Pastoralism
Research, Policy and Practice

TYPE Perspective
PUBLISHED 30 September 2025
DOI 10.3389/past.2025.15261

OPEN ACCESS

EDITED BY
Ambica Paliwal,
International Livestock Research Institute, Kenya

*CORRESPONDENCE
S. Taugourdeau,
simon.taugourdeau@cirad.fr

RECEIVED 13 July 2025
ACCEPTED 17 September 2025
PUBLISHED 30 September 2025

CITATION
Taugourdeau S, Machdoud M, Diatta O, Sebari I, Ait El Kadi K, Hammouda RF, El Aayadi S, Assouma MH, Dallahi Y, Diouf AA, Blanfort V, Bastianelli D, Borne F and Chebli Y (2025) Roadmap for a participatory observatory for rangeland monitoring based on image analysis.
Pastoralism 15:15261.
doi: 10.3389/past.2025.15261

Roadmap for a participatory observatory for rangeland monitoring based on image analysis

S. Taugourdeau[1,2]*, M. Machdoud[3], O. Diatta[4], I. Sebari[3], Kenza Ait El Kadi[3], R. F. Hammouda[5], Soufiane El Aayadi[6], M. H. Assouma[1,2], Y. Dallahi[7], A. A. Diouf[8], V. Blanfort[1,2], D. Bastianelli[1,2], F. Borne[8,9] and Y. Chebli[10]

[1]UMR SELMET, Université Montpellier, CIRAD, Insitut Agro INRAE, Montpellier, France, [2]CIRAD, UMR SELMET, Montpellier, France, [3]School of Geomatics and Surveying Engineering, IAV Hassan II, Rabat, Morocco, [4]Zootechnical Research Centre, Senegalese Agricultural Research Institute, Dahra, Senegal, [5]Laboratory of Plant Ecology and Environment (LEVE), Faculty of Biological Sciences, University of Sciences and Technology Houari Boumediene, Algiers, Algeria, [6]Department of Animal Production and Biotechnology, Institut Agronomique et Vétérinaire Hassan II (IAV Hassan II), Rabat, Morocco, [7]Laboratory of Plant Biotechnology and Physiology, Center of Plant and Microbial Biotechnology, Biodiversity and Environment, Faculty of Science, Mohammed V University in Rabat, Rabat, Morocco, [8]UMR AMAP, Univ. Montpellier, CIRAD, CNRS, INRA, IRD, Montpellier, France, [9]CIRAD, UMR AMAP, Montpellier, France, [10]Regional Center of Agricultural Research of Tangier, National Institute of Agricultural Research (INRA), Tangier, Morocco

This position article advocates for the creation of a participatory pastoral observatory, leveraging accessible technologies, including smartphones, to monitor rangeland ecosystems. Rather than reiterating the already accepted need for monitoring, we focus on how technological progress, ranging from ground-based field plots to satellite imagery, UAVs, and smartphones using Structure from Motion (SfM) methods, has transformed rangeland observation. We argue that an imagery-based community monitoring system can provide accurate, relevant, and timely data while empowering local stakeholders and informing policy decisions. We detail the operational steps of smartphone-based observatory, highlight its capacity to reduce labor-intensive biomass sampling, and discuss its feasibility when applied by pastoralists. We also draw lessons from related participatory approaches in Mongolia, Ireland, and East Africa. By integrating traditional ecological knowledge with scientific approaches, this initiative can strengthen the resilience of pastoral systems, support sustainable management practices, and contribute to evidence-based policymaking. The proposed observation framework builds on existing research and technological innovations to promote a decentralized and inclusive monitoring system. We imagine such a type of observatory could be useful in Sahel Region or in Northern Africa, could describe practical challenges (smartphone penetration, network coverage, training for low-literacy users), and outline next steps for implementation.

