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# Understanding seasonal migration and resource use among pastoralists in Tanzania: a participatory mapping and GPS tracking approach

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Pastoral systems in Sub-Saharan Africa, especially East Africa, are undergoing significant changes driven by diverse environmental and socio economic pressures. To sustainably manage livestock and pastoral resources, detailed insights into land use and migration patterns are crucial but often scarce. This study employs an integrated approach, combining participatory mapping and GPS collar tracking, to document pastoral land use and migration behaviors in Karatu, Longido, and Monduli districts in northern Tanzania. Participatory mapping was conducted in 219 villages, where community members identified critical livestock resources such as seasonal grazing areas, water sources, livestock dips, and migration corridors. These community generated maps were then digitized into a comprehensive geospatial database (dtlp.nottech.co.tz). Additionally, GPS collars were deployed on selected cattle herds to record precise herd movements over several months, offering quantitative insights into livestock migration and resource use. Initial results demonstrate continued reliance on nomadic practices and communal grazing in Longido and Monduli. Conversely, in Karatu, expanding agricultural activities have compelled pastoralists to adopt agro-pastoral strategies, including crop cultivation and stall feeding livestock. Across all districts, pasture scarcity remains a critical challenge despite extensive grazing lands, driving pastoralists to seasonal migrations. The GPS data that was collected put a concrete number that approximately an animal can walk a distance of 4,000 km in less than a year. Although migration is essential for survival during dry periods, it increases risks such as disease transmission due to herd convergence at limited grazing areas or water points. This integrated methodological approach effectively captures on-the-ground pastoral land use details not visible through satellite imagery alone, with GPS tracking providing essential quantitative validation. The findings emphasize the practical benefits and feasibility of combining indigenous knowledge and modern tracking technologies.

Ultimately, this methodology supports community driven land use planning and enhances sustainable resource management practices within pastoralist contexts.

KEYWORDS

**pastoralist, participatory mapping, GPS collars, livestock migration, rangeland management**

## Introduction

Pastoralism in sub-Saharan Africa is evolving, with many communities transitioning from traditional nomadic practices towards agropastoralism under growing pressures. Shrinking access to grazing lands and water due to demographic expansion, land-use change, and climate stress (notably recurrent droughts) has forced pastoralists to adapt their seasonal mobility patterns (Otte and Chilonda, 2002). Mobility remains a crucial strategy for ensuring livestock survival and livelihoods in these changing contexts, yet these seasonal migration patterns have historically been poorly regulated and documented in formal records (Ekwem et al., 2021). There is a major information gap regarding where and how pastoralists use land over the yearly cycle. Indeed, livestock movements often occur in an "unregulated and undocumented" fashion in African rangelands (Turner and Schlecht, 2019), making it challenging for outsiders to monitor or support pastoral land-use practices. Better insight into when and where herders move is vital for sustainable rangeland management, conflict mitigation, and policies that support pastoral livelihoods. Recognizing this need, recent studies have called for more empirical assessments of pastoral mobility and its drivers (Turner and Schlecht, 2019). For example, Turner and Schlecht's review notes that although daily grazing movements around camps are often similar across systems, seasonal travel varies widely and reflects context-specific resource needs. This variability underscores why conventional static maps or satellite imagery alone struggle to capture pastoralists' flexible and dynamic land-use patterns.

Pastoral communities, however, possess a rich store of indigenous knowledge about their environment and migrations. Herders can often recall, with remarkable detail, the locations of seasonal pastures, water points, and routes used over decades (Angassa et al., 2012). This depth of memory and observation means that pastoralists continuously adjust their movements based on rainfall patterns, forage conditions, and other environmental cues knowledge accumulated through lived experience. Documenting these community-held spatial insights is an important first step towards designing livestock systems that are sustainable and locally appropriate. Participatory mapping offers a systematic way to record this indigenous knowledge by directly involving pastoralists in mapping out their lands, resources, and migratory practices (Corbett, 2009; Flintan, 2012). Unlike top-down mapping approaches, participatory mapping allows communities to delineate seasonal grazing areas, water sources, corridors, and other key sites in their own terms, thereby visualizing resource distributions and migratory patterns that would otherwise remain part of oral tradition (International Land Coalition, 2016). Pastoralists' mental maps are thus translated into tangible geospatial data, which can complement ecological or remote-sensing information. For instance, community-led mapping in northern Tanzania has successfully identified critical wetlands, drought refuges, and livestock routes that official maps had overlooked (International Land Coalition, 2016). Similar participatory mapping exercises in other Tanzanian rangelands have proven effective for highlighting resources and routes essential to pastoral livelihoods (International Land Coalition, 2016; Aminu et al., 2022). Our own experience reinforced these findings. By working closely with knowledgeable elders and local leaders during mapping sessions, facilitating open discussions, and then conducting follow-up verification meetings (including cross-checks with neighbouring communities), we ensured that the mapped data were credible and reflected a consensus view of land-use among participants.

While elevating indigenous knowledge, it is also important to critically consider how such knowledge is gathered and used. Scholars like Agrawal (1995) caution against drawing a simplistic divide between "indigenous" and "scientific" knowledge. All knowledge is produced in context, and extracting local knowledge without regard for its cultural grounding or the community's interests can be problematic. In fact, Agrawal argues that efforts to catalog and globalize indigenous knowledge risk decontextualizing it and serving external agendas over local needs. We have taken these critiques into account by designing our participatory process to benefit the community first and foremost. The mapping activities were conducted with pastoralists as equal partners, and the resulting maps belong to them as much as to the researchers. The intent was not to appropriate traditional knowledge into a static archive, but to co-produce a living resource that communities and local authorities can use for their own planning purposes. By keeping the knowledge tied to its source community and immediate application (e.g., village land-use planning), we aim to avoid the pitfall of indigenous knowledge being "mined" and divorced from its context. In sum, blending local and scientific knowledge must be done collaboratively and reflexively, ensuring that pastoralists retain agency over how their knowledge is used.

