engineering and Mathematics). However, local residents and the traditional ecological knowledge (TEK) they hold can add value to the identification of salient research questions and hypotheses, project design, use of appropriate methods, data collection, and interpretation of results (Ramos and Culver, 2024) (Figures 1A, B). Moreover, the attitudes and actions of local residents often play a large role in shaping the degree to which research translates into real-world conservation actions (Baptista et al., 2024) (Figures 1C, D). For these reasons, effective community-engaged research is increasingly recognized as a priority among researchers and funding agencies in STEM.

Community-engaged research is particularly important in the tropics and Global South for four reasons. First, baseline ecological knowledge is sparse relative to northern temperate areas, so data generated by these studies is of exceptional importance, and inclusion of local residents in the research process can have substantial benefits for the breadth and quality of data collected (Adams et al., 2014; Haelewaters et al., 2021; Singeo and Ferguson, 2023). Second, these areas are of the highest importance for avian conservation, because they contain high biodiversity and endemism, in addition to high (and sometimes extreme) levels of threat from habitat loss and other anthropogenic impacts (Myers et al., 2000). Third, because enforcement of environmental regulations is sometimes limited, local resident actions often take on an outsized role in determining conservation outcomes in these regions. Fourth, research often takes place within or adjacent to traditionally marginalized communities with a long history of colonial, parachute-style research from Western institutions (Stefanoudis et al., 2021), and effective community-engaged research represents one concrete way to address this issue and break the cycle (Tuhiwai Smith, 2022). Yet, community-engaged research efforts in the tropics and Global South (and beyond) are still relatively rare, and those that do exist vary widely in terms of their goals, design, implementation, and efficacy (Görg et al., 2014; de la Torre and Morelos-Juárez, 2022; Ortega-Álvarez and Casas, 2022). Openly sharing the details of ongoing and past efforts can help scientific and conservation researchers to develop a more refined understanding of what approaches are likely to be most impactful and successful in the context where they work.

Here, we describe key elements of a community-engaged avian monitoring project in the Chocó biogeographic zone of northwest Ecuador. The project is a collaboration between local resident researchers associated with FCAT (Fundación para la Conservación de los Andes Tropicales), an Ecuadorian non-profit that manages a private reserve, and international or Ecuadorian researchers and students based at universities or other research-focused organizations. We focus on two key questions. First, in what ways has community engagement influenced the quality and trajectory of our scientific research? Second, to what degree and in what ways has community-engaged research had societal impacts beyond the generation of scientific knowledge of avian populations? To highlight how community-engaged research may evolve over time, we address these questions in the context of three monitoring programs of differing lengths: long-wattled umbrellabird behavioral ecology, now entering its third decade; white-bearded manakin evolutionary ecology and behavior, begun four years ago; and point count surveys of avian diversity in a restoration context, currently in its second year. In doing so, our goal is to provide a more detailed and nuanced understanding of how community-engaged research can be adopted or expanded in long-term avian monitoring efforts, and beyond.

1.1 Project context & overview

Latin America is justifiably revered for its biological diversity, but even against this impressive backdrop, the Chocó Biogeographical Region of western Colombia and northwestern Ecuador stands out. For example, the Chocó presents exceptional levels of floristic diversity (> 11,000 species) and the highest number of range-restricted endemic bird species (62) in the western hemisphere (Salaman, 1994; Birdlife International, 2024). However, the Chocó is also notable for extreme threat levels driven by extensive deforestation, habitat conversion, and unsustainable removal of plants and animals from the ecosystem. It was identified as one of the original 25 'biodiversity hotspots' and continues to be considered among the global priorities for conservation of biodiversity (Myers et al., 2000).

Our project is based in and around the 121,376 ha Reserva Ecologica Mache Chindul (REMACH) in Esmeraldas Province, Ecuador (Figure 2). The area has a long history of human occupation and use that dates back at least to the Jama period (1,500 years BCE) and likely involved substantial land clearing for agriculture (M.P. Ordoñez, personal comment). According to the 2010 national population census (latest available), 6,466 people live within the boundaries of REMACH (Marcillo et al., 2016). Inhabitants of the REMACH are primarily from three distinct ethnic groups: Indigenous Chachi (17% of the reserve population), Afroecuadorians (10–15% of the reserve population), and *colonos* or mestizo settlers (65% of the reserve population) (Ministerio del Ambiente del Ecuador, 2005). Chachi and Afro-Ecuadorian presence in the area pre-dates the arrival of mestizo colonists by several generations.

Perlin and Leguizamón (2024) provide a useful overview of the socio-historical context of the region, with particular reference to mestizo residents. Between 1964 and 1994, incentivized by land reform policies enacted by the Ecuadorian Institute for Agrarian Reform and Colonization (*Instituto Ecuatoriano de Reforma Agraria y Colonización*, known as IERAC), families migrated to the region, primarily from Manabí, the province neighboring Esmeraldas province to the South. Today the area is divided into small- to mid-sized farms (of about 10 ha on average) where the primary agricultural activities are cacao cultivation (92% of their study population) or pasture for cattle ranching (50% of their study population). Most households rely primarily on a market economy to meet their needs; the profits generated by selling agricultural products fund the purchase of food, medicine, and other household costs. Notably, since acquiring their farmland, families reported that they cleared an average of 92.5% of their total hectarage to make room for agriculture and provide financially for their families. Local residents express a desire to provide security (in the form of land

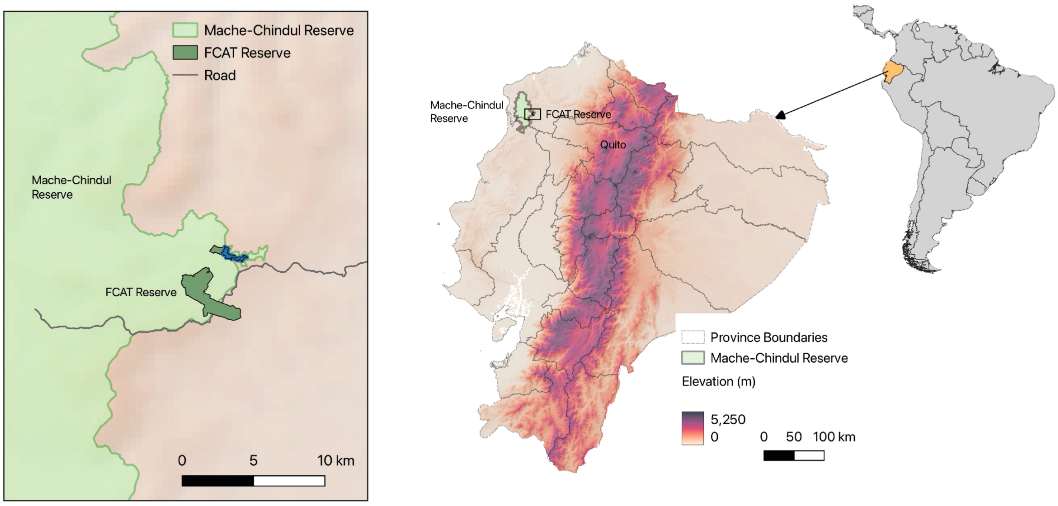

FIGURE 2
Map of the FCAT Reserve in the context of Ecuador and South America. The box to the left shows the location of the FCAT Reserve (dark green), the primary study area, in relation to the larger Reserva Ecologica Mache Chindul (REMACH, light green) and the Laguna de Cube (blue) in northwestern Ecuador. In the center image, the location of the FCAT Reserve and REMACH within Ecuador are shown. To the right, Ecuador is highlighted in orange in the context of wider South America.

tenure, access to education and medical care, and a healthy and clean environment) to future generations, but their own precarity drives them to act against these longer-term interests in the form of agriculture-driven deforestation (Perlin and Leguizamón, 2024).