KEYWORDS
rangeland ecosystems, ground-based field plots, satellite imagery, UAVs, smartphones

Introduction

Pastoralism, the use of extensive grazing on rangelands for livestock production (Blench, 2001), is central to livelihoods in many arid, semi-arid, and mountainous regions, where such systems often represent the only viable form of agriculture (Reid et al., 2014). Managed largely through mobility, rangelands are characterized by high spatial heterogeneity and strong interannual variability in vegetation productivity (Uddin and Kebreab, 2020). While the importance of monitoring rangeland conditions is widely acknowledged, the methods used have evolved considerably in the last decades.

Historically, rangeland monitoring has progressed through four main technological stages:

Firstly, monitoring can rely on ground-based plots: Field observers directly measured vegetation parameters, often with quadrats or transects. This provided accurate local data but could not capture the variability of extensive rangelands, especially in remote areas. However, these approaches required huge quantity of work. The spatialization of the ground plots to large scale relied on their representativity.

Satellite-based monitoring widely used Sensors such as Williams et al. (2006) or Daac 2018 enabled the development of vegetation indices like NDVI (Garba et al., 2017) that can be measured on long time series This allows to compare the vegetation indices between years to identify the bad years and pastoral crisis. Remote sensing can be used to estimate biomass mass from satellites it required extensive calibration datasets (Diouf et al., 2015; Diouf et al., 2016; Lo et al., 2022), which many countries lack These approaches revolutionized monitoring but were limited by coarse resolution and cloud interference.

New technologies could be used to enhance the monitoring of resources such as Unmanned Aerial Vehicles (UAVs): High-resolution imagery bridged the scale gap between field plots and satellites (Lussem et al., 2018; Wijesingha et al., 2020; Théau et al., 2021; Nungi-Pambu et al., 2023). UAV are very useful to produce high resolution maps. Furthermore, UAV produce also height estimation using photogrammetry, especially Structure from Motion (SfM) process. SfM operates in five main steps (Voroninski et al., 2017; Iglhaut et al., 2019; Taugourdeau et al., 2022) (1) capture multiple overlapping photographs or a short video while moving around the vegetation target, maintaining 60%–80% overlap; (2) detect and match distinctive features between images; (3) estimate the camera's relative position and orientation for each image; (4) generate a sparse 3D point cloud; and (5) create a dense point cloud, textured mesh, or orthomosaic from which vegetation height, volume, and biomass can be calculated. Once calibrated with traditional biomass sampling, SfM can eliminate most of the need for destructive cutting, drying, and weighing. UAVs can map vegetation cover, height, and biomass in great details but remains costly and subject to regulatory constraints in many pastoral areas.

Another option will be to use images from smartphones. Image analysis from smartphone is another option to UAVs. Deep-learning advances and their application in image analysis have proven that biomass can be estimated through image processing (Woodrow et al., 2023; Stumpe et al., 2024). A fine-tuned approach can even produce differentiated results depending on the species (Borianne et al., 2023). Image analysis is possible from individual photos or through SfM methods, which build three-dimensional models from a set of photos. The use of SfM provides additional information on vegetation volume and height, which are commonly used as proxies for available biomass (Taugourdeau et al., 2022). Examples of photogrammetric outputs from ground camera are presented in Figure 1.

An additional advantage for smartphones is that pastoralists can perform the image capture themselves, reducing dependence on technical staff and lowering costs. While published cases of pastoralists applying ground cameras. are rare, related examples exist. The Mongolian National Federation of Pasture User Groups monitor hundreds of sites using photographs (Densambuu et al., 2018); Pl@ntNet engages citizen scientists, including rural land users, in large-scale image collection (Goëau et al., 2014); and participatory rangeland management projects in East Africa have trained communities to collect overlapping ground and drone imagery. In these models, professionals handle data processing, calibration, and quality control, but field data capture is fully community-led. This suggests that pastoralist-led SfM smartphone is a realistic next step if simple protocols and feedback mechanisms are developed. Examples of SfM outputs from ground cameras are presented in Figure 1.

Building on these advances, we propose a participatory observatory in which pastoralists and other local stakeholders collect standardized images or videos using smartphones. These images are processed into vegetation metrics, calibrated with field data, and integrated with satellite observations to produce timely maps of rangeland resources. The remainder of this paper outlines how such an observatory could be designed and implemented.