At the same time, new technological tools most notably Global Positioning System (GPS) tracking provide an unprecedented opportunity to record livestock movements with high resolution and accuracy. GPS collars or loggers fitted on cattle can log the exact routes herds travel, distances covered per day, timing of movements, and even pause points or grazing concentrations. These quantitative data can complement herders' qualitative knowledge by objectively documenting movement patterns that might not be directly observable or remembered over long periods. In recent years, researchers have started using GPS tracking to capture the dynamics of pastoral mobility. For example, a study in northern Kenya equipped cattle with GPS devices over 17 months and found that cows walked on average about 10 km per day, with longer distances in the dry season than the wet season (Raizman et al., 2013). Such data confirmed seasonal differences in movement that pastoralists had reported, and provided concrete numbers (e.g., monthly distances of ~234 km) to quantify those patterns. Continuous GPS tracking of Borana cattle in Ethiopia revealed highly diverse mobility strategies even within a single region, challenging earlier one-size-fits-all models of pastoral movement (Wario et al., 2016). Other studies combining GPS data with ethnographic insights have underscored that pastoral mobility is complex and context-specific, varying with herd size, resource distribution, and management practices (Turner and Schlecht, 2019). Notably, GPS tracking has also been applied to understand how herd movements relate to disease transmission risks. In one recent study in Tanzania, researchers deployed GPS collars on dozens of cattle herds to map their fine-scale movements and points of inter-herd contact (Ekwem et al., 2021). The GPS data helped identify where and when different herds most frequently met (for instance, around dry-season water points and communal dipping tanks), information that was then used to pinpoint "hotspots" of potential disease spread (Ekwem et al., 2021). This illustrates how objective movement tracking can yield insights (e.g., daily travel distances, contact rates, home-range areas) that enrich the broader picture obtained from participatory maps and interviews. By integrating community mapping with GPS-based observations, researchers and communities can achieve a more holistic understanding of pastoral land use: the former captures long-term memory, cultural context, and community values, while the latter provides hard evidence and quantitative validation of movement patterns on the ground.

This brief research report presents a trial application of a combined participatory mapping and GPS collar tracking approach to investigate pastoral land use in three districts of northern Tanzania. The study area spans Karatu, Longido, and Monduli Districts, which represent a gradient from more agro-pastoral (Karatu) to predominantly pastoral (Longido and parts of Monduli) contexts. We focus on methods that highlighting the process of engaging pastoral communities in mapping their resources and the use of GPS technology to track livestock mobility.

# Methods

## Study area

The research was conducted in three neighboring districts of northern Tanzania; Karatu, Longido, and Monduli located in Arusha region (Figure 1). These districts are home to Maasai and other pastoral and agro-pastoral communities. The climate in all three districts is characterised by high precipitation to low precipitation with distinct wet and dry seasons. Generally, the main rains occur from February-April through May, defining a wet season when pasture and water are relatively abundant. A prolonged dry season runs from June to September, often punctuated by an extremely dry period toward the end of the dry season; with October to December experiencing low precipitation.

Longido and Monduli districts remain largely pastoral in land use: for example, Longido district covers ~7,800 km$^2$, of which over 80% is grazing land and less than 10% is considered arable (Longido District Council, 2013). Only about half of the villages in Longido engage in any cultivation, mostly those in higher-elevation zones with better rainfall, reflecting the predominantly pastoral livelihood orientation. Monduli likewise has extensive rangelands, and nearly all villages there engage in a limited farming, usually small-scale cultivation in valleys or highland areas. Karatu District lies on the southern slopes of the Ngorongoro highlands and the eastern escarpment of the Rift Valley. The area benefits from relatively fertile volcanic soils and higher rainfall compared to the semi-arid plains of Longido and Monduli. These favourable agro-ecological conditions have supported the expansion of rainfed and commercial farming, including crops such as maize, beans, wheat, onions, and coffee. Consequently, the pressure on grazing lands has been greater in Karatu than in neighbouring pastoral districts, underpinning the district's rapid transition toward agropastoralism.

This diversity in land use provided a rich testbed for mapping pastoral land use under different degrees of land pressure from Karatu's mixed farming landscapes to the more intact communal grazing systems of Longido and Monduli.

## Participatory mapping design

We implemented participatory mapping at the village level with the objective of covering all villages within the three study districts. In total, 219 villages were mapped across the three districts. Because the time available in each village was limited, careful attention was given to the selection of participants. The mapping team prioritized individuals with extensive knowledge of grazing areas, water resources, and land use practices, thereby ensuring the accuracy and reliability of the information collected. Engagement with local authorities was essential: District

