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PERSPECTIVE

Citizen scientists for MoveApps: Innovations and insights from volunteer coders in wildlife conservation

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Abstract

1. Amidst numerous global crises, decision-makers have recognized the critical need for fact-based advice, driving unprecedented data collection. However, a significant gap persists between data availability and knowledge generation, primarily due to time and resource constraints. To bridge this gap, we propose involving a novel group of citizen scientists: volunteer code developers.
2. Utilizing the modular, open-source analysis platform MoveApps, we were able to engage 12 volunteer coders in a challenge to create tools for movement ecology, aimed at animal conservation. These volunteers developed functioning applications capable of analysing animal tracking data to identify stationary behaviour, estimate ranges and movement corridors and assess human–wildlife conflicts using data sets from human infrastructure, such as OpenStreetMap.
3. Engaging citizen scientists in developing code has surfaced three primary challenges: (i) Community Building—attracting the right participants; (ii) Community Involvement—maintaining quality standards and directing tasks effectively; and (iii) Community Retention—ensuring long-term engagement. We explore strategies to overcome these challenges and share lessons learnt from our coding challenge experience. Our approaches include engaging the community through their own preferred channels, providing an accessible open-source tool, defining specific use cases in detail, ensuring quality through feedback, fostering self-organized community exchanges and prominently illustrating the impact of contributions.
4. We also advocate for other disciplines to consider leveraging volunteer involvement, alongside artificial intelligence, for data analysis and generating

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state-of-the-art, fact-based insight to address critical issues such as the global decline in biodiversity.

KEYWORDS
citizen science, conservation technology, human–wildlife conflict, knowledge generation, movement hotspots, range estimation, stationarity, volunteer coding community

1 | INTRODUCTION

The planet and human societies are presently facing multiple global crises (World Economic Forum & McLennan, 2023), including climate change, biodiversity loss and an unsustainable use of natural resources (Rinawati et al., 2013; Ripple et al., 2020). Decision-makers worldwide acknowledge the need for informed, fact-based advice to solve these pressing issues (Mikalef et al., 2019; Pettorelli et al., 2021). Technological advancements (Berger-Tal & Lahoz-Monfort, 2018; Lahoz-Monfort & Magrath, 2021; Nathan et al., 2022) have led to a surge in data collection projects, including ecological data, gathered at unprecedented rates and intensities (Farley et al., 2018; Hampton et al., 2013).

For data to be informative, it must be analysed to generate state-of-the-art knowledge (Peters et al., 2014; Wilson et al., 2015). While novel and sophisticated analytical methods are emerging, also including artificial intelligence (Tuia et al., 2022), they are often highly complex and require privileged knowledge and coding skills, limiting accessibility (Lortie et al., 2020; Wüest et al., 2020). Compounding this constraint is the limited capacity of computational analysts to develop bespoke and use-case-specific analyses, as funding, particularly in science and conservation, is often poor. The demand for quantitatively skilled professionals is highly competitive, often drawing talent into more stable and profitable careers (Kidd & Green, 2006), diverting expertise away from conservation and academic research. Thus, with the exponential refinement of technology to collect more and better data on the state of the world, setbacks in analyses are widening the gap between data accumulation and knowledge generation, particularly for applied conservation.

To bridge this gap, we propose adopting a citizen science (Silvertown, 2009) community approach to catalyse data analysis and knowledge generation. Citizen science has been successful in various fields, such as bird ringing, species censuses, water monitoring and space observations (Danielsen et al., 2022; Hognogi et al., 2023; Kobori et al., 2016). Citizen scientists in conservation biology are motivated to help by collecting data but are also involved in informing policy and public involvement (McKinley et al., 2017). The success of citizen science projects lies in the fact that many people do activities such as bird monitoring for pleasure and are highly motivated by the fact that their knowledge and involvement represent a meaningful contribution (Fraisl et al., 2022). Similarly, many academics, programmers, technologists and other experts seek opportunities to apply their skills for good, including through code development (Newman et al., 2012). Groups such as 'AI for good' and 'Data for good' (Aula & Bowles, 2023; Baeck, 2015) have successfully mobilized such expertise for conservation applications while hackathons focussed on environmental topics have enabled rapid ideation and prototype development (Chau & Gerber, 2023; Krook & Malaika, 2020; Yokoi et al., 2024).

While citizen science has traditionally focussed on data collection (Kobori et al., 2016), technological advancements are shifting challenges from issues of data quality and bias to areas such as data management and analysis (Fraisl et al., 2022; MacPhail & Colla, 2020). With an emerging new group of citizen scientists, namely volunteer code developers (see also the 'Code for Science' call at universe.eu), challenges such as method suitability, code quality assurance, community support and ongoing engagement become more critical, as code contributions are often highly complex. Central to this shift are the concepts of open science and open source, which enable sharing and discussion of data, code and insight within both the research community and the public, thus accelerating research and knowledge generation (Ramachandran et al., 2021). Emerging open discussion platforms, as wildlabs.net in the field of conservation technology, further ease collaborative efforts (Speaker et al., 2022). By embracing the open-source movement, which is already strongly linked with citizen science (Wehn et al., 2020), we want to support the self-organization and empowerment of a citizen science coding and analysis community that jointly shrink the gap between data collection and knowledge generation.

In the field of wildlife conservation and movement ecology (see terms in Table S1), rates of data collection by tracking and biologging devices are unprecedented (Kays et al., 2022; Nathan et al., 2022). To accelerate knowledge extraction from these data, we have established MoveApps (www.moveapps.org), a platform where code developers can contribute open-source analysis code (as modules that are called Apps, Kölzsch et al., 2022). Apps are based on contributed, open code, packaged in containers for execution in MoveApps, and can be interactively combined into Workflows by data owners and domain experts without requiring coding expertise. Workflows are stable structures that can be repeatedly used over long time frames and easily adapted to different data sets (Kölzsch et al., 2022). The platform is in beta testing but has already over 1500 registered users and has been used for scientific, outreach, management and real-time intervention applications (Kölzsch & Gal, 2023).