Observatories of pastoral resources

Information collected by local stakeholders offers a low-cost complement to remote sensing, especially where formal monitoring is sparse. In a participatory observatory, multiple observers collect data following simple protocols, after which the data are cleaned, processed, and mapped. Successful examples already exist: PastureBase Ireland compiles grass productivity data from farmers and researchers nationwide

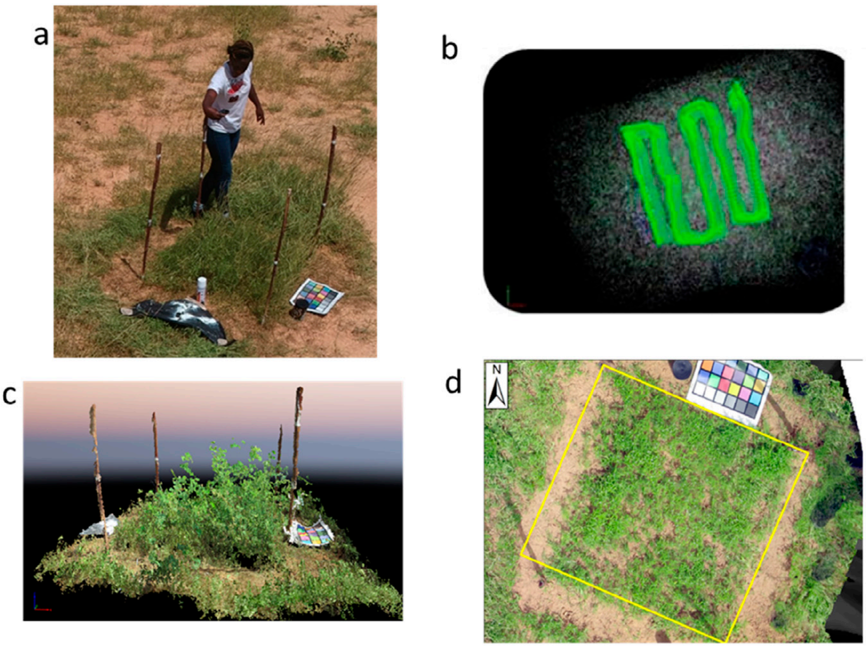

FIGURE 1
Example of Structure from Motion from a ground camera on Sahelian vegetation in Northern Senegal: **(a)** field photograph showing the acquisition method, **(b)** trace of image positions used for photogrammetry, **(c)** resulting 3D model, and **(d)** orthomosaic obtained after processing. Adapted from Taugourdeau et al. (2022).

(Hanrahan et al., 2017), and in Mongolia, herder groups assess rangeland condition via photographs and plant identification (Densambuu et al., 2018).

For our proposed system, West Africa and specifically the Sahel region offers a promising pilot site due to its active pastoral networks, existing extension services, and moderate smartphone penetration. Recent surveys in Northern Senegal suggest that more than 65% of pastoral households own at least one smartphone, with ownership skewed toward younger men, who are also the most mobile ones. Network coverage is generally good near settlements and main grazing corridors but remains patchy in more remote transhumance zones. These conditions shape image quality, upload frequency, and participant demographics.

To address the potential challenge of low literacy among pastoralists, the observatory's training component should be deliberately designed to be visual, practical, and participatory. Materials should use pictorial guides, icon-based smartphone interfaces, and short videos in local languages to demonstrate each step of image capture and upload. Initial sessions should be delivered in person within communities, using live demonstrations and hands-on practice. Local pastoral leaders and youth should be trained as 'community facilitators', providing ongoing peer-to-peer assistance. Where feasible, the mobile application should include voice prompts in local languages. Follow-up will be provided through market-day refreshers, social network groups, and radio-based feedback to correct errors and reinforce good practices. This approach builds on participatory monitoring programs in Africa where visual, facilitator-led training has proven effective with low-literacy participants. This kind of method has already proved effectiveness in other African community projects. In Kenya, for instance, the Northern Rangelands Trust trained local "eco-monitors" using picture-based guides and even cartoons in Swahili and Maa to help largely illiterate pastoralists engage in rangeland management (Galvin et al., 2021). In Niger, the RESILAC program supported pastoralists and local municipalities to map grazing zones and develop land-use plans through icon-based tools and formalized community land committees (Foin, 2022). These examples show that with the right visual tools and local support, low literacy should not be a barrier to active participation.