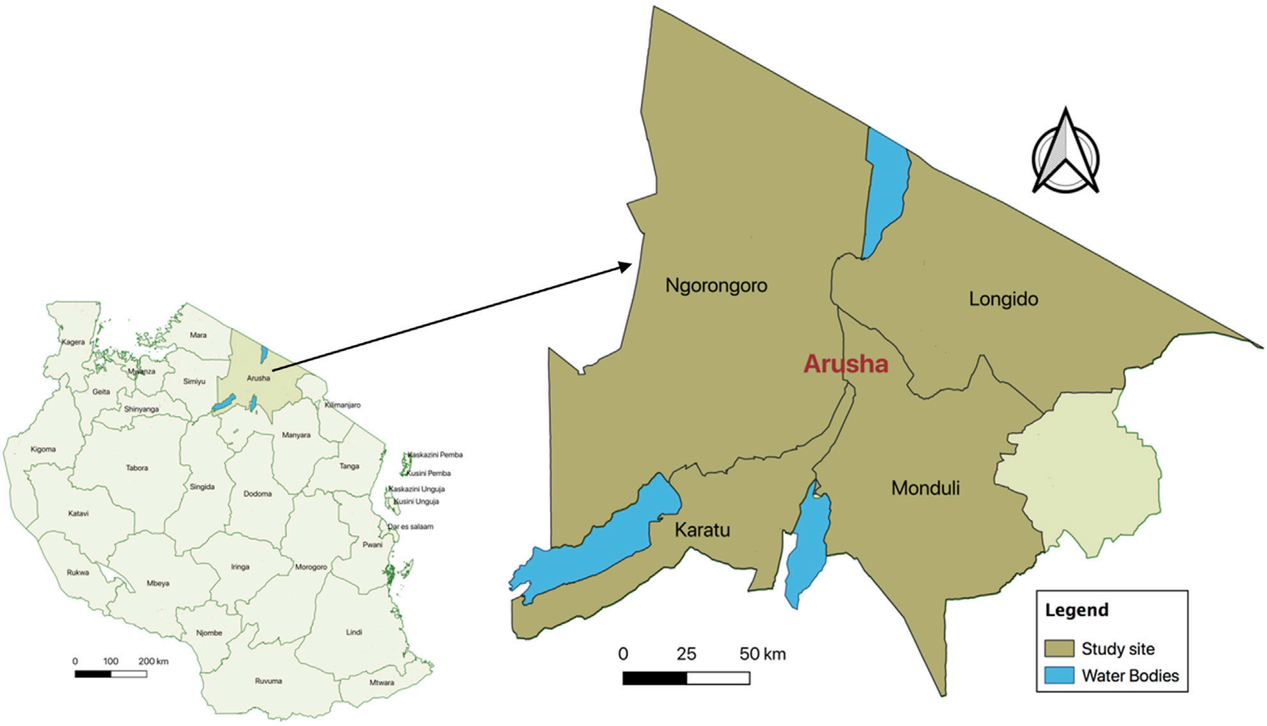


FIGURE 1
Shows the districts that were surveyed at Arusha region.

Councils and village leaders provided official authorization, facilitated coordination with the research team, and organized community meetings to support the mapping exercise.

Prior to field deployment, base maps were prepared for each village. These maps combined high-resolution satellite imagery with official administrative boundaries, printed in large format to serve as mapping canvases. The participatory mapping followed a facilitated focus-group model, drawing on established approaches for rangeland mapping (Irwin et al., 2015; Corbett, 2009). In practice, the mapping team typically spent one full day in each village. The day began with a structured mapping session involving a focus group of community representatives, followed by the systematic documentation of mapped features and associated narratives. Trained local enumerators and livestock officers supported the process by recording spatial data, annotations, and oral histories. Participants were drawn from a cross-section of community members knowledgeable about livestock management and land use. This commonly included village elders, experienced herders, members of natural resource or land-use committees, the village chairperson or sub-village leaders, and local extension workers or livestock officers. To enrich perspectives, women were also actively encouraged to participate, recognizing that they often hold distinct and complementary knowledge such as insights on seasonal water sources, household-level resource use, and crop-livestock interactions that are sometimes overlooked in male-dominated discussions (Onyango and Paliwal, 2024).

Group size varied depending on local availability and willingness to participate but generally ranged from 8 to 15 participants per village. This size was sufficient to allow for diverse perspectives while maintaining a manageable group dynamic conducive to focused discussions. The participatory approach not only captured spatial data on grazing lands, water points, and migration routes but also documented associated narratives, cultural interpretations, and management practices. These qualitative insights were critical for contextualizing the mapped features and ensuring that the outputs reflected community realities and priorities.

All research activities involving interviewing of participants were conducted in accordance with the approved protocol. Ethical approval for the community based, participatory aspects of this study was obtained from the Kibong'oto Infectious Diseases Hospital Research Ethics Committee. Moreover, all participants were provided with informed consent (after being informed of the study's aims and their rights), prior to taking part in interviews and participatory mapping sessions. We also ensured confidentiality and emphasized that participation was voluntary.

## Mapping procedure

Each session began with an introduction to the goals of the mapping and a review of the base imagery so that everyone could orient themselves by identifying known landmarks such as roads, hills, or settlements on the map. Followed by guiding participants in marking key livestock resources and land-use features on the map (Supplementary Figure S1). The main categories of features to be mapped were decided in advance based on pastoral resource types identified in a preliminary survey: grazing areas, water points, livestock routes (corridors), and other infrastructure like cattle dips (for tick control). Participants used markers and stickers to delineate these features on the printed maps. We asked the group to indicate the approximate boundaries of important grazing areas, especially distinguishing areas used in the wet season versus those reserved for the dry season including drought reserves, if any. They drew livestock routes used for moving animals within the village and to outside areas e.g., routes to seasonal pastures or markets. Water sources such as perennial springs, wells, dams, or seasonal ponds were marked with symbols, as were locations of any veterinary facilities like dips or restraining facilities. Participants often described how far herds travel, what challenges they face, and changes in resource access. These narratives were recorded to contextualize the mapped features for instance, noting if a grazing area has shrunk over time or if a traditional route is now blocked by farms. We also employed a handheld GPS unit in the field to take point coordinates for the specified features e.g., the exact location of a waterhole or grazing area where feasible, to aid in georeferencing the features during digitization.

## Data validation and processing

Careful data validation was done through cross-checks and follow-ups after each village mapping session. First, we consolidated the annotated maps and notes and, where necessary clarified any ambiguous marking. We also, compared the community identified features with any existing secondary data such as checking if water point marked by the community appears on the official topographic maps, or if a grazing area overlaps known land cover classifications.

Where discrepancies arose between participants (e.g., if two elders delineated a boundary differently), we first facilitated a group discussion to try to reach a consensus, informing participants of the official government defined boundaries during the dialogue. If no agreement was possible after discussion, we deferred to the official government maps for the final boundary delineation. This approach ensured that the recorded boundaries aligned with official records and helped avoid future conflicts once the data became publicly available.