Mirroring the broader trend of deforestation across the Ecuadorian Chocó, recent studies demonstrate a total loss of 10.1% of forested area from 2000–2008 in REMACH, making it the ecological reserve with the highest deforestation rate within the Ecuador Protected Areas System (SNAP) (Van Der Hoek, 2017; Kleemann et al., 2022). Deforestation rates within the boundaries of REMACH are slightly lower than outside the reserve. There are clearly major disconnects between the law establishing the reserve which outlined accepted activities within the boundaries (*i.e.*, prohibiting extractive enterprises within the reserve) and the reality of the lived experience of local people residing within the boundaries of REMACH. This, along with an ambiguous land tenure system stemming from the aforementioned land reform policies enacted by IERAC and a lack of informed consent by all residents during reserve establishment in the 1990s, has led to tension between residents and representatives of the Ministry of Environment who are tasked with managing activities within the reserve (Perlin and Leguizamón, 2024). Foreign and locally-funded NGOs have actively supported ecological conservation in the area, yet they have mixed track records in terms of the sustainability and longevity of projects and providing alternative sources of income for locals (Perlin and Leguizamón, 2024).

Fundación para la Conservación de los Andes Tropicales (FCAT) is an Ecuadorian NGO that owns and operates the FCAT Station and Reserve (Figure 2), most of which is situated inside the borders of REMACH. A core component of the mission of FCAT is to enable, enhance, and support research that serves to (i) advance basic knowledge, (ii) train Ecuadorian, US, and international students, (iii) build local capacity, and (iv) achieve real-world conservation gains. FCAT members began working together in 2003 in the nearby, privately owned Bilsa Biological Reserve, which is owned by another Ecuadorian NGO, the Jatun Sacha Foundation. Bilsa is the largest continuous forest area in the REMACH area (3,500 ha) and was the main focus of FCAT's research efforts for nearly a decade. FCAT members went on to form a legally recognized Ecuadorian non-profit organization in 2011 and expanded from Bilsa to include research on privately owned farms and patches of forest throughout REMACH (e.g, Walter et al., 2017). FCAT established the FCAT Reserve in late 2018 via an initial purchase of 164 ha. In 2019, FCAT constructed a field station with housing for 60 people and basic laboratory facilities that serves as a base for ongoing research and conservation programs. At present, the reserve is 656 ha in size.

FCAT's research program is anchored in a community-engaged approach (Figure 1). In principle, this means that local residents collaborate on a non-hierarchical, horizontal playing field with formally trained scientists. The idea is that team members from very different backgrounds each bring a distinctive, valuable suite of talents, skills, knowledge, experience, perspectives, and capacities to a shared research effort. The degree to which this is realized has varied considerably across projects, years and teams over the past 20 years, but this philosophy has been central to FCAT's research program from its inception to the present. At present, FCAT employs more than 20 local resident researchers and supports a portfolio of research projects; some are led and implemented exclusively by FCAT (*e.g.*, climatic conditions; plant phenology), some are close collaborative efforts with external scientists (*e.g.*, habitat restoration); and some are conducted by external scientists with minimal logistical and administrative support from FCAT. Complementing these research projects are a suite of social programs that include a youth environmental club, a women's art collective, and a regenerative agriculture project.

2 Case studies

This article examines some of the ways in which FCAT's model of community-engaged research has influenced the trajectory of our scientific research and the nature and breadth of any societal impacts arising from that research. Community-engaged research is built on relationships, both interpersonal as well as between individuals, the natural system, and the research process. Both types of relationships develop over time, and as a consequence, the nature of community-engaged research projects are also likely to change. As such, we present case studies from lines of research that are at early, mid, and mature stages, in reverse chronological order. The information presented below is largely qualitative in nature; in future work we plan to assess scientific, social, and conservation impacts using both qualitative and more quantitative approaches.

2.1 Long-wattled Umbrellabird

2.1.1 Project overview

Cephalopterus penduliger, the long-wattled umbrellabird, is endemic to the Chocó forests along the western slope of the Andean cordillera in Colombia and Ecuador (Snow, 1982; Del Hoyo et al., 1992). The species is considered Vulnerable to extinction by the IUCN due to habitat loss and fragmentation, with an estimated total population size of less than 15,000 individuals across its range (IUCN, 2022). The long-wattled umbrellabird is known for its striking appearance and lek mating system (Snow, 1982; Jahn et al., 1999; Kirwan et al., 2011), but many gaps in our knowledge of basic biology and conservation status persist.

Our work with the long-wattled umbrellabird began in 2003 and represents our team's longest continuing avian monitoring project. The principal investigators on this research have been two local residents Jorge Olivo and Domingo Cabrera and two international researchers Luke Browne and Jordan Karubian. JO, DC and JK began working together on umbrellabird research at the Bilsa Biological Station in early 2003. This initial connection was enabled and strengthened by Carlos Aulestia, the manager of the Bilsa Reserve at the time, and Luis Carrasco, an Ecuadorian ornithologist working at Bilsa. These relationships and individuals served as the nucleus for future growth of FCAT. Renata Durães Ribeiro, a tropical ornithologist, joined the project in 2006 and LB joined in 2011 as a PhD student. The seven of us continue to work together at FCAT, over twenty years later.

Monitoring of the umbrellabird has evolved over time, and has involved many local, Ecuadorian, and international researchers and students. Initially, the project had two main goals, one related to sexual selection and mating dynamics, and a second related to characterizing habitat use, foraging ecology and reproductive biology to inform conservation planning. Moreover, characterizing natural history and basic biology have always been a focus, in part because the species was so poorly known at the inception of this project. In the early years of the project, we surveyed large areas of forest within and adjacent to Bilsa, searching for active lek sites. Upon discovery, we began to monitor active leks on a continuous basis to characterize patterns of activity and male courtship displays (Olivo et al., in review). We also characterized female behavior, nesting biology, and nestling development, as well as foraging ecology and social behaviors away from the lek (Olivo et al., in review). This baseline of natural history information, which we continue to gather, provides a foundation for additional research on umbrellabird behavioral ecology. It also serves as a vehicle for similar, descriptive studies of endemic, threatened and poorly known Chocó avifauna such as banded ground-cuckoo *Neomorphus radiolosus* (Karubian et al., 2007) and brown wood-rail *Aramides wolfi* (Karubian et al., 2011).