Incentives might combine small financial payments with rapid feedback—e.g., estimated biomass and grazing value—displayed in an icon-based mobile interface.

The images are processed using SfM to create 3D vegetation models, which are then calibrated with field measurements to estimate biomass or other selected metrics. These outputs can be linked to satellite-derived indicators to produce spatially explicit maps of rangeland resources for both local herders and decision-makers. Figure 2 summarizes this process.

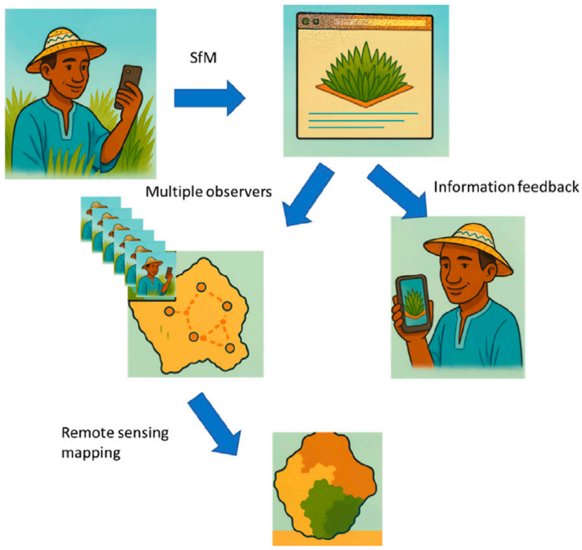

FIGURE 2
Proposed workflow for the participatory observatory: (1) observer records video using a smartphone; (2) video is processed via Structure from Motion (SfM) to generate vegetation metrics; (3) indicators are returned to observers; (4) aggregated predictions are combined with remote sensing to produce resource maps for dissemination to pastoralists, extension agents, and policymakers.

Key considerations for developing the observatory

Motivation of observers

The observatory should primarily rely on pastoral herders who are directly present on rangelands. However, in many pastoral regions, additional stakeholders, such as ministry agents from agricultural and environmental ministries, are also involved. We propose that the observatory integrates a diverse range of actors who may follow different image acquisition protocols.

The first step in establishing such an observatory is to select observers and train them in image acquisition protocols. A key question is how to motivate observers. The motivation of observers is essential to the sustainability of a participatory observatory, and approaches must be adapted to pastoral contexts. Local communities could agree to participate, even without any feedback, to contribute to science and the common wellbeing. Other people may be reticent to share information (position) or want to keep the resources for themselves.

1. Immediate Information Retrieval: Observers may be motivated if they receive immediate feedback. For example, users of Pl@ntNet receive instant plant identification results from their photos (Bonnet et al., 2020). This approach requires efficient image analysis processes and meaningful feedback to sustain engagement. Protocol must be simple and communication must be made to reach the maximum of observers. The vegetation metrics provided must be relevant to local actors. Standard forage quality metrics may not be helpful for pastoral herders, whereas species presence, suitability for specific livestock, or grazing potential may be more relevant. Additionally, feedback must be understandable for users with limited literacy skills. Integrating culturally appropriate visual interfaces and mobile alerts could further improve engagement and usability.
2. Financial Incentives: Observers could be paid for their contributions, leveraging the increasing use of mobile payment applications among livestock herders. Specific training must be done for the observer to enhance the quality of the acquisition. This system would require an automatic quality control mechanism and limitations on the number of images that can be submitted. A budget should be allocated to sustain image acquisition over multiple years. Financial incentives must be transparent and consistent to maintain participation, particularly during low-activity or drought seasons when motivation may decrease.