## GPS collar tracking

While the participatory mapping provides community wide spatial knowledge, we also collected GPS tracking data from a sample of individual herds to capture fine scale movement behavior. We deployed GPS collars on cattle in each district as follows. With the help of local livestock officers, we identified a few "representative" pastoral herds in each area aiming to select herds that regularly migrate or move seasonally (since a completely sedentary herd would be less informative for our purposes). In Karatu, nine cattle herds from villages known to engage in long dry-season migration were selected. We collared thirty-one herds in all the districts (11 in Karatu, 10 in Longido, 10 in Monduli). Each herd's GPS unit was fitted on one lead cow that can have a group of more than a hunded cattles and in some cases an adult cow presumed to stay with the main herd. The GPS devices were rugged tracking collars programmed to record the animal's position at 30 min intervals. The collars were deployed in the dry season (around June) and left on through the subsequent wet season, for a herd total monitoring duration of approximately 10–13 months. This timeline captured the transition from extreme dry conditions into the wet season when animals return to wet-season pastures.

We retrieved the GPS units after the tracking period and downloaded the data for processing. The raw data consisted of timestamped latitude-longitude coordinates for each collared animal. Prior to analysis, obvious GPS errors or outlier points were filtered out e.g., implausible jumps due to signal error. We then computed basic movement metrics for each herd: the total daily distance traveled by summing distances between successive GPS points per day and the convex hull area of all points as an estimate of the herd's grazing range during the study period. The GPS coordinates were plotted over high-resolution base maps using QGIS and Google Earth and also overlaid onto the layers from the participatory maps. This overlay analysis was crucial to compare the empirical tracks with community identified resource areas and routes. For instance, we checked whether cattle frequently visited the water points that the community had marked on the maps, and whether the furthest movements of the collared herds corresponded to the known migration corridors drawn by participants. We also examined the timing of movements in relation to rainfall events: since our tracking period spanned the start of the rains, we looked at whether and when animals moved back from dry-season grazing areas to wet-season areas. Given the limited number of collared herds, these checks were qualitative, but they helped assess consistency between the two data sources.

# Results

The participatory mapping conducted across Karatu, Longido, and Monduli districts provided detailed insights into pastoral resources and traditional land-use practices, reflecting distinct local knowledge and management strategies. Additional data and visualizations from this study can be explored at[1].

## Land allocation and seasonal grazing dynamics

Despite notable environmental and socio-economic diversity among the surveyed districts, certain common patterns emerged. Across Longido and Monduli, and in selected villages of Karatu, pastoralists consistently identified and mapped distinct wet-season and dry-season grazing zones (Supplementary Figures 2A–C). These maps highlight how rainfall variability drives systematic shifts in herd location, but also how communities deliberately organize space to sustain forage availability. Wet season grazing typically occurred close to settlements on communal lands, fallow fields, and residential areas where pastures regenerate quickly and daily herding demands are lower. In contrast, dry-season zones were located further afield, and some in landscapes less suitable for farming (e.g., rugged hills, swamps, saline plains). By reserving these marginal areas as grazing "banks," pastoralists effectively created drought reserves. Importantly, the participatory maps pinpointed the location, size, and accessibility of these zones, providing information that can be directly integrated into village land-use planning something that anecdotal knowledge alone does not capture.

In Karatu District, grazing areas have higher agricultural potential and thus face dual pressure from both livestock grazing and crop cultivation. Approximately 93% of villages in Karatu engage in crop farming, a level significantly higher than in Longido and Monduli. This agricultural expansion has substantially altered landscapes that were historically dominated by pastoralism. As a result, communities increasingly identify hills, valley bottoms, and wetlands areas less suitable for cultivation as crucial remaining grazing resources. The district has transformed into a significant agricultural zone, cultivating commercial crops such as onions, maize, wheat, and coffee. As a result, clear seasonal grazing distinctions were less pronounced. Nevertheless, communities described adaptive strategies such as opportunistically utilizing valley bottoms during wet periods and extensively relying on stored crop residues for feeding livestock during dry spells. Prominently, participants in Karatu district emphasized practices like zero-grazing and stall feeding, reflecting critical adaptations due to reduced grazing land availability.

1 https://dtlp.nottech.co.tz/about.html

The size and availability of communal grazing lands differed considerably among the districts (Supplementary Figure S3). Approximately 62.0% and 63.3% of land in Longido and Monduli respectively are dedicated to grazing, reflecting their predominantly pastoral livelihoods. Karatu allocates about 44.4% of land for grazing, fragmented by substantial agricultural expansion. Despite the large areas and communities regularly practicing deliberate zoning, reserving certain pastures exclusively for dry season, pastoral households with larger livestock holdings are often compelled to migrate their animals beyond district boundaries during prolonged dry seasons.

## Other resources distribution

Water availability emerged as a critical element influencing pastoral land use and movement. Participants marked numerous water sources, differentiating between perennial sources such as permanent wells, springs, and rivers and seasonal ones such as rainfed ponds (traditional name "Lambo") and ephemeral streams. However, perennial water sources were notably scarce across all three districts, emphasizing their strategic importance (Supplementary Figures S4a,b). Maps frequently depicted just one or two reliable dry-season water sources serving multiple villages, situated several kilometers from primary grazing areas. For example, deep wells and boreholes in Longido and Monduli were highlighted as essential communal resources during peak drought periods, with others primarily relied on natural highland springs. In Karatu, on the other hand, artificial water infrastructure such as wells and nearby water distribution points around settlements played an essential role, aligning with local practices like zero-grazing. Additionally, some water points (Boreholes) were strategically placed near cultivated areas, illustrating how pastoral communities adjusted to evolving land use patterns by integrating livestock water access within agricultural landscapes.

Participants when asked where specifically they would need additional dry season water points, participants emphasized careful planning careful planning in positioning water points approximately 10–20 km away from primary dry grazing areas. They described this approach as a deliberate conservation strategy to manage pasture usage more sustainably. Specifically, placing water sources at these distances requires livestock to limit water access to fewer than 15 times per month, resulting in animals alternating days between grazing and traveling to water points, particularly during extreme dry periods. This management technique effectively curbs excessive grass consumption, as cattle, when thirsty, naturally reduce their grazing intensity on non-watering days though may have long health effects to animals. Thus, animals feed sparingly when deprived of water and subsequently spend dedicated days traveling to access water, helping conserve grazing resources during critical dry spells.