Observations of umbrellabirds foraging at large-seeded tree species and subsequently regurgitating or defecating those seeds at lek sites raised questions about how frugivory by umbrellabirds impacts progeny survival and subsequent distributional patterns of the plant species they feed on. One of the key food sources for umbrellabirds in REMACH is *Oenocarpus bataua*, a canopy palm that produces a large-seeded fruit that relatively few resident bird species besides umbrellabirds and toucans are able to ingest and disperse (Mahoney et al., 2018). After showing that umbrellabirds disperse a large proportion of seeds they ingest into the lek (Karubian et al., 2012), we explored the ecological consequences of umbrellabird directed dispersal into the lek by comparing *Oenocarpus* seedling survival and growth in lek sites to control areas outside the lek (Karubian et al., 2016). We also characterized recruitment by *Oenocarpus* and other palm species across a range of habitat types in REMACH (Lueder et al., 2022). In another study, we evaluated how *Oenocarpus* phenology may intersect with observed patterns of behavior (Ramirez-Parada et al., 2020). We also used molecular analyses of dispersed seeds to explore the degree to which umbrellabirds from different lek sites overlap in foraging range (Ottewell et al., 2018). And, given the high incidence of forest loss in our project area, we assessed habitat fragmentation and habitat loss may disrupt the processes we observed in natural settings (Walter et al., 2017). Taken together, this body of work has improved our collective understanding of the basic biology and behavioral ecology of umbrellabirds, and their indirect effects on plant genetic and ecological diversity.

2.1.2 Impacts of community engagement on scientific research

2.1.2.1 Traditional ecological knowledge

Local researchers JO and DC entered the project with a high degree of baseline traditional ecological knowledge (TEK), gained by growing up in and interacting with rainforest habitat and flora and fauna throughout their lives. Their lived experience also provides an ability to navigate through the forest that far exceeds that of most visiting researchers. These attributes have enabled exceptional contributions to our research program, such as discovery of new leks. Umbrellabird leks are sparse on the landscape (the pairwise distance between neighboring leks is 1.8 km; Ottewell et al., 2018), and this work requires surveying large areas of the forest and navigating to lek sites by following the sounds of male calls, audible up to one mile away. This TEK also contributed to finding nests of umbrellabirds and other poorly known, threatened species (Karubian et al., 2007, Karubian et al., 2011, Olivo et al. in review), observations of close mutualisms with certain tree species (Figure 1A) and other novel information about diet (*e.g.*, umbrellabirds killing and eating snakes), and predation attempts (*e.g.*, a large hawk attacking an umbrellabird); and documenting previously unappreciated associations between umbrellabirds and other species (*e.g.*, oropendolas, toucans, and fruitcrows); and finding individuals of particular tree species in a given phenological state (*e.g.*, ripe fruits or flowering) to enable research on frugivory (Mahoney et al., 2018) or pollen flow (Diaz-Martin et al., 2023).

2.1.2.2 Technical contributions

JO and DC contribute a degree of technical capacity and capability that enables our team to collect types of data that otherwise would not have been tractable (Figure 1B). For example, JO and DC developed and refined a method to place mist nets up to 25 m above the forest floor to capture umbrellabirds in the canopy. To do so, they built and used catapults to shoot nylon fishing cords attached to weights above major tree limbs, then created a pulley system to raise and lower the mist nets. This technique had been used previously in other contexts, but they were unaware of these antecedents when they developed it. JO and DC also developed a novel system to raise motion-activated camera traps high into the canopy to record instances of fruit removal at fruiting palms and other trees while anchoring each camera in place to avoid spurious or blurry photos due to wind movement. To do so, they designed a pulley system with a series of guy lines from the cameras to nearby trees to hold it in place. JO was fundamental in developing a sampling methodology involving playback and audio/visual surveys for estimating the occupancy of umbrellabirds and secretive ground-dwelling birds such as the banded ground-cuckoo and brown wood rail in forest fragments (Walter et al., 2017). These and other technical contributions underlie fundamental information for our research project, including the ability to measure, ring and attach tracking units to birds and to characterize frugivory patterns and foraging ecology.

2.1.2.3 Intellectual and natural history contributions

There is a long history in ecology and evolutionary biology of natural history observations leading to the development of new hypotheses, conceptual frameworks, and theoretical insights, and the observational ability and natural history talents of local residents have spurred a number of such advances in the context of the umbrellabird project (Figure 1A). One example is the observation that umbrellabirds may be effectively "eco-engineering" their habitat by creating "gardens" of their preferred food sources in lek sites via seed dispersal. This led to the development of tests about whether this results in a survival advantage for these seeds (Karubian et al., 2012) and predictions about the degree to which males from different leks may overlap in foraging range (Ottewell et al., 2018). Observations of males moving in a coordinated manner away from lek sites generated predictions and preliminary tests about the ecological and evolutionary underpinnings of this unexpected behavior (Anderson et al., 2023). One topic that has raised considerable interest and speculation among our team, but not yet resulted in a formal study, is 'floating males' that do not appear to hold steady territories on a single lek. JO and DC have each co-authored at least ten peer-reviewed publications, each of which involves a meaningful intellectual contribution.

2.1.3 Societal impacts of community engagement

2.1.3.1 Education

As longtime community residents and leaders in our project area, JO and DC are well positioned to share the rationale, methods, results and implications of our team's research on umbrellabirds (and other topics) locally (Figure 1C). Educational activities directed toward local adults and children include informal talks, powerpoint presentations, and experiential learning in the field. Prior to electricity being available in the mid-2010's, JO and DC would carry generators and fuel long distances to arrive at communities and make powerpoint presentations (today, logistics are much easier). JO and DC have also moved into a role as educators and mentors to visiting students and scientists at the FCAT Reserve. As co-instructors on multi-day field courses, they give formal and informal presentations about their research and professional trajectories and help to co-lead short-term student projects on a wide range of topics. They also train and mentor undergraduate and graduate students and PhD-level scientists conducting longer-term independent research projects at FCAT. For example, they provided LB with training in how to identify focal species of plant and bird at various life stages and how to identify frugivore seed deposition sites, and HLA in radio tracking. JO and DC also educate constituents at regional and international scales. They have participated in multiple conferences in Ecuador and internationally (Colombia, Peru) and presented oral and poster presentations, each receiving formal recognition for the quality of their presentations and impact. Serving as lead or co-authors of scientific publications has also helped disseminate their work on an international scale.

2.1.3.2 Capacity building & professional development

JO and DC build local capacity by training fellow local residents and FCAT staff in research methodologies, study design, and interpretation of results, including radio tracking, phenology, plant identification, and camera trap placement and management. They have also helped to identify the need for and to arrange workshops by professionals in themes relevant to local communities, including crop management and water security. They also played a significant role in inspiring younger locals to join FCAT, and then training them in a range of methods (Figure 1D). It is also worth noting that JO and DC built significant capacity during their two decades of work on the project. They learned GPS, computation, compass, radio telemetry, mist netting and handling birds, scientific research design, repeatability, hypothesis formulation and testing. This professional development also extends to public speaking, preparing presentations, and running workshops as well as participation in professional development events such as regional workshops and conferences. While working on the project, DC returned to his studies and graduated from high school, and JO received the Local Conservation Hero Award from the Disney Conservation Fund.

2.1.3.3 Conservation

JO and DC have gathered and published data that have informed IUCN classifications of endangered species such as the banded ground-cuckoo and long-wattled umbrellabird. By gathering reliable data on these and other at-risk populations, they provide necessary justification to convince funders to invest in land purchase and reserve establishment. For example, they identified key tracts of forest to prioritize for conservation, due to the number and density of threatened species residing within them, helped to negotiate their purchase and management with local landowners, and have directly contributed to restoration of degraded habitats on that land. On a social level, their ability to interact with local residents as peers may enable more effective communication with locals about challenges, opportunities, and strategies associated with conservation relative to official representatives of an NGO or the government.