For ministry and NGO agents, motivation is less of a concern but must still be addressed with their hierarchy to integrate this activity into their workload. Budget allocations, particularly for travel expenses, should be planned. The main question remains the motivation of the overall institution and the amount of data it will obtain from the observatory. Institutional buy-in is essential, and integrating the observatory's activities into existing programs can help ensure continuity and accountability.

Site selection strategies

The collected data must be linked to remote sensing information to map rangeland vegetation metrics. Two site selection strategies are possible:

1. Free Site Selection: Observers take images at their convenience, as in the Pl@ntNet application. This approach is most effective when motivation is driven by information retrieval. However, data collected this way may not be representative. For instance, pastoral herders might take more pictures in areas experiencing favorable grazing conditions. Understanding the factors influencing data collection is essential for proper analysis. This strategy promotes scalability and inclusivity but requires robust analytical frameworks to address potential spatial biases.
2. Pre-Selected Sites: Specific sites, representative of the region, are designated for regular monitoring. This approach aligns

better with paid image acquisition models or governmental and NGO initiatives. Structured site selection improves monitoring efficiency. Due to the low spatial resolution of image acquisitions, sites should be physically marked, for instance, with QR codes to facilitate identification. These markers could also serve as references for image analysis calibration, ensuring consistency in reflectance and height measurements.

Combining the two strategies can offer a hybrid model that balances representativeness and flexibility. It means having a set of permanent sites with paid observers that will serve as the basis of the monitoring for the year, and free sites with opportunistic observers.

Selection of vegetation metrics

When information retrieval is the primary motivation, selecting appropriate vegetation metrics is crucial for success. Discussions with observers should guide the selection of metrics to ensure relevance. A key advantage of image-based monitoring is that the same raw data (images) can be used to assess multiple metrics. Collaborations with agricultural and environmental ministries should also define their requirements for mapping pastoral resources. Involving end users from the outset strengthens ownership and ensures that the produced data are actionable and meaningful at the local level.

Most image-based studies assess vegetation quantity, such as dry mass or species identification. Dry mass estimation typically focuses on green biomass, which correlates with vegetation indices. However, in pastoral systems, grasses are often consumed in their senescent stage during periods of drought. Monitoring dry mass dynamics in the dry season is crucial for pastoral management. Additional metrics such as pastoral value, forage quality indicators, and biodiversity indices could also be valuable. A modular approach to measurements could allow observatories to evolve and adapt to emerging priorities, including climate impacts and land-use changes.

Image acquisition and calibration

A practical approach to image acquisition involves recording videos using a moving camera, following a grid pattern similar to UAV flight paths (Figure 1). Videos can then be split into multiple images, and photogrammetry techniques (Structure From Motion) can be used to generate 3D models of grass structures. For analyses relying on single images (e.g., species identification using CNN models), multiple images from different angles can provide a more realistic representation of ground conditions. Encouraging best practices in image capture can enhance data quality while reducing the need for observer training.

One key factor is the storage and preprocessing of the data (identification of high-quality video) and the automatic structure of the motion process. Server and informatics development are required to create and maintain the pipeline of processing.

Calibration is essential to ensure output quality. After selecting vegetation metrics, extensive field measurements should be conducted to develop calibration datasets, either for image analysis models or for correlating with vegetation indices. Calibration should be performed before establishing the observatory, while validation measurements should continue throughout the observatory's operations to ensure prediction accuracy. A robust calibration and validation plan is essential to maintain scientific credibility and ensuring policy relevance.

Discussion

In this paper, we have outlined a roadmap for a participatory pastoral observatory based on smartphone imagery and SfM photogrammetry. Beyond its technical feasibility, the approach offers significant cost and labor savings once calibrated and empowers pastoralists to contribute directly to rangeland monitoring.

To move from concept to reality, we recommend piloting the observatory in a defined region such as northern Senegal, where pastoral networks and smartphone penetration are sufficient for testing. The pilot should: (1) co-design data collection protocols with local users; (2) train observers through visual, low-literacy-friendly materials; (3) test both free and fixed-site sampling strategies; and (4) evaluate accuracy, participation rates, and data timeliness over at least one full seasonal cycle.