In November 2022, the MoveApps platform was granted a Conservation Tech Award by the Allen Institute for AI's (AI2) EarthRanger (Wall et al., 2024). Recognizing the platform's potential for leveraging animal tracking to safeguard wildlife across the globe, the grant has been utilized to enhance MoveApps for conservation efforts. To engage volunteers from outside and within science, the MoveApps team organized a coding challenge with conservation use cases (www.moveapps.org/news, 'EMAC23 coding challenge'). Twelve experienced researchers and volunteer coders with strong interest in wildlife conservation participated, created analysis Apps for MoveApps, and joined a follow-up workshop.

Here, in a joint effort by the MoveApps team, academic ecologists and volunteer coders, we present the main outcomes of the coding challenge and workshop. First, the volunteer coders of the EMAC23 coding challenge present the Apps they developed for four conservation use cases, highlighting their applications in conservation and showcasing the value of volunteer contributions to conservation technology. Second, we jointly present a framework outlining three main challenges identified in involving a volunteer coding community as citizen scientists. For each challenge, we describe experiences and present advice for improving engagement. Looking forward, volunteer coder involvement can significantly enhance citizen science, applied conservation and other disciplines.

2 | MoveApps CONTRIBUTIONS FOR CONSERVATION

During the EMAC23 coding challenge, participants developed creative tools to address one selected animal conservation challenge around human–wildlife conflicts (Peterson et al., 2010). The set of posed challenges covered different components of animal movement relevant for conservation decision-making (see details below and a list of terms in Table S1). Apps were developed in Python, R or R-Shiny, utilizing GPS example data from Movebank (Kays et al., 2022; Kranstauber et al., 2011) as input. All used data are from previous projects so that no fieldwork was performed for this study. App outputs were presented as filtered data sets, maps, figures or tables for download, or an interactive User Interface.

The coding challenge emphasized MoveApps' modular approach (Kölzsch et al., 2022), where creative building blocks (Apps) are combined into comprehensive analysis Workflows, rather than providing complete solutions. After internal testing, the resulting Apps were made available to all MoveApps users, who can interactively integrate them into Workflows. Tests by involved movement ecologists demonstrated high proficiency and usability, and some Apps are now regularly used for real-time behaviour analysis, such as stationarity detection and road usage.

2.1 | Use case 1: Detection of stationarity

Animals may become stationary due to injury, entrapment or death (due to poaching, accidents or natural causes). A tracking device can also become stationary when it is shed or lost by the animal that is carrying it. Reliably identifying stationarity of tagged animals is of paramount importance in wildlife conservation, as it empowers key stakeholders, such as rangers and park managers, to quickly act upon this information. This allows them to address poaching, rescue injured, poisoned, or trapped animals, or recover lost tags (de Knegt et al., 2021; Peshev et al., 2022).

Here, we present four Apps that can be used for efficient detection of stationarity in tracking data. We consider an animal stationary when it remains within a specified area (e.g. 100 m radius) for a certain period of time (e.g. 24 h). The size of the area and the minimum duration of a stationarity event are App Settings that can be specified by the user. They likely vary by species, tag type and the environment (McKinnon & Love, 2018).

The 'Detection of Permanent Stationarity' App (Neves 2023, see Supporting Information) extracts permanently stationary tracks from input data, excluding tracks that continue movement after an interval of stationarity. This is useful for real-time detection of natural mortality or tag loss but might be problematic if human hunters transport the tag and the signal is lost. The 'Stationary Tags' App (Minchin 2023, Supporting Information) generates an interactive map, displaying stationary stops and providing additional information on the stops. The 'Stop Detection and Visualizer' App (Armfield 2023, Supporting Information) enables users to examine an animal's movements after any detected stop on a map, which may aid in further characterizing the stop. The 'Stationarity Dashboard' App (Böck & Merdian-Tarko 2023, Supporting Information) offers an interactive dashboard comprising a movement statistics table, a plot of daily distances moved and a map of clustered stop locations.

We illustrate the Apps' uses with a Workflow (Armfield et al., 2024) to identify stationarity of white storks (*Ciconia ciconia*) along their migration routes (Fiedler et al., 2019). Of the 10 selected white stork tracks, all four Apps could quickly identify the five stationary ones and some mapped their movement up until then (Figure 1). While we used a test data set, scheduling this Workflow on MoveApps to run periodically on a live data set has allowed data owners to act immediately on stationarity information and monitor the well-being of the individuals. For example, when a tracked white stork became stationary, it was investigated and found trapped in a landfill ventilation shaft, leading to its rescue.

2.2 | Use case 2: Interaction with human infrastructure

Globally, human activity and infrastructure have a tremendous influence on animal movement and behaviour (Tucker et al., 2018). Animals may make use of roads and other linear features as movement corridors (Underhill & Angold, 2000), they may scavenge for food in urban areas (Soulsbury & White, 2015), or be confined in their movement by barriers (Jakes et al., 2018). Given the pervasive nature of potentially detrimental human activities (Venter et al., 2016), understanding how animals interact with human activities and infrastructure is critical for implementing appropriate conservation strategies.