2.2 Project Manacus

2.2.1 Project overview

Among the most common and charismatic birds in our study area is the white-bearded manakin *Manacus manacus*, one of four manakin species found on the FCAT Reserve. This species is notable for its unusual courtship behavior: males create display courts on the forest floor where they leap between saplings and smash their wings together behind their backs to produce explosive 'snapping' sounds (Bodony et al., 2016), and females visit male courts to join in coordinated 'dances', assess male quality, and mate. Male display courts are clustered together in areas called leks, and one or a few males obtain the vast majority of copulations. Perhaps unsurprisingly, considering their abundance in Neotropical secondary forests, remarkable display behavior, and high degree of male reproductive skew, manakins in the genus *Manacus* have served as important systems for studies of sexual selection (*e.g.*, McDonald et al., 2001; Shorey, 2002; Stein and Uy 2006; Barske et al., 2011; Schlinger et al., 2013; Bennett et al., 2021).

We have studied white-bearded manakins at the FCAT Reserve since late 2020 in the context of H. Luke Anderson's dissertation project. A primary aim of Project Manacus is to better integrate sexual selection theory with ecology—two fields that have been traditionally largely separate, potentially due to the historical split between natural selection (concerned with survival, fecundity, and an organism's fit with the environment) and sexual selection (concerned with mating and fertilization success, as well as individual preferences and traits that often seem to defy expectations of natural selection; Darwin 1871). Manakins offer an exciting opportunity to bridge this gap due to their unusual natural history, foraging ecology, and mating system. Because the white-bearded manakin is a generalist frugivore, a major environmental variable we are tracking through time is the abundance of ripe fruit in proximity relative to male display areas. Males spend up to 90% of their time on courts during breeding periods (Snow, 1962), and thus resources at small spatial scales (*e.g.*, in the area immediately surrounding courts) may be important drivers of male allocation to display behavior. The project aims to track sexual selection dynamics in our population longitudinally, given that intra-annual variation in resource availability, precipitation, and other variables may impact the form, strength, and direction of sexual selection (Cornwallis and Uller 2010; Miller and Svensson 2014). To achieve this, we are using motion-activated camera traps at male display courts to constantly monitor patterns of male display, female visitation, and mating among color-banded individuals while concurrently tracking the availability of fruit resources around male display courts via twice-monthly visual surveys.

Thus far, we have uncovered a number of interesting connections between frugivory, resource ecology, and sexual selection processes in the manakin system. First, we have extended findings in Amazonia that manakins situate leks on resource "hotspots" (Ryder et al., 2006), demonstrating that the number of fruiting plants, total fruit biomass, the number of melastomes, and fruiting plant diversity is significantly higher at manakin leks and display courts compared to surrounding forest (Casement et al., in prep). We have also experimentally demonstrated that manakin gut passage accelerates the germination of *Miconia rubescens*, a common melastome shrub, suggesting that manakins may be effective dispersers of key pioneer species in regenerating secondary forest habitats (Rompf et al., 2024). Finally, we have observed previously unappreciated connections between fine-scale fruit availability and male sexual trait expression, with average fruit biomass within 10 m of male display courts positively predicting male display rates, which in turn predict rates of female visitation (Anderson et al., 2024). Radio telemetry has revealed that male movements are centered around lek areas, yet space use is largely distinct even among individuals belonging to the same lek. With continued monitoring, Project Manacus aims to further resolve the ways that ecological fluctuations over space and time interact with individual genotypes to shape sexual selection processes in natural contexts, potentially providing insight into the mechanisms maintaining genetic variation under strong sexual selection (*i.e.*, the so-called 'paradox of the lek'; Kotiaho et al., 2008).

2.2.2 Impacts of community engagement on scientific research

2.2.2.1 Traditional ecological knowledge

Project Manacus has benefited tangibly from community members' TEK and familiarity with the local area. When manakins were identified as a group of interest in 2020, local researchers JO, DC, and Nelson González, along with Luis Carrasco, conducted an initial survey of Reserva FCAT and Bilsa Biological Station to locate display grounds of all lekking manakin species in the area (*i.e.*, redcapped manakin, *Ceratopipra mentalis;* velvety manakin, *Lepidothrix velutina;* golden-winged manakin, *Masius chrysopterus;* and white-bearded manakin, *Manacus manacus*). These surveys involved exploring large swathes of unmapped forest habitat, which was facilitated by the local knowledge and navigational skill of community members. Ultimately, this survey generated data for a publication about lek habitat selection by manakins (Sheehy et al., in review) and helped inform HLA's decision to focus on the white-bearded manakin due to the species' relative abundance and proximity of leks to research facilities.

Local resident Jairo Cabo became involved in Project Manacus in 2021, bringing considerable local and traditional ecological knowledge that advanced the science. A major longitudinal component of Project Manacus involves visually surveying ripe fruits around male display courts. In part due to his experience in agriculture and crop cultivation, as well as his familiarity with the local flora, JC was able to quickly and accurately define and identify various stages along the continuum of fruit ripeness for multiple plant species, dramatically reducing the time required to conduct surveys. JC is able to survey all display courts in the population in 2–3 days, which would have previously required ~3 surveyors to accomplish. With JC leading data collection, we have been able to consistently conduct twice-monthly surveys at all male display courts, and nearly 3 years of this data has been collected to date.

Local residents often rapidly develop competence in mist net extraction with little training or guidance, which may be due in part to their experience with traditional gill-netting techniques. JC explains his process: weighted nets are tossed into rivers at night to capture fish sleeping on the riverbed; when nets are tossed, they sink to the bottom and cause fish to startle and swim upward, trapping their gills and spines in the net. Extracting fish from these nets requires similar technique and fine motor control as extracting birds from mist nets: the direction of entry and points of entanglement are identified, and careful yet confident movements disentangle the animal. The aptitude of local residents in mist netting procedures has been essential for the success of Project Manacus and other avian monitoring projects in the FCAT Reserve.

Importantly, the TEK of local residents also keeps visiting researchers safe while conducting fieldwork. For example, tracking manakins with radio telemetry requires following birds away from established trails, often in regenerating areas with dense undergrowth or fallen debris. These conditions can be dangerous, as terrestrial venomous snakes like Chocoan bushmasters (*Lachesis achrochorda*) and fer-de-lance (*Bothrops asper*) are common at the site. These dangers are also present during visual fruit surveys: observers must sometimes reach into dense shrubs to expose and count fruits, and highly camouflaged eyelash palm-pitvipers (*Bothriechis schlegelii*) may be coiled among the foliage. JC, JO, and others provide constant reminders to step only in locations where the ground is fully visible, using long sticks or other implements to probe occluded areas on the ground or in bushes before proceeding. Residents also regularly share valuable local knowledge about snake behavior (*e.g.*, bushmasters are particularly likely to emerge after rainstorms to warm themselves) and a variety of other potential hazards (*e.g.*, bullet ants, poisonous plants), helping to ensure the safety of students and volunteers involved with Project Manacus.