Comparisons with Mongolia and Ireland will help identify which challenges are context-specific (e.g., connectivity gaps, transhumance distances) and which are common across pastoral systems. If successful, the model can then be scaled to other regions, using the pilot results to guide adjustments in training, incentives, and technical infrastructure.

Ultimately, the proposed observatory would serve as both a scientific tool and a community platform, enhancing early warning systems, informing policy, and supporting adaptive management of rangelands in view of climatic and socioeconomic change.

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.

Author contributions

ST: Conceptualization, Writing – Original Draft Preparation, Visualization. MM: Writing – Review and Editing. OD: Writing – Review and Editing. IS: Conceptualization. KA: Conceptualization. RH: Writing – Review and Editing. SE: Writing – Review and Editing. MA: Writing – Review and Editing. YD: Writing – Review and Editing. AD: Writing – Review and Editing. VB: Writing – Review and Editing. DB: Conceptualization. FB: Writing – Review and Editing. YC: Writing – Review and Editing.

Funding

The author(s) declare that no financial support was received for the research and/or publication of this article.

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.

Generative AI statement

The author(s) declare that Generative AI was used in the creation of this manuscript. ChatGpt Was used to produce a figure and to make some correction in the manuscript to improve the english.

Any alternative text (alt text) provided alongside figures in this article has been generated by Frontiers with the support of artificial intelligence and reasonable efforts have been made to ensure accuracy, including review by the authors wherever possible. If you identify any issues, please contact us.

References

Blench, R. (2001). "You can't Go home again," in *Pastoralism in the new millennium*. London: Overseas Development Institute.

Bonnet, P., Joly, A., Faton, J. M., Brown, S., Kimiti, D., Deneu, B., et al. (2020). How citizen scientists contribute to monitor protected areas thanks to automatic plant identification tools. *Ecol. Solutions Evid.* 1, e12023. doi:10.1002/2688-8319.12023

Borianne, P., Sarron, J., Borne, F., and Faye, E. (2023). Deep mango cultivars: Cultivar detection by classification method with maximum misidentification rate estimation. *Precis. Agric.* 24, 1619–1637. doi:10.1007/s11119-023-10012-0

Daac, O. (2018). *MODIS and VIIRS L and products global subsetting and visualization tool.* Oak Ridge, Tennessee: ORNL DAAC. Subset obtained for MOD13Q1 product at various sites in Spatial Range.

Densambuu, B., Indree, T., Battur, A., and Sainnemekh, S. (2018). in *State and transition models of Mongolian rangelands*. Editor M. N. F. o. PU Groups (Ulaanbaatar, Mongolia: TEPE).

Diouf, A. A., Brandt, M., Verger, A., Jarroudi, M. E., Djaby, B., Fensholt, R., et al. (2015). Fodder biomass monitoring in sahelian rangelands using phenological metrics from FAPAR time series. *Remote Sens.* 7, 9122–9148. doi:10.3390/rs70709122

Diouf, A. A., Hiernaux, P., Brandt, M., Faye, G., Djaby, B., Diop, M. B., et al. (2016). Do agrometeorological data improve optical satellite-based estimations of the herbaceous yield in Sahelian semi-arid ecosystems? *Remote Sens.* 8, 668. doi:10.3390/rs8080668

Foin, T., Seydou Moussa, K., Neneck, A. K., Daoud, L., and Njouonang Djom, H. G. (2022). Approche territoriale en contexte de crise: levier pour le renforcement de la résilience. *Groupe URD, projet RESILAC.*

Galvin, K., Bruno, J. E., Reid, R. S., Rowland, M. M., Pickering, T., Walker, S. E., et al. (2021). *Northern rangelands trust.*

Garba, I., Salifou, I., Sallah, A. H., Samba, A., Toure, I., Yapo, Y., et al. (2017). Mapping of zones at risk (ZAR) in west Africaby using NGI, VCI and SNDVI from the e-station. *Int. J. Adv. Res.* 5, 1377–1386. doi:10.21474/ijar01/3953

Goëau, H., Bonnet, P., Joly, A., Affouard, A., Bakic, V., Barbe, J., et al. (2014). "Pl@ntnet mobile 2014: Android port and new features," in *Proceedings of international conference on multimedia retrieval* (ACM), 527.