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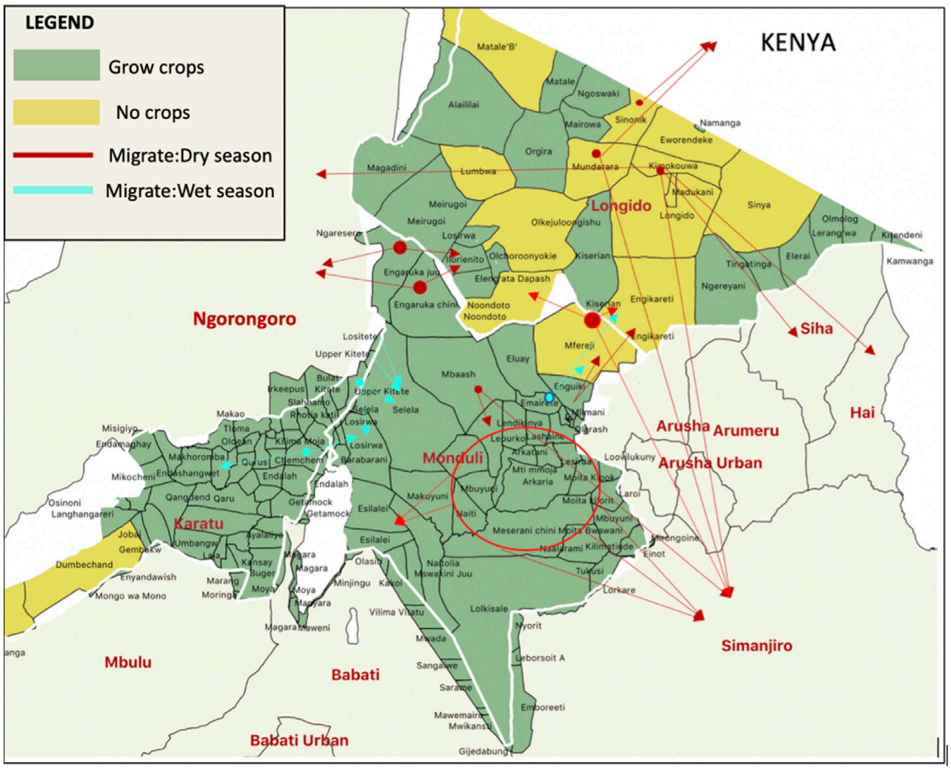


FIGURE 2
Showing season migration for the pastoralist during wet or dry season, where each village specified their preferred migration destinations.

## Pastoralist adaptation strategies to drought and climate change

### Livestock mobility and migration patterns

The preferred migration destinations varied by district; Figure 2 maps the main migration destinations. From Karatu, many pastoralists actually migrate during the wet season. This counterintuitive pattern is linked to agriculture: during the rainy (cropping) season, Karatu pastoralists often send animals to nearby districts like Monduli to avoid crop damage and to take advantage of fresh pastures elsewhere while their own fields are planted. They have arrangements with pastoralists in Monduli such that when Monduli's dry season begins, both groups can then move animals to share crop residues back in Karatu or other areas.

In Longido and Monduli, on the other hand, migrations predominantly occur in the dry season around June–October (Supplementary Figures S5a–e). The most favored destination mentioned for both was Simanjiro district (to the south-east), known for its extensive rangelands and fewer permanent settlements. Herders from Longido/Monduli often trek eastward towards Simanjiro starting around July, aiming to arrive by August when their home pastures are depleted. In Longido, mapped routes frequently crossed international borders, reaching Kajiado county in Kenya, highlighting the cross-boundary dimensions of pastoral resilience. A notable livestock corridor traced from central Longido through Kamwanga Ward into Hai district at Kilimanjaro region to Simajiro district was identified as critically important during recent drought periods (Figure 3). Participants revealed that reliance on the Simanjiro corridor has increased over the last decade due to the increase in drought. While these corridors are vital for drought survival, they are also sites/hot spots zones for diseases transmissions.

### Animals movement patterns

The GPS collar data provided concrete examples of herd movement patterns, which broadly supported the participatory findings while adding quantitative detail. All collared cattle remained healthy and with their herds throughout the tracking period, yielding usable movement data for 31 herds (11 in Karatu, 10 in Longido, 10 in Monduli) and for each animal collared had a cattle group of 200–500 cattle. Because the tracking spanned late dry season into early wet season, we observed a clear shift in movement behavior corresponding to the seasonal transition. During the late dry season (before rains), herds ranged widely and often made long forays to reach water or lingering pastures. Once the rains began (January- February in