2.2.2.2 Technical contributions

Following the initial survey of leks, local resident Nelson González was instrumental in early mist netting efforts to begin banding and monitoring manakin study populations, building on previous mist netting experience with umbrellabirds and other species in the area, which was essential given that HLA had limited experience in these techniques at the time. Later in the project, JO leveraged his extensive experience tracking long-wattled umbrellabirds to train HLA in radio telemetry methods. Telemetry can be challenging in rugged forested landscapes, as radio waves emitted from transmitters may reverberate in ravines and valleys (making it difficult to determine the origin of the signal) or be disrupted by trees and ridgelines (preventing signal detection altogether). JO and HLA spent several weeks tracking together, with JO transferring essential knowledge of the nuances and challenges of tracking in difficult tropical environments and enabling HLA to eventually undertake tracking efforts independently. The long-term involvement of local residents in avian research has meant that, in addition to providing crucial TEK, local residents are also able to train visiting researchers in scientific research methods like mist netting and radio telemetry.

JC's involvement in the project coincided with the initiation of larger-scale camera trapping operations at male display courts at our site, and he immediately made important methodological contributions to camera trap placement and court discovery. Prior to his involvement, camera traps were mostly affixed to tree trunks or other existing vegetation near male display courts, which greatly constrained camera placement. However, like many local resident farmers, JC is highly skilled with a machete and immediately suggested cutting smaller branches and dead wood to be used as camera posts. The facility with which JC could accomplish this greatly improved the speed and flexibility of camera placement. Given that as many as 35 cameras may be placed in the field at a given time, and cameras need to be regularly moved as courts become active or inactive, this was an essential time-saving innovation. In addition, JC is a keen observer, which has translated to being highly skilled at discovering manakin display courts in the field. Unlike other species and subspecies in the genus *Manacus*, which may clear fairly large areas of the forest floor for their courts, the cleared area created by males in our population is relatively small (~30 cm) and can easily be overlooked. False positives are also common: sites that upon first glance appear to be display courts may actually be game trails or mammal resting sites, as agoutis and pacas create similar cleared areas among secondary forest saplings, leading to wasted camera hours. JC has noted several criteria that, when met, reliably identifies a court: (1) vertical saplings surrounding the cleared area will be cleaned of all moss; (2) plants in the area immediately around the court have a 'chewed up' appearance, as the court-holding male gradually rips small pieces of leaves to dismantle a plant that is too large to directly move; and (3) claw marks are sometimes visible on the sticks most heavily used by the male. Confirming the presence of these three criteria prior to placing a camera improved the success rate of display court identification and, in turn, the efficiency of data collection.

A major ambition of Project Manacus has been achieving continuous data on display and mating behavior across variable ecological conditions for multiple annual cycles. Such data may yield important insights into sexual selection processes, as tropical birds often breed opportunistically throughout the year (Stouffer et al., 2013), and monitoring behavior during a set 'breeding season' may yield only a portion of the information about mating success and reproductive skew in a given population. Crucially, the involvement of JC in the project has enabled continuous data collection in the system even when HLA and other foreign researchers are not present at the site.

2.2.2.3 Intellectual and natural history contributions

Through Project Manacus, JC has spent hundreds of hours in lek sites, and his observations have yielded important natural history information and raised interesting questions about this understudied subspecies (*M. manacus leucochlamys)*, many of which may eventually lead to formal investigations. For example, he has frequently observed males displaying in mobile groups on the border of lek areas and away from established courts: as many as 11 individuals (including both adult and green-plumaged males) display in close proximity, often leaping between branches in the mid-story or sub-canopy in a circular fashion. Because these groups appear to contain a mixture of adult and juvenile males, JC speculates that the adult males in the group may be directing the flock or teaching the younger males how to produce the display. Given that little is known about the learning and development of complex motor displays (Spezie et al., 2022), this may represent a valuable avenue of future research in manakins. In addition to field-based observations, JC also conducts preliminary reviews of videos while transferring SD card data to hard drives and reports interesting natural history observations. For instance, he directed HLA to a peculiar video gathered in April 2024 that captured an adult male mounting a juvenile male, which has been reported in a population of *M. m. gutterosus* in the Brazilian Atlantic forest (Cestari, 2017) but had not been documented in our population. Natural history information such as this generates a slew of questions for further research, with JC noting that whenever he thinks he understands *Manacus*, he observes something that defies his expectations and motivates him to learn more.

To date, resource monitoring around male display courts has uncovered connections between fine-scale fruit availability and sexual selection processes: males with high densities of fruit immediately surrounding their courts display at higher rates, and females preferentially visit males with high display rates (Anderson et al., 2024). However, JC has anecdotally observed that, over longer timescales, phenological disconnects may occur between fruit availability and display behavior. He has noted that periods of high population-level display rate often seem to occur in times of low landscape-level availability, potentially suggesting that birds accumulate important energy reserves during periods of high resource availability that influence display and mating outcomes later in the annual cycle. JC has also expressed interest in monitoring the display and foraging behavior of males at leks occurring in cacao plantations, which harbor few fruit resources for males. Whether sexual selection dynamics at these sites differ from resource-rich leks in secondary forest habitat remains an area of interest for further study.

2.2.3 Societal impacts of community engagement

2.2.3.1 Education

JC has used Project Manacus as a platform for sharing his knowledge with community members and international visitors to the FCAT station. On six occasions, he has led visitors on tours of lek sites, explaining the ecology of the system and sharing personal observations from the field. He has also developed and given two lectures about the project to visiting field courses and friend-and-ally groups (including foundation donors).

2.2.3.2 Capacity building and professional development

Thus far, JC has built considerable capacity via his involvement with Project Manacus, developing proficiency with computers, data entry, use of GPS and other instruments, radio telemetry, mist netting, camera trapping, behavioral observation, experimental methods, and public speaking. On a professional level, he has given poster presentations of research results at Ecuador's national ornithological conference (Reunión Ecuatoriana de Ornitología) and plans to continue doing so in the future. On a personal level, JC appreciates how the project enables him to learn new skills, gain new knowledge, and participate in the investigation of nature. Like formally trained researchers, community members are motivated to participate in science by the inherent joy that comes from curiosity, investigation, and discovery.

JC has also engaged his family members in various phases of the research process. His wife and children enjoy reviewing camera trap footage, and numerous extended family members have joined JC and HLA in mist netting excursions in the field. In addition, several other local residents have been trained to accomplish the tasks associated with Project Manacus (*e.g.*, maintaining camera traps, monitoring lek sites, surveying fruit resources) so that data collection can continue if JC is unable to work or more hands are required for experimental manipulations.

2.2.3.3 Conservation

To date, the conservation impacts of Project Manacus have primarily been through raising awareness of local conservation issues. The camera trapping component of Project Manacus generates considerable 'bycatch', including videos of charismatic local mammals and birds. JC curates interesting videos from the camera trap footage and shares them with his family and friends via social media, which increases awareness and appreciation of the local fauna among community members. Some videos are also featured in FCAT social media posts, which helps raise attention about the reserve and its biodiversity to a broader audience. In addition, JC's engagement with research at FCAT is a common topic of conversation with community members unaffiliated with the organization, helping to raise awareness and interest about the methods, motivations, and findings of research within the reserve. The white-bearded manakin has also become a minor symbol among local resident researchers, who sport an image of the bird on the sleeves of their local soccer team, providing a conversation-starter about conservation issues and biodiversity in the area. Youth members of the environmental club also reported particularly enjoying learning about manakins during visits to the reserve, suggesting that the charismatic nature of this species offers a promising avenue for sparking the interest of community members in biodiversity and conservation themes more broadly.