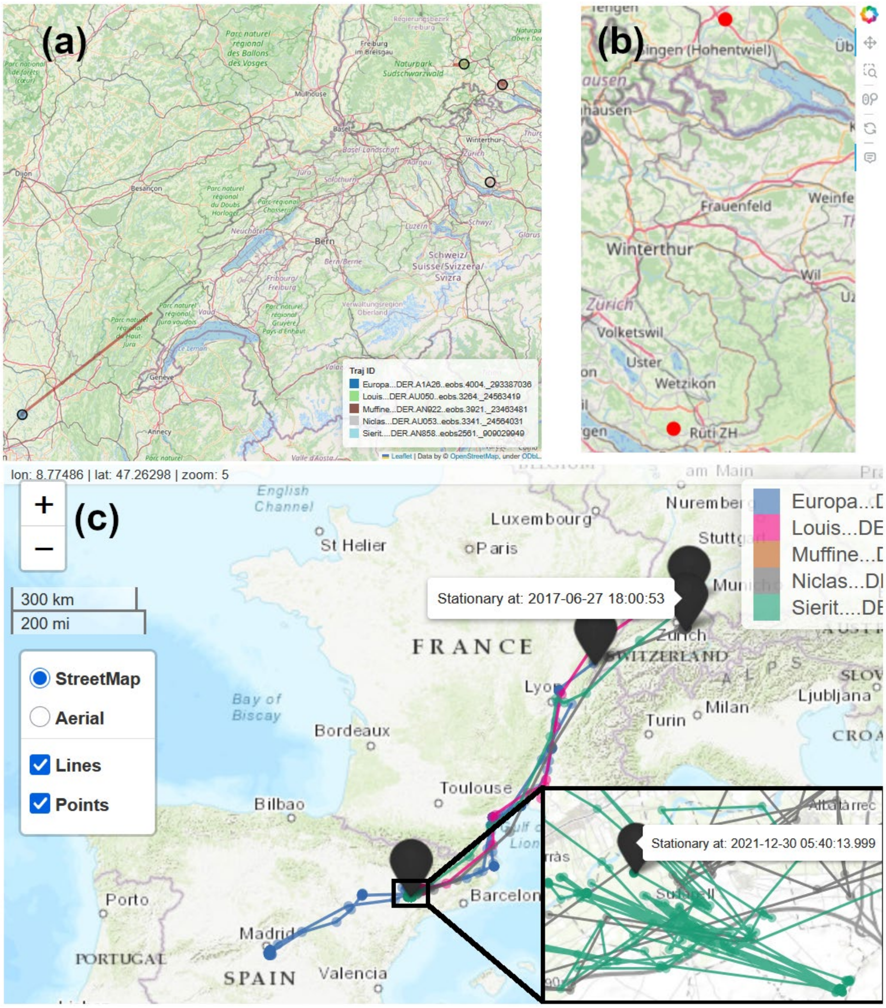

FIGURE 1 Map outputs from the (a) 'Stationary Tags', (b) 'Stop Detection and Visualizer' and (c) 'Stationarity Dashboard' App. In (a), all stops are indicated, in (b) only final stops. (c) Output at two different scales with black markers indicating the final stop of each stationary individual, lines representing the trajectories, and smaller coloured dots indicating non-final short stops. Colours indicate individual animals.

We present two Apps that explore how animal tracks interact with human infrastructure, each based on an open, global infrastructure data set. We used the OpenStreetMap (OSM) data set (OpenStreetMap Contributors, 2023), providing data on the global transportation network, built-up areas, building footprints, administrative/regional boundaries and natural features such as lakes, rivers and coastlines (among others). Strava's Global Heatmap (Strava, Inc, 2019) was used to capture the intensity of human outdoor recreation activity, a resource previously used in movement ecology (Corradini et al., 2021).

The 'Road Crossings' App (Brown 2024, see Supporting Information) maps locations where animals cross roads by identifying where the straight line connecting two sequential tracking fixes intersects with a road segment in the OSM data. Each crossing location contains attributes such as individual ID, the road type, speed limit, locations of bridges and tunnels, and the number of lanes on the road, where applicable (Figure 2a). The 'HI Outdoor Recreation' App (Ketchin 2023, Supporting Information) extracts the intensity of human activity from the recent month from Strava for all tracking fix locations and displays an interactive map of fixes associated with non-zero intensity values (Figure 2b).

We demonstrate the Apps with telemetry data of three African wild dogs (*Lycaon pictus*) in Kruger National Park in South Africa (van Schalkwyk, 2024). Our 'Interaction of Wildlife and Human Infrastructure' Workfow (Brown et al., 2024) identifies where the animals interact with human infrastructure and outdoor activity. Comparing the two maps (Figure 2), we observe differences in interactions with trail versus road features. Outdoor recreation intensity is lower on smaller trails in the Southwest of the map, where road crossings are more frequent, while higher recreation levels are visible along the major road feature in the east, where road crossings are less frequent. The wild dogs' focal area is located between the trail and the road, requiring trail crossings to reach the river for water.

2.3 | Use case 3: Range estimation

Mapping animal spatial ranges using tracking data is a cornerstone of wildlife conservation (Loveridge et al., 2007; Perona et al., 2019; Schofield et al., 2013). An animal's range reflects how it uses its habitat and is important for understanding its behaviour and ecology (Nathan et al., 2008; Noonan et al., 2019). Estimating range distributions can inform high-profile decisions, such as locating priority habitat to protect, planning reintroduction efforts and mitigating the effects of climate change (Sutton et al., 2022). It can also inform day-to-day operations,