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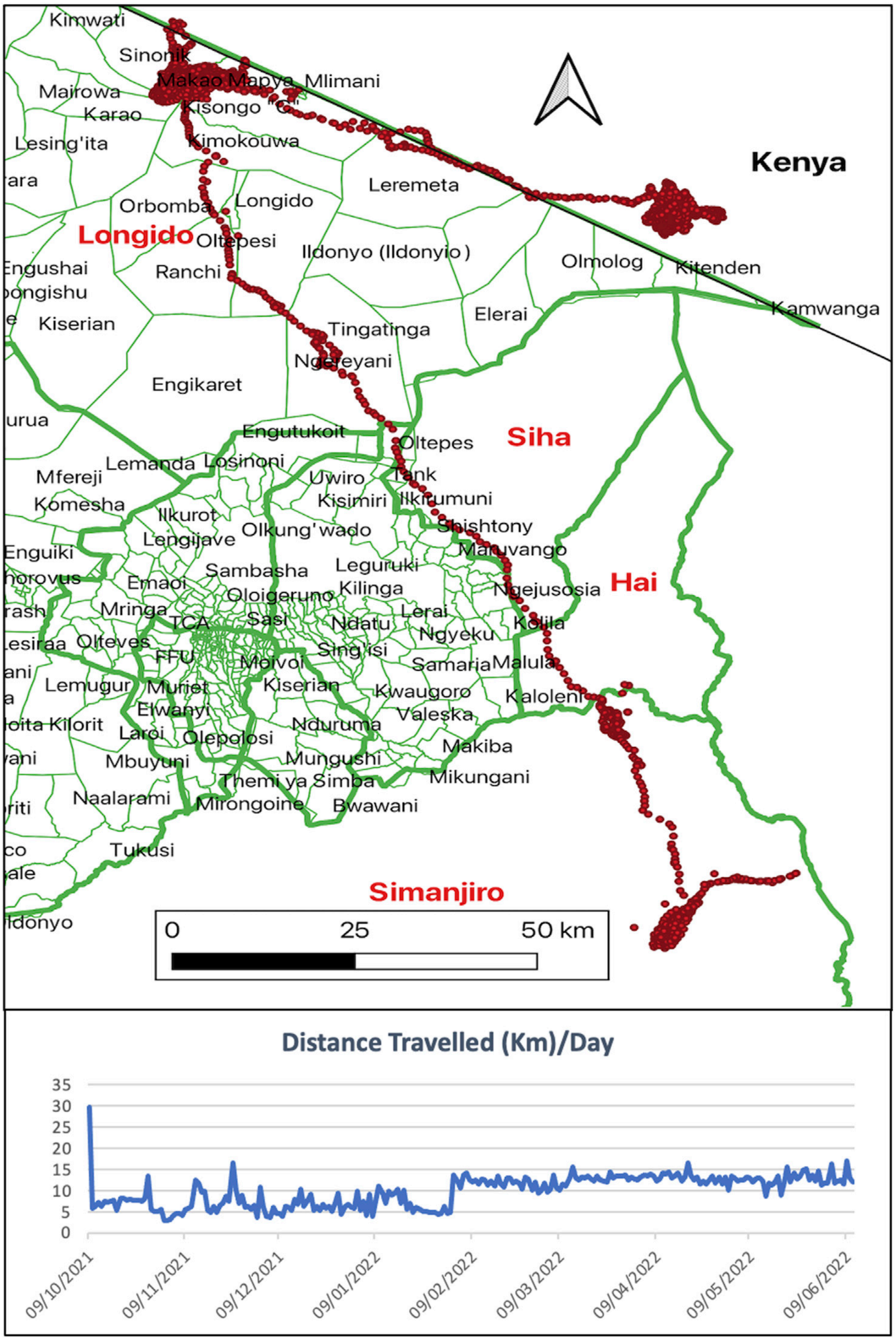


FIGURE 3
Shows GPS collar data collected from the first tracked animal to monitor movement patterns. The animal originated from Engikareti village in Longido and migrated to Siha, Hai, and Simanjiro districts, covering a total distance of 4,920 km over 9 months.

our study timeline), the collared herds in most cases changed course–moving back toward their wet-season home areas or dispersing to take advantage of fresh pasture growth near their villages.

A striking result was the distance that some herds traveled on a routine basis. Our data showed the longest daily distances (15 km up to ~35 km in a day) occurring during the late dry season, when animals had to travel from depleted local grazing