2.3 Monitoring birds in regeneration plots using point counts

2.3.1 Project overview

Bird species respond in different ways to changes in habitat structure, stature and plant composition (Menger et al., 2017). Understanding these changes at both individual species and avian community levels is a useful surrogate to comprehend the effects of habitat recovery on biodiversity either after natural or assisted regeneration processes (Bregman et al., 2014). A higher bird species richness is expected in landscapes that combine secondary forests at different growth stages with primary forest and borders as compared to large fragments of continuous mature forest (Blake and Loiselle, 2001; Martínez-Núñez et al., 2023). However, community composition differs as species more tolerant to open, human-modified habitats dominate in young secondary growth while forest-based species prevail in more mature forests (Barlow et al., 2007; Sekercioglu, 2012).

In order to assess changes in community composition and bird species abundances in experimental regeneration plots in the FCAT Reserve, we are currently undertaking a bird monitoring project using point counts. This bird monitoring is part of the "Choconexión" restoration project carried out by FCAT since 2021 in collaboration with Dr. Leighton Reid and Dr. Rakan Zahawi. This landscape-scale experiment, which currently covers 42 ha, examines how different combinations of reforestation methodologies impact biodiversity, carbon, and economic trajectories. A key element of the experiment is to understand how the diversity and community composition of important bioindicators, such as birds, recover over time in these experimental plots relative to reference forested areas. Another key goal is to assess the degree to which restoration plots in which FCAT plants tree species that produce bird-friendly fruits (*e.g.*, figs) are associated with more abundance or species richness of frugivorous birds, which might indicate increased seed dispersal into these sites. As such, avian monitoring represents a crucial means of assessing the efficacy and outcomes of the competing restoration methods being compared in the Choconexión experiment.

In November 2022, we set up six point count stations in each of two experimental regeneration parcels (12 total stations). Each point count station is surveyed six times in the morning and three times in the afternoon in every field visit, alternating the surveying sequence in order to start each observation day at a different point count. Bird counts have been carried out by Juan Freile and two local residents, Gregory Paladines and Gloria Loor, since the very first day of monitoring. In each point count we undertake 10-minute counts of all birds observed, estimate distance to the nearest 5 m within a 50-m radius and estimate height above the ground. As of August 2024, we have carried out four complete 12-day surveys in the rainy season (January–June) and two complete 12-day surveys in the dry season (July–December). The remaining surveys will be carried out until four surveys have been conducted in each season. In the future, we plan to expand sampling to include reference mature forest plots and use of passive audio recorders, and we are beginning relevant pilot work.

To date, 160 species have been recorded. Regeneration plots are dominated by species tolerant to degraded areas that includes omnivorous tanagers, sallying flycatchers, and granivorous seedeaters. Point counts situated in areas with taller secondary growth, more vegetation strata or those closer to forest borders have more forest-based species like bark-searching and understory insectivores and forest-dependent frugivores. Interestingly—and despite the short timespan covered by our study—in some point counts that have experienced a marked growth of secondary trees and bushes during our surveying period, forest-dependent species have already been observed. This apparent turnover in species from pasture-tolerant to more forest-based includes observations of species endemic to Chocoan lowland rainforests like orange-fronted barbet *Capito squamatus* and scarlet-browed tanager *Heterospingus xanthopygius*.

The three researchers started working in the field in November 2022, with JF training GP and GL, who had no previous training in point count sampling and bird identification. Training in species identification is being performed both in the field and in intensive office sessions using updated field guides to the birds of Ecuador (Ridgely and Greenfield, 2001; Freile and Restall, 2018) and online resources. Karlson and Rosselet (2015) recommend progressive accumulation of observation experience and skills for beginning birders, prior to focusing on the intricacies of morphological, structural and behavioral diagnostic characters. However, we were compelled to work simultaneously on both of these approaches to species identification and field surveying when initiating point count sampling. To reduce mistakes, species identification in the field by GP and GL is most of the time corroborated by JF, the professional ornithologist. Ultimately, we aim to continue monitoring in the long-term with GP and GL fully in charge of field work and data compilation, and this current stage of training is a critical step toward this goal.

2.3.2 Impacts of community engagement on scientific research

2.3.2.1 Traditional ecological knowledge

Local researchers GP and GL have demonstrated a rapid learning ability in species identification and in the point count protocol, but particularly in species identification. This is partially explained by the fact that they already knew some of the species by their local names or knew some bird species vocalizations. To date, both researchers identify with confidence the 60 most abundant species and are rapidly learning to identify less abundant taxa. Further, their previous general knowledge of local nature has helped them notice that some bird species rely on open habitats (*e.g.*, cultivated land and cattle pasture) and others are more forest-dependent, even though they did not have a name for many of those 'small brownish or yellowish birds'. For several species, they knew basic natural history information that resulted either in easier identification learning or in understanding their relative abundance in the sampling plots. For example, GP and GL were already aware that crested guan *Penelope purpurascens* and rufous-headed chachalaca *Ortalis erythroptera* differed in their tolerance to forest disturbance, that there are two look-alike toucan species that occupy fragmented landscapes but rely on forest patches for long-term survival, and that caciques and oropendolas perform seasonal movements. These phenomena have been witnessed during our sampling; the chachalaca is more often found in the regenerating plots than the guan, the two toucans are readily identified by voice, and the chestnut-headed oropendola *Psarocolius wagleri* has only been recorded in the drier months when *Erythrina* trees are blooming.

2.3.2.2 Technical contributions

As a consequence of being raised in the rural area neighboring the FCAT Reserve and their sharp vision, GP and GL began the project with strong pre-existing skills in detecting birds and calculating distance to the birds in the different vegetation strata sampled. These abilities complemented the poorer vision capacity of JF and resulted in more visual detections in most point counts than expected if point counts were performed by a single observer. In fact, in some sampling sessions JF only took notes of birds counted and verified species identifications if needed. Further, GP knew the sampling plots prior to establishing point counts, and his knowledge was decisive for determining the most appropriate places to survey, as were GL and GP's skills navigating in this rough, mountainous terrain. Lastly, their developing identification skills—both visual and auditory—have led to increasing confidence by JF on the species they observe, resulting in increasing time to observe and detect more birds on his own. At least two species originally misidentified by JF on the basis of voices were later reidentified when heard, detected and described by GP and GL. Although we have already recorded c. 40% of the species known to occur in the area (Carrasco et al., 2013), new species are found in every new field session, many of them first spotted by either GL or GP.

2.3.2.3 Intellectual and natural history contributions

Since this project is only in its second year of development, it is premature to assess the impacts of community members' engagement in hypothesis development, tests, and scientific outcomes.

2.3.3 Societal impacts of community engagement

2.3.3.1 Education

GP and GL have been working in the point count project for less than two years, but they have been involved in other activities at the FCAT reserve for 2.5 and 3 years, respectively. GP is a former member of the FCAT's 'Nueva Generación' local youth environmental club and has played a leading role in the club, and he has also worked for other projects including palm sampling and tree phenology. Meanwhile, GL is one of the first women working for FCAT involved in fieldwork and research, rather than the more typical professional gender role of cooking and cleaning the station. As such, she is forging a critical role inspiring young women from neighboring communities that participation in scientific studies and conservation action is possible. Her impact in the community is only in the very beginning. Being a young mother raising her children alone and working part-time in catering services and part-time as a field researcher in FCAT, she also manages her cacao plantation alone and is planning on starting an online university career, demonstrating to other local women that empowerment and courage can make the difference in a society marked with gender inequity and disparities. The outcomes of their roles as young environmental leader and field researcher (GP) and young environmental leader, role model, and mother (GL) will be seen in the next few years and can be witnessed in the fact that the youth environmental club increased in participation from 15 in January 2023 to 30 in January 2024.