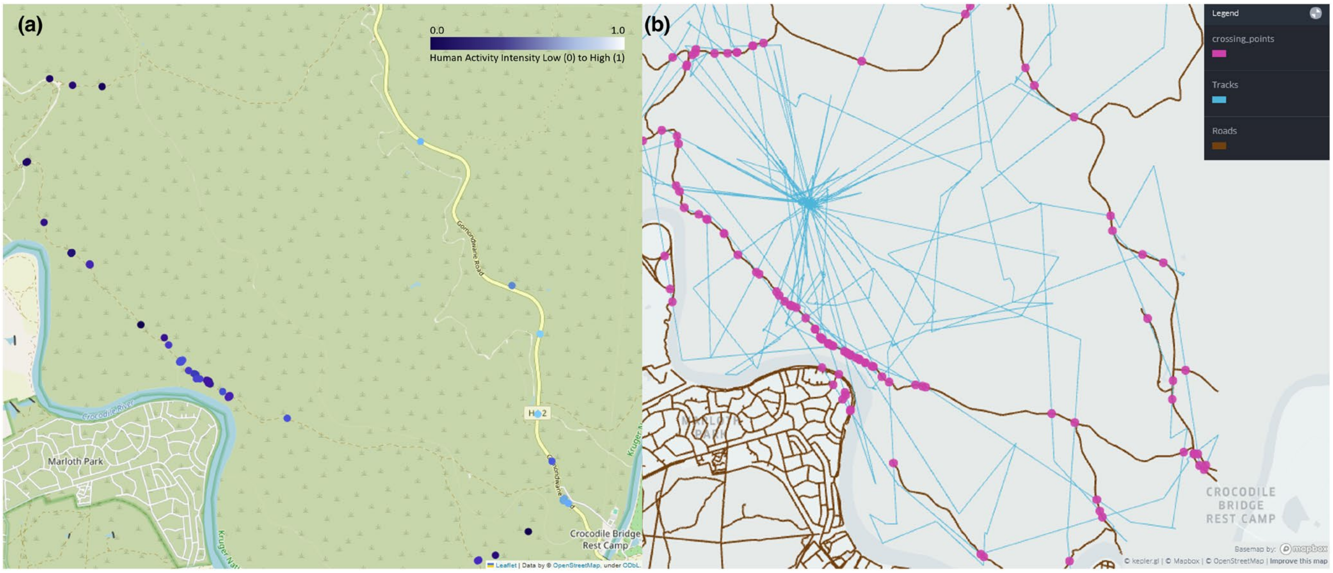

FIGURE 2 Map outputs of the (a) 'HI Outdoor Recreation' and (b) 'Road Crossings' Apps for wild dogs in the Kruger National Park, South Africa. (a) GPS positions coloured by Strava recreation index, (b) maps interpolated locations where animals cross roads. Note that the Strava data were accessed on 2 November 2023.

including identifying territories or hotspots to optimize search activity for on-the-ground managers. One set of widely used methods to estimate animal's ranges (a.k.a. utilization distributions) from movement data are kernel density methods (Worton, 1989).

We present two Apps calculating kernel utilization distributions. The 'Recent core area range and points' App (Jain 2024, see Supporting Information; based on R package 'amt') estimates the 50% isopleth (i.e. core area) of individual animals across a user-defined time period, typically the past week. In addition, an overview of the numbers of locations in the core area by time indicates when animals are most likely to be found in the area. The 'Home Range (Kernel Utilization Distribution)' App (Beaupre 2024, Supporting Information) calculates the utilization distribution with different options to filter the data and provides population as well as individual home range polygons.

By the 'Range Estimation' Workflow (Beaupre & Jain, 2024), we showcase these Apps with tracking data of Cape Buffalo (*Syncerus caffer*) in the Okavango Delta, Botswana (Bennitt, 2010). Main questions revolved around home ranges and buffalo movement in relation to fluctuations of water availability (Bennitt et al., 2014). Our results (Figure 3) show that individual ranges overlapped strongly, especially in the western part, and that temporal use patterns varied strongly between days. These findings can be used to identify territories, manage protected area boundaries and track possible preference regions.

2.4 | Use case 4: Movement hotspots

At all scales, animals utilize specific areas exclusively for passage, such as migration corridors, connections of fragmented habitat or routes to drinking holes (Doherty & Driscoll, 2018). When many individuals move through the same areas, movement hotspots emerge. Identifying these can reveal existing barriers in the environment that animals have to overcome and circumvent as well as sensitive areas that, if disturbed or interrupted, might have a tremendous effect on the individual or population (Taylor et al., 1993). An improved understanding of the spatial and temporal aspects of movement hotspots on a population or community level is crucial for the management and conservation of highly mobile species.

We present the 'Movement Hotspot Detection' App, which identifies areas where multiple animals have crossed pixels of a user-defined size at least once. This App is especially useful for identifying areas used by multiple individuals over time, regardless of their movement type. We illustrate the App with the 'Movement Hotspots' Workflow (Eichler & Scharf, 2024), using tracking data from 122 African wild dogs (*Lycaon pictus*) in Kruger National Park in South Africa (van Schalkwyk, 2024). The results show (Figure 4) that the movement hotspots with the largest number of individuals are associated with roads. These results align with known wild dog behaviour, as many carnivores use roads for travelling (Abrahms et al., 2016), and as shown in Use Case 2, often cross roads while moving across their range.

3 | CHALLENGES OF CODING COMMUNITY INVOLVEMENT

Citizen science has a long tradition, with established principles (European Citizen Science Association [ECSA], 2015) emphasizing meaningful participation in research and feedback for volunteers. Principles such as engaging participants at various stages of a project and ensuring open access to outcomes are often advised to maintain stable involvement of volunteer coders as citizen scientists (Krook & Malaika, 2020). Other relevant principles point towards

