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RESEARCH ARTICLE

Participatory mapping of local people's values in restoration landscapes in Western Rwanda

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Abstract

Introduction: Landscape restoration is critical to addressing deforestation, land degradation, and biodiversity loss while promoting human well-being. However, its success largely depends on local knowledge and values, which are often overlooked, reducing the effectiveness and long-term sustainability of restoration.
Objectives: This study used a participatory approach to map landscape values and perceptions of well-being in Western Rwanda. The goal was to identify priority restoration areas, uncover potential conflicts, and explore the socio-demographic factors shaping landscape value perceptions within the context of restoration.
Methods: A Public Participation Geographic Information System (PPGIS) survey was used to capture the landscape values and restoration practices' impact on local communities. Our analysis focused on understanding spatial and statistical variations in perceptions.
Results: In total, 3,047 locations were identified, with regulating values, crop production, and benefits from trees most frequently mapped. Mapped values varied from site to site, reflecting local land use with regulating values, clustered around forests in Rutsiro, whereas in Nyabihu, they were mainly mapped on terraced farmlands. Socio-demographic factors influenced value perceptions, with landless respondents prioritizing crop production while wealthier landowners emphasized water supply. While restoration was generally viewed as beneficial, concerns were raised about the use of non-native species in restoration. These species were seen as potential threats, as they could reduce access to key resources, lower crop productivity, and disrupt cultural and traditional uses. Additionally, the same tree species perceived as harmful to livelihoods were also recognized for their negative impacts on biodiversity.
Conclusions: Overall, the findings underscore the need to balance ecological goals with local socio-economic realities and demonstrate the value of PPGIS in participatory restoration planning.
Implications for Practice: Restoration should account for landscape values that support local livelihoods and well-being. Ensuring that interventions enhance these benefits will increase community ownership and restoration success. Strong spatial clustering of values highlights a need for involving local stakeholders in participatory decision-making to balance ecological objectives with community needs. Different perceptions of restoration must be considered to avoid and resolve conflicts and ensure equity. Addressing concerns about access and impacts will build stakeholder trust and legitimacy for restoration initiatives.

Key words: landscape values, participatory mapping, PPGIS, Rwanda, social-ecological restoration, sustainable land management

Introduction

Within the context of the UN Decade on Ecosystem Restoration, the essential role of stakeholders in driving successful restoration efforts has been increasingly recognized. Ecosystem restoration involves helping degraded ecosystems, such as forests, grasslands, and wetlands, recover and regain their ecological functions while enhancing human well-being (Suding 2011; Aronson et al. 2020). However, in many regions, landscapes are mosaics combining natural ecosystems, such as montane forests and wetlands, with human-managed systems, including arable land, terraces, pastures, and agroforestry plots. In these settings, restoration must therefore extend beyond ecological recovery to also support agroecosystems and other managed landscapes that are central to subsistence agriculture and pastoralism (van Noordwijk et al. 2020). Depending on local environmental and social contexts, restoration can encompass a range of goals, including biodiversity conservation, enhancing ecosystem

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services, and supporting local livelihoods. Methods include promoting natural regeneration, tree planting, controlling invasive species, and conserving soil (Strassburg et al. 2020). In this broader context, Rwanda has implemented diverse restoration practices including agroforestry, terracing, woodlot establishment, and natural regeneration, often in areas that are intensively cultivated or facing soil erosion (Mukuralinda 2016; Majoro et al. 2020; Nyiramvuyekure et al. in review).

Incorporating the perspectives and values of local people is critical to ensuring that restoration interventions are both ecologically effective and socially acceptable (Chazdon et al. 2017; Fischer et al. 2021). Effective restoration hinges on a holistic strategy that incorporates sociocultural and economic outcomes, promoting environmental sustainability and community ownership (Jellinek et al. 2019). Especially in densely populated and farmed countries such as Rwanda—our focus in this paper—considering local perspectives is essential to ensure that restoration activities are aligned with the needs of communities (Buckingham et al. 2021; Frietsch et al. 2024).

A "people with nature" approach to ecosystem restoration, as described by Reyers and Bennett (2025), goes beyond the traditional "people and nature" concept by highlighting the inseparable relationship between social and ecological systems. This perspective aligns with the social-ecological systems framework, which views landscapes as interconnected networks where ecosystem health and human well-being are closely intertwined (Fischer et al. 2021). Using this approach, our study explicitly considers the values, knowledge, and livelihoods of local people as integral components of restoration outcomes. Social-ecological restoration provides the basis for reversing environmental degradation and biodiversity loss by restoring ecosystem functions while recognizing multiple ways in which people benefit from their landscapes (Perring et al. 2015). In this context, landscape values are defined as both tangible benefits that landscapes provide to people (for instance, crops, water supply, and biodiversity) and intangible benefits such as cultural practices, aesthetic appreciation, and spiritual connections to the land (Bieling & Plieninger 2013; Plieninger et al. 2015). Integrating these values into restoration initiatives can enhance both ecological recovery and community well-being (Schultz et al. 2022). Further, understanding which values are prioritized can improve the equity and effectiveness of restoration planning (Lyver et al. 2016). Recent assessments have called for incorporating human dimensions more strongly into restoration planning for more inclusive and effective governance (Erbaugh et al. 2020; Fischer et al. 2021; Mansourian et al. 2024).