2.3.3.2 Capacity building and professional development

To date, GL and GP have participated in birdwatching meetings and ornithology training workshops despite their 'green' careers in bird-related topics. Both participated in the XII South American Bird Fair in Mindo, Ecuador, staffing the FCAT stand and providing visitors with information about the reserve and its ongoing projects and activities. GP participated as a speaker in a round table discussion about the vision of local birders and young researchers regarding nature conservation, observation, and study. At FCAT, they often participate as field assistants for visiting international students and in field courses, and were coauthors on a presentation at VIII Reunion Ecuatoriana de Ornitología. Yet, GP and GL believe they need further training in bird research protocols, including data systematization, georeferencing, basic data analysis, and use of research and identification devices and other resources, as well as in the theoretical background of bird biology, morphology, and evolution. At the beginning of the project, GL felt compelled to learn and start identifying birds and applying a field protocol, two activities she was largely unaware of beforehand.

2.3.3.3 Conservation

GP has participated in the youth environmental club since its conception and is, as such, perceived as a young local conservation leader. Yet, he sees little influence on adults, including members of his own family. Similarly, GL has experienced mostly negative attitudes from her adult relatives and friends when she tells stories about the birds she is studying or when she seeks to highlight the importance of forest conservation. Despite these adverse attitudes, both feel they can have a positive influence on children and youth, as they already experience with relatives, in GP's case with the youth club, and in GL's case with her own children. Getting involved in a bird research project has been a life-changing experience for GL, who currently feels a connection with birds made out of joy and tranquility. She could inspire other local women to see a future in conservation related issues, either with FCAT or not.

3 Challenges

We have encountered several challenges implementing and scaling our model of long-term community-engaged research, many of which are likely to be shared more widely (Table 1). We have struggled with integrating community-engaged research with the norms and expectations of the academic establishment in two important ways. First, the scientific publishing system has several explicit and implicit barriers in place that limit the equitable inclusion of local community members as authors. English being the *de facto* language of science represents a major barrier for both the consumption and production of science for local community members from non-English speaking areas (Amano et al., 2016), including this study. The increased availability of translated abstracts is a step towards increasing access to non-English speaking communities, though the vast majority of the scientific literature remains inaccessible, often behind expensive paywalls. Implicitly, negative bias in the review process for authors coming from non-English speaking countries may work against inclusion of local community members on publications, though a double-blind review process may address this bias (Fox et al., 2023).

Second, at many universities the processes for evaluation of professional accomplishments (*e.g.*, PhD thesis committee review, promotion and tenure system) has been slow to recognize and reward community-engaged scholarship, in part because the products generated by community-engaged research (*e.g.*, workshops, reports that do not pass through formal peer review) may not fall into long-established categories used as indices of professional achievement in academia (*e.g.*, publications, conference presentations) (Barnes et al., 2016). This creates tensions at all levels of academia in which there can be a perceived or real trade-off between investing in community-engaged research vs. increasing traditional metrics of scholarly success (Hale, 2008). In our own experience, we have found that investing in a community-engaged approach may take more time at the onset of a project, but that it pays substantial dividends over the longer term, as described in this article.

TABLE 1 Challenges our team encountered implementing community-engaged research program and strategies for overcoming them.

Challenges	Strategies for overcoming
Academic publishing system	• Recognizing local contributors with authorship on published works • Double-blinded peer review
Faculty evaluation/ promotion	• Recognizing and valuing broader societal research impacts beyond publishing
Technology access/training	• Holding workshops for local residents to learn to use word processing, data entry software • Funding for technology transfer
Communicating research to residents	• Hosting gatherings where local residents can visit the reserve, engage in cultural exchange with researchers, and learn about research aims and outcomes • Visiting local schools to present information about research and conservation initiatives • Publishing article abstracts or entire articles in multiple languages
Social and ethical considerations	• Regularly providing formal and informal venues for stakeholders and community members to give feedback on conservation initiatives

A third, generalizable challenge is related to technology access and capacity. Especially in the early years of this project, technological barriers have been a hindrance to community-engaged research: many local community members lacked access to internet and electricity and the technical training necessary to effectively use tools like email and word processing and data entry software. Also, when equipment fails it can take months to replace it. Overcoming these technological barriers requires significant and ongoing investments of time, resources, and support that may disincentivize both international researchers and local residents from engaging in collaborative research.

At the local scale, perceptions and relationships with communities outside the FCAT Reserve are mixed, and there are opportunities to strengthen communication, understanding, and ties. The FCAT station is run and staffed by local residents from one dozen communities surrounding the reserve, and strong relationships exist with many locals through family ties and friendships. JC notes that community members and friends unaffiliated with FCAT are often curious about the work occurring within the reserve, but many others are unaware of or misinformed, for example equating FCAT with the Ministry of Environment. Moreover, other members of the FCAT team note more complicated reactions from family and community members that can include jealousy and mockery. Expanding past and current efforts at outreach, demonstrative teaching, and communication with community members and schoolchildren outside FCAT about research motivations, methodologies, and results is likely to help demystify the goals and activities of the organization and local resident staff while providing important context and education (Holt-Giménez, 2006). Hands-on experiential learning can be particularly effective; for example, JC describes his own first experience holding a bird in the hand as “magical”, stating that such close proximity to such a delicate creature brought him a new appreciation of the biodiversity around him.

Scaling up, we also draw attention to the complex societal and ethical dynamics that arise when community-engaged research involves actors from dramatically different social, cultural and economic backgrounds and contexts (Wilson, 2020; Tuhiwai Smith, 2022). On the one hand, our community-engaged research model can be seen as an engine for societal change, via a ‘one hand feeds the other’ dynamic in which the community engagement improves the quality of the research while also providing economic and educational opportunities for participating local resident researchers. For example, community-engaged research has helped attract research funding by improving both the intellectual merit as well as broader impacts of our science, which in turn has resulted in job creation and resources for education and capacity building, as well as providing funding for the establishment of the FCAT Reserve and associated infrastructure. At the same time, it is critically important to acknowledge important ethical and practical considerations involved with leveraging international funding to influence dynamics in rural, developing landscapes like the area around FCAT (Lewis 2016; Incite, 2017). For example, locals face personal, familial, and logistical challenges when navigating working at FCAT and maintaining their own farms; there are issues with economic stability due to short term, project-based funding cycles; economic benefits tend to be restricted to locals employed by or working directly with FCAT; and, in some cases, local resident researchers have used income from FCAT to pay for the costs of extending their agricultural footprint.