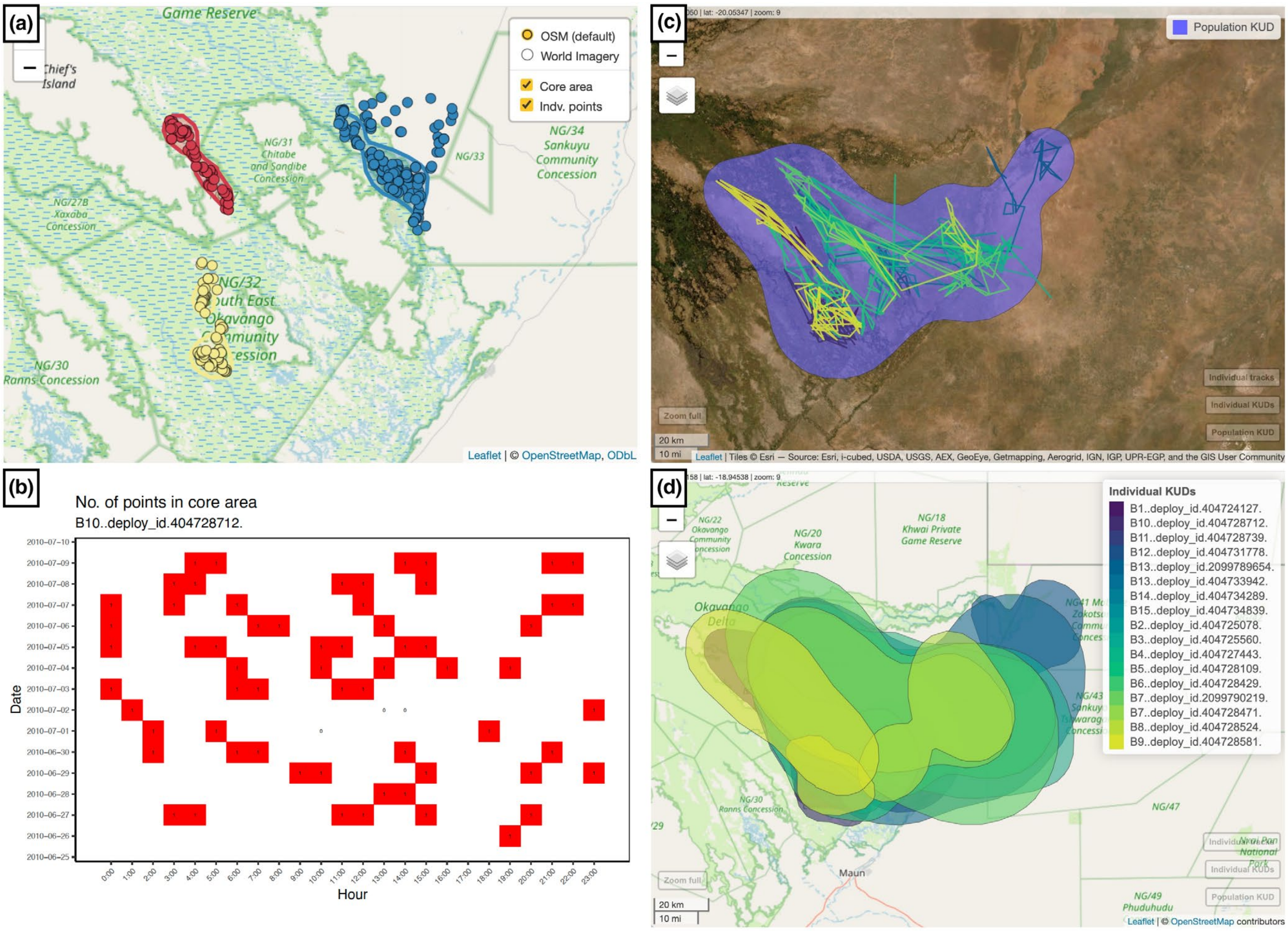

FIGURE 3 Outputs from the 'Range Estimation' Workflow. The 'Recent core area range and points' App produces (a) an interactive map depicting core areas (polygons) for individuals and their tracking data points, and (b) a visual summarizing the frequency of points within the core area, per hour and day. The 'Home Range (Kernel Utilization Distribution [KUD])' App returns shapefiles and an interactive map showcasing (c) the population KUD (purple) and individual tracks, and (d) individual KUDs, both defined at the 95% isopleth.

managing citizen science communities, which demands skills in communication, community building and participant management (Fraisl et al., 2022). Additionally, when data collection or processing is involved, providing a suitable tool is key for the project's success (Newman et al., 2012; Sharma et al., 2019).

Similar to citizen science involvement, the organization of hackathons (Chau & Gerber, 2023; Molin et al., 2024) has highlighted issues around how to gain optimal outcomes (Hackathon.com, 2025; Nolte, 2019). Special focus has been on the importance of the post-event phase, continued collaboration and ongoing support to foster long-term commitment (Emmanouil et al., 2024; Sutton et al., 2022; Temiz, 2021).

We present a framework of challenges and lessons learnt from integrating volunteer coders into data analysis projects, focussing on the 'Equip MoveApps for Conservation' initiative. This collaboration with coders has large potential to enhance data-to-knowledge conversion through a platform that integrates the interests of diverse stakeholders. MoveApps connects App users, System developers and App developers around a common goal of conservation, where community building, involvement, and retention, especially of coders, are crucial (Figure 5).

3.1 | Challenge 1. Community building: How to interest the right audience?

One of the most important steps for community involvement is understanding volunteer motivations to participate (Fraisl et al., 2022) and ensuring their participation is easy and enjoyable. Especially in conservation projects, the aim of a meaningful contribution to nature needs to be met and made as transparent as possible (Krook & Malaika, 2020).

3.1.1 | Raise the interest of the community on their channels

To gain the attention, interest and commitment of a volunteer coding community, the MoveApps team launched a coding challenge with the reward of a fully covered workshop hosted at the Max Planck Institute of Animal Behaviour for the 10 best projects submitted. The chance to experience the impact of the developed tools at a research institute was highly motivating for participants.