Hanrahan, L., Geoghegan, A., O'Donovan, M., Griffith, V., Ruelle, E., Wallace, M., et al. (2017). PastureBase Ireland: a grassland decision support system and national database. *Comput. Electron. Agric.* 136, 193–201. doi:10.1016/j.compag.2017.01.029

Iglhaut, J., Cabo, C., Puliti, S., Piermattei, L., O'Connor, J., and Rosette, J. (2019). Structure from motion photogrammetry in forestry: a review. *Curr. For. Rep.* 5, 155–168. doi:10.1007/s40725-019-00094-3

Lo, A., Diouf, A. A., Diedhiou, I., Bassène, C. D. E., Leroux, L., Tagesson, T., et al. (2022). *Dry season forage assessment across senegalese rangelands using earth observation data.*

Lussem, U., Bolten, A., Gnyp, M., Jasper, J., and Bareth, G. (2018). Evaluation of RGB-based vegetation indices from UAV imagery to estimate forage yield in grassland. *Int. Archives Photogrammetry, Remote Sens. Spatial Inf. Sci.* 42, 1215–1219. doi:10.5194/isprs-archives-xlii-3-1215-2018

Nungi-Pambu, M., Lo, A., Fassinou, C., Tageson, T., Fensholt, R., Diouf, A. A., et al. (2023). A framework for national-scale predictions of forage dry mass in Senegal: UAVs as an intermediate step between field measurements and Sentinel-2 images. *Int. J. Remote Sens.* 45, 4199–4218. doi:10.1080/01431161.2023.2290992

Özyeşil, O., Voroninski, V., Basri, R., and Singer, A. (2017). A survey of structure from motion. *Acta Numer.* 26, 305–364. doi:10.1017/s096249291700006x

Reid, R. S., Fernández-Giménez, M. E., and Galvin, K. A. (2014). Dynamics and resilience of rangelands and pastoral peoples around the globe. *Annu. Rev. Environ. Resour.* 39, 217–242. doi:10.1146/annurev-environ-020713-163329

Stumpe, C., Leukel, J., and Zimpel, T. (2024). Prediction of pasture yield using machine learning-based optical sensing: a systematic review. *Precis. Agric.* 25, 430–459. doi:10.1007/s11119-023-10079-9

Taugourdeau, S., Diedhiou, A., Fassinou, C., Bossoukpe, M., Diatta, O., N'Goran, A., et al. (2022). Estimating herbaceous aboveground biomass in Sahelian rangelands using structure from Motion data collected on the ground and by UAV. *Ecol. Evol.* 12, e8867. doi:10.1002/ece3.8867

Théau, J., Lauzier-Hudon, É., Aubé, L., and Devillers, N. (2021). Estimation of forage biomass and vegetation cover in grasslands using UAV imagery. *PLoS ONE* 16, e0245784. doi:10.1371/journal.pone.0245784

Uddin, M. E., and Kebreab, E. (2020). Review: impact of food and climate change on pastoral industries. *Front. Sustain. Food Syst.* 4, 543403. doi:10.3389/fsufs.2020.543403

Wijesingha, J., Astor, T., Schulze-Brüninghoff, D., Wengert, M., and Wachendorf, M. (2020). Predicting forage quality of grasslands using UAV-borne imaging spectroscopy. *Remote Sens.* 12, 126. doi:10.3390/rs12010126

Williams, D. L., Goward, S., and Arvidson, T. (2006). Landsat. *Photogram. Eng. Remote Sens.* 72, 1171–1178.

Woodrow, L., Carter, J., Fraser, G., and Barnetson, J. (2023). Using continuous output neural nets to estimate pasture biomass from digital photographs in grazing lands. *AgriEngineering* 5, 1051–1067. doi:10.3390/agriengineering5020066