These are complex issues that extend far beyond the scope of long-term avian monitoring *per se*. At the same time, they cannot be ignored or overlooked: they are unavoidable and of critical importance for the long-term success of this and other projects. Our perspective is that addressing these ongoing and very challenging issues requires change on multiple scales. This involves advocating for more equitable and transparent practices in the publishing process (Ruelas Inzunza et al., 2023) and for additional investment in technology and capacity building in the Global South. On the local scale, we believe that interdisciplinary, grassroots strategies can promote forest conservation on privately managed land while acknowledging and respecting local residents' reliance on agriculture to provide for their families. Iterative, long-term partnerships between researchers and local residents creates space for cooperative creativity, bringing us closer to better striking a balance between positive ecological and social outcomes.

4 Discussion

Over the past several decades, there has been a growing realization among scientists and funding sources that a more inclusive approach to research is needed, for both ethical and practical reasons. Accordingly, community-engaged research has received considerable attention and interest, but STEM practitioners (and indeed the academic community as a whole) are still learning how to implement these methodologies effectively. This paper seeks to advance these initiatives by providing information on a twenty-year effort to conduct community-engaged avian monitoring in northwest Ecuador (Figure 3).

A community-engaged approach has improved the quality of our scientific research via TEK, much-needed technical capacity, and valuable intellectual contributions. Moreover, a community-

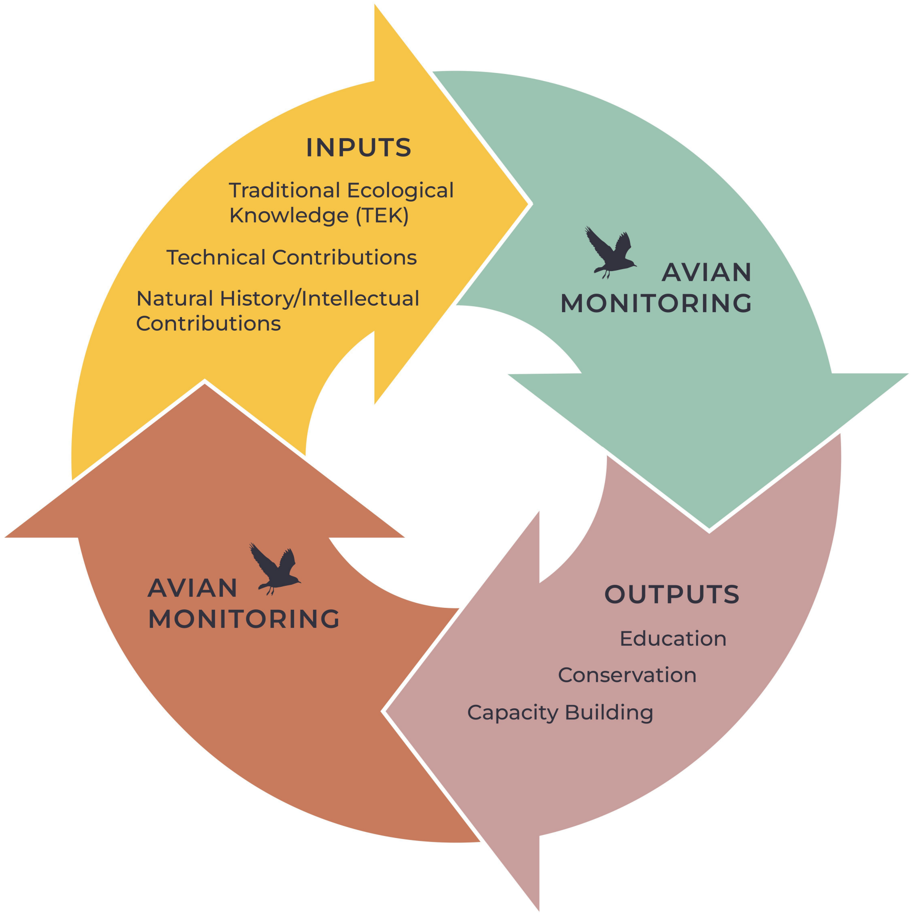

FIGURE 3
Schematic illustrating how FCAT's community-engaged approach to avian monitoring research improves both the quality of the science and its societal impact. As time goes on, a positive feedback loop can develop between the 'inputs' and 'outputs' of the avian monitoring research.

engaged approach has enabled year-round data collection, providing an opportunity for novel insights into ecological interactions, behaviors, and seasonal patterns that would not have been possible with the more restricted cadence of research typically followed by university-based researchers working at remote field sites. Community-engaged research has also enhanced the breadth and quality of societal impacts, in terms of education, capacity building, and conservation, particularly through the formation of an ecological reserve that protects threatened species and habitat. In our case, it has served as a vehicle for conservation and education activities that have helped establish the long-wattled umbrellabird as a flagship symbol for conservation. Based on these findings, we conclude that community-engaged research can improve the intellectual merit and broader societal impacts of long-term avian monitoring, and we advocate for continued investment and efforts in this space. In future work, we aim to present quantitative and systematic evaluations of the conservation project and its societal impacts (per Suich and Dawson, 2023); data collection toward this end is ongoing.

Collaborative identification and development of research questions and hypotheses, along with relevant methods to address them, is one sign of a healthy community-engaged research project because it requires meaningful interchange between residents and scientists (Figure 1A). In our experience, this process often plays out via an ongoing dialogue that spans many years and follows a predictable sequence, beginning with observations of unusual or unexpected behaviors or phenomena in the field. This then leads to speculation about the observed event or pattern, why or how it might be occurring, and what its significance might be. In some cases, these speculative explanations (*i.e.*, hypotheses) have been both directly relevant to established theoretical areas in ecology, behavior, or evolution and testable (Figure 1A). Through additional conversation, we fleshed out these predictions and worked together to generate and pilot a research plan to test them, followed by implementation. As we all continued to learn about the natural system and the existing bodies of relevant work, our collective ability to work as a team to identify, frame, and interrogate research questions improved.

We also noted a general, iterative cycle of development and refinement of research capacity in the context of a community-engaged approach. As farmers living and working in rural areas, local people have ample opportunities to design and implement solutions to practical fieldwork problems without outside assistance, and therefore enter research projects with a baseline level of technical, engineering, and problem-solving capacity far exceeding that of most university-trained researchers coming from other areas (Figure 1B). They apply this capacity to meet practical needs of various research projects (*e.g.*, capturing birds or recording frugivory events in the canopy), and they gain new insights into the natural history and ecology of the local system by viewing and interpreting the results of that data collection. This leads to at least two important advances: a refined understanding of how to engineer even more elegant technical solutions, and an increased ability to identify biological questions that could be addressed via these technical solutions. For visiting scientists, the progression is often characterized by a growing appreciation of how significant the gaps in knowledge and capacity are when one attempts to translate theory and ideas into on-the-ground research, and by extension how much value the TEK, technical capacity, and intellectual contributions of local resident counterparts can contribute.

The key attributes that make this aspect of community-engaged research possible are active curiosity about how the natural world works; inclination, and language to talk about it; and the resources and energy to do the work. Another crucial take-home point is that this process requires years (not weeks or months) to play out: in our experience, there is no substitute for time in the development of healthy and productive community-engaged working relationships. The case studies presented here, which fall along different points of this timeline, help to illustrate this point.

Data availability statement

The original contributions presented in the study are included in the article/supplementary material. Further inquiries can be directed to the corresponding author.

Ethics statement

The animal study was approved by Tulane Institutional Animal Care and Use Committee and all research was conducted in accordance with appropriate permits and institutional requirements.

Author contributions

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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