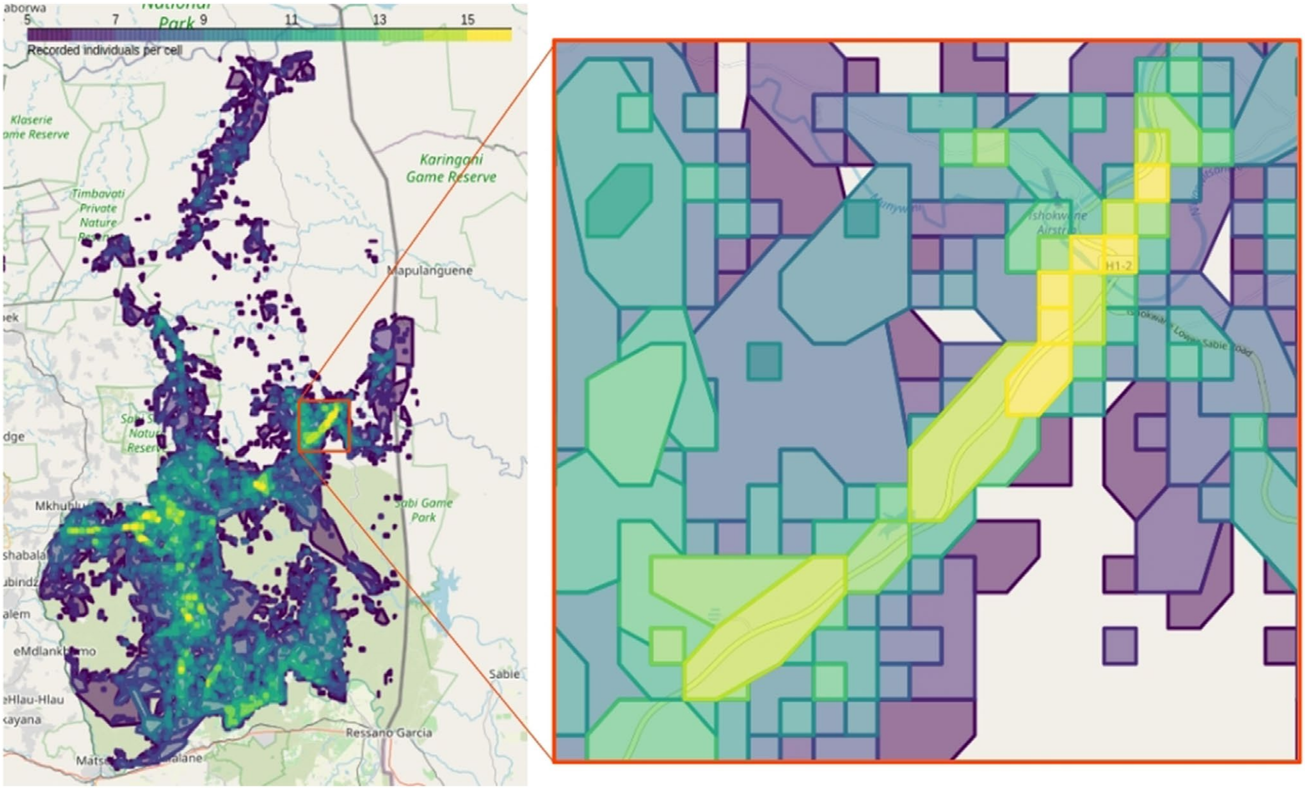

FIGURE 4 Movement hotspots of African wild dogs. Colours represent the number of individuals that moved through a cell (500 × 500 m), with lighter colours representing a higher number of individuals. Each individual is only counted once per pixel.

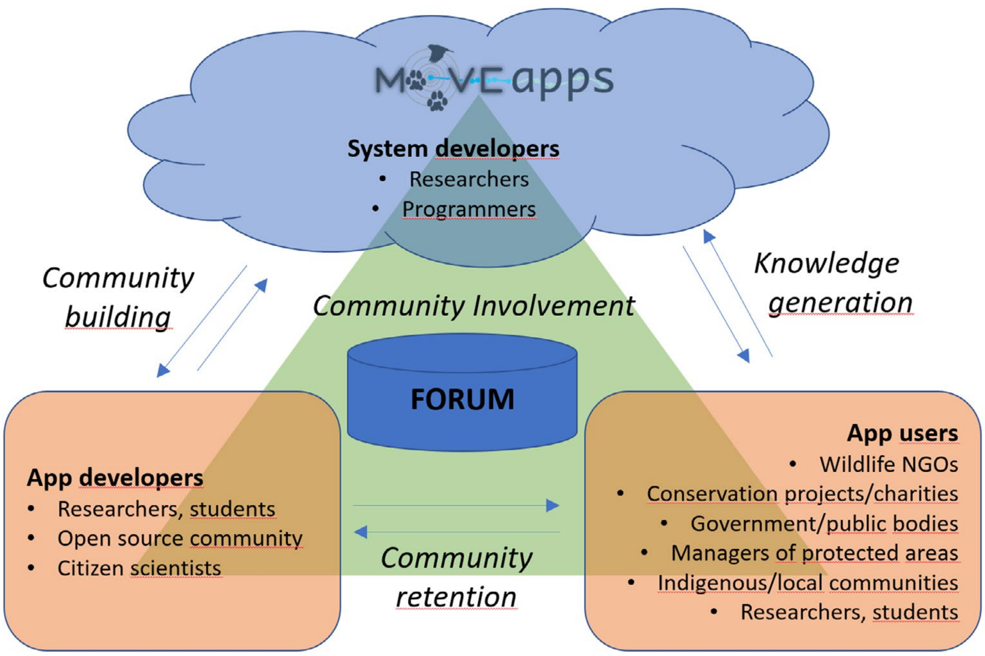

FIGURE 5 Outline of different MoveApps platform stakeholders and how the involvement of a volunteer coding community (App developers), including community building, involvement and retention, can strengthen the platform and ultimate process of knowledge generation.

Challenge contributions were requested to be small, functioning analysis modules (Apps) relating to one of five use cases. Those were specified to align with the most urgent requests from wildlife conservationists in Africa, thus providing high motivation to the volunteers: detection of wildlife crime, reduction in human–wildlife conflict and informed designation of protected areas. Real example data sets and their easy integration into MoveApps improved testability and the personal experience of the coders.

The coding challenge was posted on moveapps.org, X (Twitter), wildlabs.net and distributed through personal networks. Following feedback from participants (who are all authors on this paper), the organizing team became aware of further, unknown community channels. A thorough understanding of the addressed community and relevant communication channels is crucial to reach interested volunteers.

3.1.2 | Provide an easy-to-use tool and enable open-source development

MoveApps has been developed to easily connect analysis code developers and data owners for sustainable, competent and efficient knowledge generation from movement data (Kölzsch et al., 2022). It has various features that highlight its ease of use and potential impact. It is a serverless and cloud-native platform (Jakóbczyk, 2020), allowing use and App integration entirely in a browser, without the need to consider hardware issues.