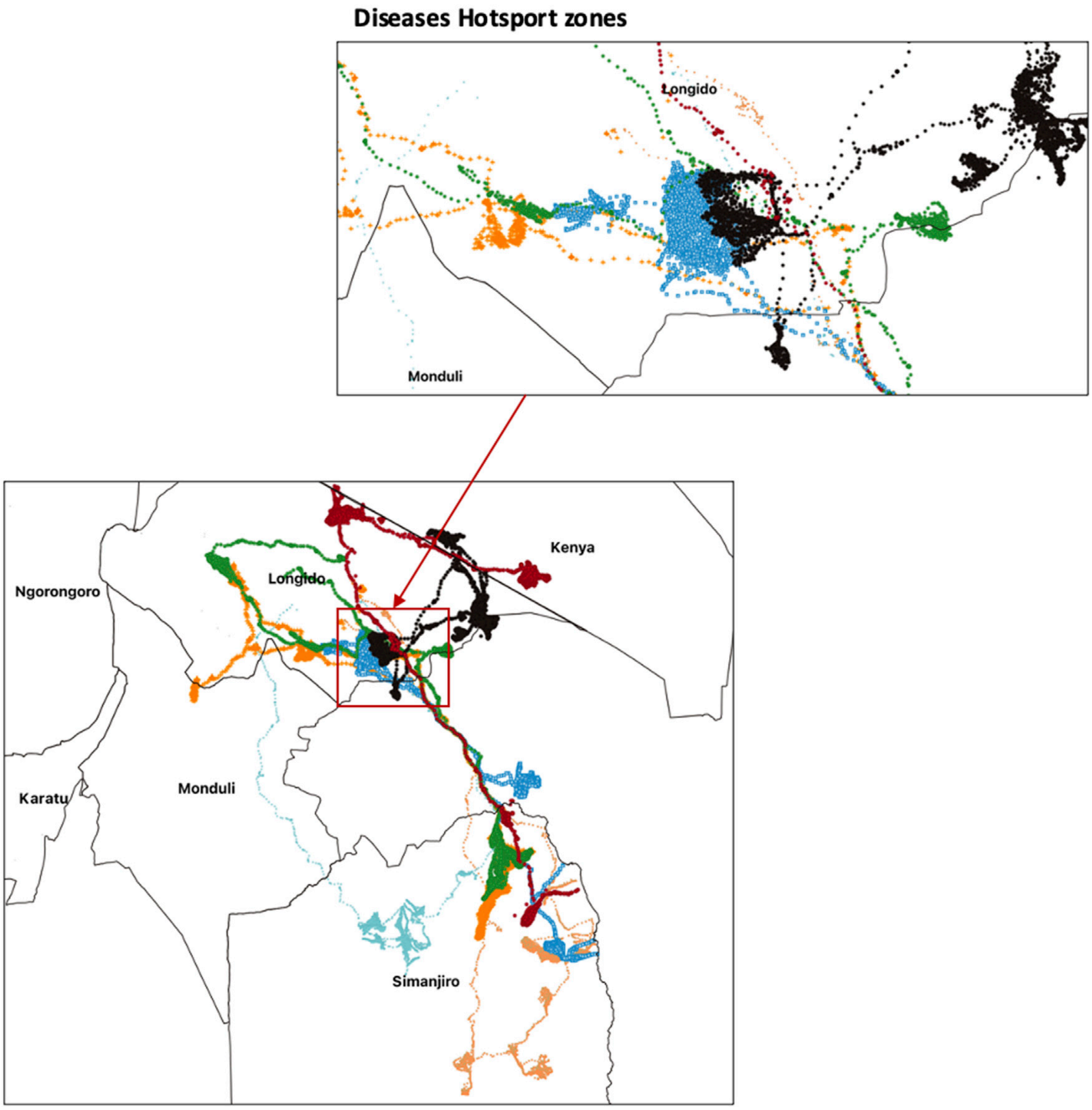


FIGURE 4
Presents sample GPS data illustrating interactions between animals from different locations, highlighting potential hotspots for disease transmission. Note: GPS-collared cattle were traveling with a herd size of approximately 300 to 1,000 cattle.

areas to distant water points and back or during migrating to other districts. The daily distance moved, averaged across all herds, was about 5–12 km per day if they graze along their household or camp to the grazing areas. Once the rains started and local forage regenerated, daily movement distances tended to decrease somewhat (closer to 4–12 km per day in some herds).

Crucially, the GPS data helped identify specific sites and times of herd congregation. For instance, analysis of the movement trajectories showed that multiple collared herds (from different villages) converged at certain grazing points (Figure 4) at the height of the dry season. In other case, multiple herds from different parts of the district all visited the same borehole on several occasions, suggesting it is a regional dry-season watering hub. These convergence points correspond to the "hotspots" that community maps had flagged (in this example, the borehole was indeed marked on several village maps). Such points of convergence are of interest because they can become areas of resource congestion and also increase livestock contact, with implications for disease spread.

Community members had described generally that they "go far" with cattle in dry times and come back during the rains. The GPS put a concrete number on this pattern (approximately an animal can walk a distance of 4,000 km in less than a year). This kind of quantitative evidence can help policymakers or planners appreciate the scale of movement involved in pastoral systems, something that may be underestimated without empirical data.

By overlaying GPS tracks on participatory maps, we were able to validate many features of the community maps. Herds largely stayed within the broad grazing areas delineated by participants, and the furthest points reached by GPS-tracked animals often coincided with the boundaries of what communities had identified as their traditional grazing territory. For example, one Longido herd's track extended to the northern border of Longido District, aligning with a transboundary corridor that elders had sketched leading into Kenya. Additionally, GPS points clustered around the exact water sources that were marked on the participatory maps, confirming that those sources were indeed being used as indicated. There were cases where GPS data revealed additional nuance for instance, one herd frequented a small valley that had not been highlighted in the village map, perhaps because it was considered part of a larger grazing area, suggesting that area is an especially favored micro-habitat. Such details illustrate how GPS tracking can enrich the understanding gained from community mapping.

Overall, the combination of methods demonstrates strong complementarity. The participatory mapping provided the big-picture landscape of resources and seasonal movements as perceived by pastoralists, while the GPS tracking offered measurable specifics on movement distances, timing, and exact routes. Notably, wherever overlap in information existed e.g., location of a water point, general extent of grazing, the agreement between the community maps and the GPS data was sought. This lends confidence that the participatory maps, when properly conducted and validated, accurately reflect on-the-ground realities.

## Discussion

This trial study demonstrates the utility of combining participatory mapping with GPS tracking to investigate pastoral land use in a data sparse context. The approach yielded complementary insights: community mapping captured the collective knowledge of resource distribution and customary movement patterns, while GPS collar data provided empirical verification and fine detail on livestock mobility. The results, though preliminary, suggest that this integrated method is feasible and valuable for pastoral land use research and can inform practical management discussions.

A key contribution of this work is methodological. We showed that participatory mapping even when conducted across a large number of villages can systematically document pastoral resources and seasonal movements in a format amenable to GIS analysis. By engaging local pastoralists in mapping, we accessed information that is often unrecorded in official data sources, such as the location of traditional dry season grazing reserves or the routes that herders take across village boundaries. Similar participatory mapping exercises in other Tanzanian rangelands have proven effective for identifying resources and routes critical to pastoral livelihoods (International Land Coalition, 2016), and our findings reinforce those experiences in a new geographic setting. In our case, involving knowledgeable elders and local leaders, facilitating open discussion, and conducting follow-up verification; feedback meetings, cross-checks with adjacent communities helped ensure that the mapped data were credible and represented a consensus view. In fact, the strong agreement we found between mapped features and GPS-recorded behavior builds confidence in the accuracy of the participatory maps. It demonstrates that, when properly executed, participatory mapping is not merely anecdotal but can produce data aligning closely with objective measurements. Unsurprisingly pastoralists' indigenous spatial knowledge is typically well grounded in reality (Oba and Kaitira, 2006).

On the GPS side, the study illustrates the added value of even a small sample of tracking data. Tracking only a handful of herds over a few months yielded quantification of movement (distances, areas, timing) that enriched our interpretation of the maps. For instance, community members in Longido district described migrating "far" with their cattle in dry times, and the GPS data put a number to that an animal can travel up to 30 km/day in our case. Moreover, GPS tracking allowed us to capture temporal dynamics (e.g., precisely when herds moved back after rains, or how movement speeds changed before vs. after the wet season onset) which participatory mapping alone could only generalize. This temporal aspect is critical for understanding how pastoral land use adjusts to rainfall variability an insight relevant for anticipating climate change adaptation needs in these communities. Such information can help external stakeholders appreciate the scale and necessity of mobility in pastoral systems.

Previous research in East Africa and elsewhere has highlighted that cattle from traditional pastoral systems often move several kilometers per day and regularly come into contact with other herds at shared resources (Ekwem et al., 2021). We observed that at these shared resources, cattle from multiple communities graze together, our case study concurs, earlier findings (Ekwem et al., 2021) that traditional pastoral herds often come into contact at common water or grazing sites, thereby underlining issues like resource congestion and potential disease transmission risk at certain sites.