Several features to improve usability for code developers align with the open source, collaborative development and reproducibility paradigm (Powers & Hampton, 2019): (i) support of different open-source programming languages (R, Shiny, Python), (ii) requirement to host all Apps on a public GitHub repository, (iii) provision of GitHub templates, (iii) use of dependency management libraries (renv, mamba) and (v) the ability to privately test new App submissions on MoveApps in trial mode. This open and collaborative approach ensures high App quality and provides developers with the comfort and ability to intercept code integration issues early.

3.2 | Challenge 2. Community involvement: Quality standards and how to direct tasks?

One central challenge in citizen science directed towards data collection is data quality and bias (Kosmala et al., 2016). For code development, this translates into method suitability and code quality, which can be addressed by open-source community involvement to exchange and collaborate. However, tasks and goals must be stated clearly so that collaborative work is possible (Krook & Malaika, 2020). In addition, the open-source framework easily handles code sharing and ethical concerns by adhering to open licensing (Ramachandran et al., 2021).

3.2.1 | Detailed specification of use cases

The use cases in the MoveApps coding challenge were described rather broadly to raise the interest of the community and allow for variability and creativity. However, we realised that the details were not sufficient for some, especially those without a background in ecology. Based on the received feedback, more detailed requirements would likely have made participation easier and more straightforward. Interestingly, some participants reached out asking for further details, which created a first contact and insight into community motivation and background.

3.2.2 | Quality insurance, support and feedback

The incentive of challenge participants to reach out and ask for details highlights the importance of dedicated support. A tool can be highly intuitive and well-designed, but many minds and especially people from different backgrounds often have new ideas for creative tool improvement (Sharma et al., 2019). Therefore, friendly, knowledgeable and quick support is paramount to the success of a platform that benefits from volunteer participation (Hahn et al., 2022). In addition, online Q&A sessions mid-way during the coding challenge could have provided valuable insight and made it easier for potential participants to request feedback.

As a first step to reach wider usability, each submission of EMAC23 participants was reviewed by 4–5 domain experts and the MoveApps team. The reviews included favourite features and suggestions for improvement. While not all feedback could be implemented due to time constraints, participants greatly appreciated the reviews. They emphasized that receiving feedback on the quality and potential usage of their tools was most rewarding and motivating.

3.3 | Challenge 3. Community retention: How to motivate long-term engagement?

Finally, after having built and engaged a citizen science community, maintaining engagement is a crucial task that requires ongoing communication and social engagement, often more than scientific excellence alone (Emmanouil et al., 2024; Fraisl et al., 2022; Newman et al., 2012; Nolte, 2019). Social and competitive features have proven particularly effective in fostering involvement (Eveleigh et al., 2014), as demonstrated in the strong enthusiasm among EMAC23 participants for future coding challenges and workshops. Ultimately, this underscores the importance of understanding participant motivations and providing feedback that reinforces the meaningful impact of their contributions.

3.3.1 | Enable easy community exchange

The opportunity to interact with institute scientists was highly appreciated by workshop participants, with many expressing a desire for more discussions on tools that might be needed and their practical applications. To improve this vital exchange within and between communities, we have set up and linked a GitHub Discussion Forum to facilitate structured interactions among the various stakeholders involved in MoveApps. This forum includes curated categories such as 'App wish list', 'Data wish list', 'Become a buddy' and 'Show and tell' to encourage focused discussions. Such a forum, linked with established platforms such as wildlabs.net (see wildlabs.net/inventory/products/moveapps), might lead to increased social contact as well as direct feedback.

3.3.2 | Prominent illustration of App usage and impact

Finally, the code developers expressed a strong interest in seeing how their Apps are being used. In response, MoveApps has implemented anonymised App usage tracking, with plans to summarize it and provide credit by visibility, showing a list of the 10 most recently submitted Apps as well as the last month's 10 most used Apps. Furthermore, each App will show how many times it has been used in Workflows over the last 30 days. This approach highlights new Apps, frequently and recently used Apps, and also fosters a friendly, competitive and motivating environment. For wider visibility, regular newsletters and posts on platforms like wildlabs.net will highlight App development and inspire other coders to join the community.

To further enhance impact and accessibility, Workflows of Apps in MoveApps can be published and archived with a DOI, embracing the FAIR principles for research software citation (Lamprecht et al., 2020). This ensures that analysis tools remain reproducible for future research and comparisons, while also counting as a citable publication for scientists. This is a high reward for researchers (Vale, 2015) and can also hold some value for citizen scientists. However, feedback from our workshop made it clear that direct evidence of App usage for conservation are more strongly valued.

4 | DISCUSSION

Through a coding challenge to equip our data analysis platform with proficient analysis modules for conservation use cases, we have extended the usefulness of MoveApps for wildlife conservation applications and gained a volunteer code developer community eager to contribute their expertise. Our experience has led to a framework of challenges and lessons learned, demonstrating how volunteer code developers can be effectively engaged as a novel type of citizen scientist. This collaboration benefits both conservation science and the developer community, addressing the increasing complexity and volume of ecological data (Farley et al., 2018) while providing participants with the incentive to contribute positively to nature and cultivate environmental citizenship (Aula & Bowles, 2023; Gal, 2024).

An alternative or complementary to improving conservation data analysis is the integration of machine learning and artificial intelligence (Cortés et al., 2000; Gonzalez et al., 2016; Tuia et al., 2022). Already at the point of data collection by sensors, machine learning algorithms can pre-process data and run statistical analyses, helping to generate knowledge and insights more efficiently (Kays et al., 2015; Tuia et al., 2022). Still, those models and processing steps require ongoing implementation and maintenance, which can be done or improved upon either by professionals or by highly qualified and motivated volunteers.

The potential of improved knowledge generation with the involvement of volunteer code developers offers broader benefits. By participating in conservation-driven problem-solving, volunteers develop a deeper understanding of scientific thinking and ecological challenges (e.g. wildlife conservation), which they can bring to their networks, gaining environmental citizenship (Gal, 2024) and increasing public acceptance of potential management decisions (Adler et al., 2020). Furthermore, collaborating within an extremely interdisciplinary group such as the MoveApps coding community provides new insights for all sides, prevents duplicated efforts, and enhances scientific outcomes (Goldstein & Goldstein, 2013).

Historically, hackathons and similar tech volunteer-driven initiatives have been criticized for being highly work intensive, but often remaining incomplete, and lacking sustainable impact (Chau & Gerber, 2023; Emmanouil et al., 2024; Nolte, 2019; Temiz, 2021). Organizers face challenges in providing the necessary coordination and support to ensure that volunteer-driven projects result in long-term, usable tools for stakeholders (Berger-Tal & Lahoz-Monfort, 2018; Krook & Malaika, 2020). We believe the modular structure of MoveApps, combined with a coding challenge and workshop format, enhances the potential for lasting impact. By focussing on a small, self-contributed App that must reach publication readiness, participants can contribute manageable yet meaningful components of a larger question. Interactively combining basic Apps (e.g. for data download or filtering) with the developed, specific App into complete analytical Workflows, enables any MoveApps user to test and apply the analysis tools on their data, making them immediately applicable to real-world conservation. This collaborative and iterative development process ensures final usability, fosters ongoing refinement based on user needs and encourages sustained engagement from volunteers.

The nomination of MoveApps as conservation-tech award grantee (Kölzsch et al., 2022) underscores its potential to meet the growing demand for fact-based conservation insights. With its user-friendly design and the ready accessibility of standardized tracking data from Movebank (Kays et al., 2022), we expect further continued growth in MoveApps adoption, amplifying the impact of all contributed Apps. Furthermore, MoveApps provides the ability to not only democratize scientific exploration for highly educated adults but also make conservation technology more accessible and fun for the general public and a younger audience. By engaging all generations, MoveApps contributes to a future where data-driven conservation becomes a collective effort, inspiring broader stewardship of our natural world.

5 | CONCLUSIONS

We are confident that the platform-mediated involvement of volunteers is one way to improve the efficiency of knowledge generation from data. On a global scale, translating data into actionable insights is crucial for decision-makers (Dalal & Bonaccio, 2010). For instance, the IUCN not only calls on open sharing of biodiversity data but also invites the transparent and reproducible development of tools for gaining biodiversity and conservation knowledge from data (IUCN, WCC-2020-Res-063-EN, 2020). Furthermore, the United Nations recognizes that we are in the middle of a sustainability crisis (Sachs et al., 2019) and calls for the involvement of digital development as well as citizen involvement for solving these issues (Sauermann et al., 2020).

The concept of engaging a volunteer coder community serves as a valuable model for other disciplines to involve volunteers in modular tasks that traditionally fall outside the scope of citizen science. The coding-adept public are eager to support scientists in generating knowledge for fact-based decision-making, which is essential for addressing pressing global environmental and societal crises (Sauermann et al., 2020). While scientists play a crucial role in providing guidance, communication and platforms for stakeholder interaction (Emmanouil et al., 2024; Fraisl et al., 2022), data analysis cannot be their sole responsibility. We encourage not only movement ecology but also other scientific disciplines to embrace open-source data analysis platforms and empower volunteer communities to contribute meaningfully to solving global crises.

AUTHOR CONTRIBUTIONS

Andrea Kölzsch, Anne K. Scharf and Kamran Safi conceived the initial ideas and organized the coding challenge and workshop. Margaux M. Armfield, Chloe Beaupre, Matthias Böck, William Brown, Christoph Eichler, Varalika Jain, Matthew W. Ketchin, Jed A. Long, Alexander V. Merdian-Tarko, Lauren Minchin, Tomé Neves de Matos and Ambati Rakesh participated in the coding challenge and workshop, developing Apps for MoveApps. Andrea Kölzsch, Anne K. Scharf and Clemens Hahn helped integrating the Apps in MoveApps. Emily Bennitt, Wolfgang Fiedler, Ockert Louis van Schalkwyk and Martin Wikelski contributed tracking data and led use case discussions. The framework of challenges was conceived by Andrea Kölzsch, Anne K. Scharf and Kamran Safi. The manuscript writing was led by Andrea Kölzsch, with contributions from all authors.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflict of interest.

PEER REVIEW

The peer review history for this article is available at https://www.webofscience.com/api/gateway/wos/peer-review/10.1111/2041-210X.70101.

DATA AVAILABILITY STATEMENT

Tracking data for illustrating the functionality of the contributed Apps were collected in previous or parallel efforts and are available on Movebank. The white stork data is stored in the Movebank study 'LifeTrack White Stork SW Germany', the African wild dog data in the study 'African wild dogs—Greater Kruger Monitoring Platform' and the Cape buffalo data in the study 'Cape buffalo movements in the Okavango Delta, Botswana'. The white stork data is available to the public and stored in the Movebank Data Repository via https://www.doi.org/10.5441/001/1.ck04mn78 (Fiedler et al., 2019), all others contain sensitive data that cannot be made openly available, but can be provided upon reasonable request. The four MoveApps Workflows with Apps developed in the coding challenge are shared as public Workflows in MoveApps (www.moveapps.org) and published in the Movebank Data Repository. The Stationarity Detection workflow is available via https://doi.org/10.5441/001/1.613, the Interaction of Wildlife and Human Infrastructure workflow via https://doi.org/10.5441/001/1.624, the Range Estimation workflow via https://doi.org/10.5441/001/1.347 and the Movement Hotspots and Corridors workflow via https://doi.org/10.5441/001/1.639. The code for all Apps is available there and on GitHub, with links provided in the Supporting Information.

STATEMENT OF INCLUSION

Out study brings together authors from a large number of countries of four different continents, including scientists based in the countries where the re-used data had been collected and contributed analysis modules are hosted. All authors were engaged in the coding challenge and workshop to ensure that the diverse set of perspectives they represent was considered.

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SUPPORTING INFORMATION

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

Table S1. Definitions of used movement ecology terms and tools. Details and citations of all Apps developed in the discussed coding challenge.

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