## Key findings and implications

Our integrated approach not only reveals how pastoral land use is evolving under growing pressures but also demonstrates how such knowledge can directly inform decision-making processes. By combining indigenous knowledge with quantitative GPS tracking, we generated evidence that is both spatially explicit and locally validated, making it credible and actionable for policymakers. This approach offers a practical pathway for embedding pastoral mobility needs into formal planning frameworks, while also identifying areas where negotiation, institutional support, and conflict resolution are still required. For instance, in Karatu, the participatory maps vividly documented the near absence of communal grazing areas and the growing dependence on crop residues. When paired with GPS data confirming livestock confinement, this evidence underscores the urgency for district officials to strategize around alternatives such as zero-grazing systems, improved forage production, and cross-district grazing arrangements. In Longido and Monduli, by contrast, mapping highlighted the presence of critical dry season reserves and GPS data identified specific herd congregation points. These insights provide a strong foundation for formally integrating such reserves and corridors into village land-use plans, ensuring they remain protected from conversion, while also supporting coordinated management of transboundary routes that are becoming increasingly contested.

One encouraging insight is that traditional strategies for resource management (like reserving dry-season pastures and maintaining shared corridors) are still in use and proved essential in the face of drought. The participatory mapping documented many instances of such strategies, and the GPS evidence showed them in action (e.g., herds actually moving to those reserved areas when needed). However, the maps and discussions also highlighted emerging challenges: for example, several transhumance routes that were historically used are now reported as blocked by private farms or enclosures. This indicates a need for proactive planning to ensure pastoral routes and key resources are recognized and legally preserved in land-use plans (FAO, 2016). The brief results shared here can also spark discussions among stakeholders about pastoral mobility needs and land governance. For example, district officials in Karatu may use this evidence to acknowledge their interdependence with Monduli (since Karatu herds need access to Monduli pastures), potentially leading to inter district agreements or cross-border resource management initiatives. Likewise, the clear identification of critical water points and corridors provides an opportunity for authorities and communities to collaborate on protecting these features (e.g., by demarcating livestock routes in village land use plans or by investing in water infrastructure at heavily used sites).

From a development perspective, integrating indigenous knowledge with modern tracking technology as demonstrated could inform more inclusive land-use planning. Rather than relying solely on top-down data, this approach empowers communities to contribute their spatial knowledge, which when validated can carry equal weight to conventional data. It also helps build trust: in our experience, pastoral participants were enthusiastic that their knowledge was being taken seriously and recorded on maps that might reach decision-makers. The method can be seen as a tool for participatory monitoring of rangelands as well communities can update their maps over time, and periodic GPS tracking could be done to quantify changes or emerging patterns (González-Gordon et al., 2023).

This study is an initial step and highlights several avenues for further research. One clear need is to scale up GPS tracking to more herds and over multiple seasons or years to capture variability. With a larger sample of tracked herds, one could investigate, for instance, how different types of households (large herds vs. small herds, purely pastoral vs. agro-pastoral) use space differently, or how movement patterns change in unusually dry years versus wet years. Another extension is to incorporate animal health and productivity measures: by linking movement data with health outcomes (e.g., disease incidence, weight gain), we could better understand the trade offs pastoralists face in mobility decisions. Additionally, the participatory mapping itself could be expanded into a more participatory planning process. In other words, after mapping resources and routes, communities and officials could jointly identify areas for intervention such as where to open a new water point, which corridor to formally document, or where conflicts are likely and need mediation.

In conclusion, our combined participatory mapping and GPS tracking approach proved to be a powerful way to document and analyze pastoral land use and movement patterns. It respects and leverages local knowledge while introducing empirical evidence into the conversation. The approach holds promise for other pastoral regions where data on mobility and resource use are sparse. As climate variability and land competition intensify, tools that improve our understanding of pastoral systems and engage communities in generating solutions will be invaluable for building sustainable futures for pastoral livelihoods.

## Limitation of the study

Due to the rapid nature of our fieldwork (only 1 day of data collection in each village), there was limited time for prolonged engagement and deep trust-building with community members. This approach may have inadvertently excluded or underrepresented certain local knowledge and perspectives. Despite the effort that we encourage women to participate, we recognize that the brevity of our visit could mean some voices (such as those of certain women, youth, or other marginalized community members) were not fully captured. We also acknowledge our positionality as outside researchers and the possibility that our presence and time constraints influenced who participated and how freely they shared information.

## Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found below: dtlp.nottech.co.tz.

## Ethics statement

The studies involving humans were approved by Kibong'oto Infectious Diseases Hospital- Nelson Mandela African Institution of Science and Technology- Centre for Educational Development in Health, Arusha (KIDH-NM-AIST CEDHA) -KNCHREC. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. The animal studies were approved by Kibong'oto Infectious Diseases Hospital- Nelson Mandela African Institution of Science and Technology- Centre for Educational Development in Health, Arusha (KIDH-NM-AIST CEDHA) -KNCHREC. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent was obtained from the owners for the participation of their animals in this study.

## Author contributions

GM led the conceptualization and coordination of the study, designed the participatory mapping framework, managed GPS collar deployments, supervised data collection in the field, and led manuscript drafting. DE contributed to the study design, particularly in integrating GPS tracking methodologies, and guided spatial data validation and analysis. He also reviewed and edited the manuscript for intellectual content. MC provided scientific oversight on livestock mobility analysis and pastoral systems, advised on GPS data interpretation, and contributed to methodological refinements. GS supported institutional coordination, facilitated stakeholder engagement with district and village authorities, and provided critical feedback on mapping protocols and validation processes. All authors contributed to data interpretation, reviewed the manuscript drafts, and approved the final version for submission. The collaboration combined field-based participatory methods and empirical GPS tracking to reflect both indigenous knowledge and quantitative evidence. The authors collectively affirm that the work represents a shared scientific contribution and acknowledge the vital role of local communities, extension officers, and local government authorities in shaping the research outcomes.

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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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## Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontierspartnerships.org/articles/10.3389/past.2025.15233/full#supplementary-material

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