Ensuring that local people's landscape values are included in restoration planning requires the development of appropriate tools to capture their perceptions. Spatial methods provide a means to assess diverse landscape values, supporting sustainable land use planning and management (Alessa et al. 2008; Gottwald et al. 2022). Public Participation Geographic Information System (PPGIS) has emerged as a tool for mapping place-based values to inform environmental planning efforts (Brown & Reed 2009). Initially developed in the 1990s to raise marginalized stakeholders' voices in decision-making, PPGIS is a powerful tool that integrates socio-cultural, economic, and ecological knowledge in spatial planning (Brown 2012; Ghose 2017). Its application can bridge the gap between predominantly top-down landscape planning and neglected local needs by empowering local people to map landscape values, thereby contributing to an inclusive and collaborative restoration process (Brown et al. 2020). While some studies adopted standardized typologies to classify landscape values (e.g., Brown & Reed 2000), others emphasized inductive, place-based approaches reflecting local experiences and knowledge (Raymond et al. 2009; Brown & Fagerholm 2015; Fagerholm et al. 2019). This study builds on the latter approach to explore how people in Western Rwanda perceive and spatially express values in restoration landscapes.

In many African countries, where data scarcity and top-down planning often limit local participation, advancing the PPGIS approach could be particularly valuable (Fagerholm et al. 2019; Cho & Mutanga 2021). To date, PPGIS has been used on the continent to map landscape services, provide particular insights into how local communities interact with and depend on their environment, and guide participatory spatial planning and land-use decisions (Fagerholm et al. 2019; Hemmerling et al. 2019). Beyond Africa, PPGIS has been more widely applied, for example, to assess spatial patterns, synergies, and trade-offs in ecosystem services from urban and rural landscapes (Plieninger et al. 2019); and to explore how landscape features influence community well-being and sense of place (Gottwald et al. 2022; Polas et al. 2024). To the best of our knowledge, PPGIS has not been used in restoration planning so far, although it may be particularly useful in this context, as many restoration initiatives lack systematic tools to capture place-based values and perceptions. PPGIS approaches could fill this gap by enabling communities to identify areas of importance—referred to as hotspots—and to reveal how land management and landscape-related values contribute to well-being (Davies et al. 2015; Ernoul et al. 2018).

Several barriers have hindered the widespread use of PPGIS in sub-Saharan Africa. These include insufficient institutional and financial support, limited access to digital resources, and a lack of technical capacity (Cho & Mutanga 2021). In a restoration context, these challenges may result in top-down approaches that prioritize biophysical and economic objectives while overlooking socio-cultural values, thereby putting long-term community ownership and sustainability at risk, similar to other land development strategies (Termorshuizen & Opdam 2009). Recognizing these barriers is important for understanding the context of our study, highlighting why participatory mapping of landscape values is rarely implemented and the challenges that must be overcome to do so effectively. Our study, therefore, aimed to map landscape values within restoration landscapes in Western Rwanda using PPGIS, focusing on capturing local people's perspectives despite these challenges. Our research questions were:

(1) Which landscape values do local people perceive in restoration landscapes, and how does the location of mapped values relate to features such as homes, roads, forests, and water bodies?

(2) How do socio-demographic characteristics of local people shape their perception of landscape values?
(3) How do local people perceive restoration contributing to their well-being, and what conflicts and preferences regarding landscape values arise in this context?

Methods

Study Area

The study area was located in the Albertine Rift region, a globally significant tropical biodiversity hotspot in Central and East Africa that stretches across several countries, including Burundi, the Democratic Republic of the Congo (DRC), Uganda, Rwanda, and Tanzania (Plumptre et al. 2020). The Albertine Rift is home to approximately 7,500 species of plants and animals, of which over 1,000 are endemic to the region (Goodman et al. 2013). The region is characterized by significant environmental challenges, including deforestation, soil erosion, and biodiversity loss (Akinyemi 2017). Because of its biodiversity and environmental vulnerability, the region is a focal point for ecosystem restoration. Specifically, Western Rwanda includes some of the country's most important and ecologically rich regions, including the Volcanoes and Gishwati-Mukura National Parks.

We conducted our study in eight villages in Nyabihu and Rutsiro districts (Fig. 1A), characterized by montane forests, wetlands, arable land, grasslands, and pasture lands (Karamage et al. 2017). Both districts are densely populated (Table 1, NISR 2022), and local communities rely heavily on natural resources for their livelihoods. As in many rural areas in the Global South, subsistence agriculture, pastoralism, and small-scale trade form the backbone of their economies (Masozera & Alavalapati 2004). Both Nyabihu and Rutsiro have been targeted by restoration initiatives to address environmental problems such as soil erosion and landslide risks, but also to reduce biodiversity loss (IUCN 2023).

The villages selected for this study were chosen to capture a diversity of ecological and socio-economic conditions (Baumann et al. 2025). They allow for comparisons between different types of restoration landscapes that are prevalent in

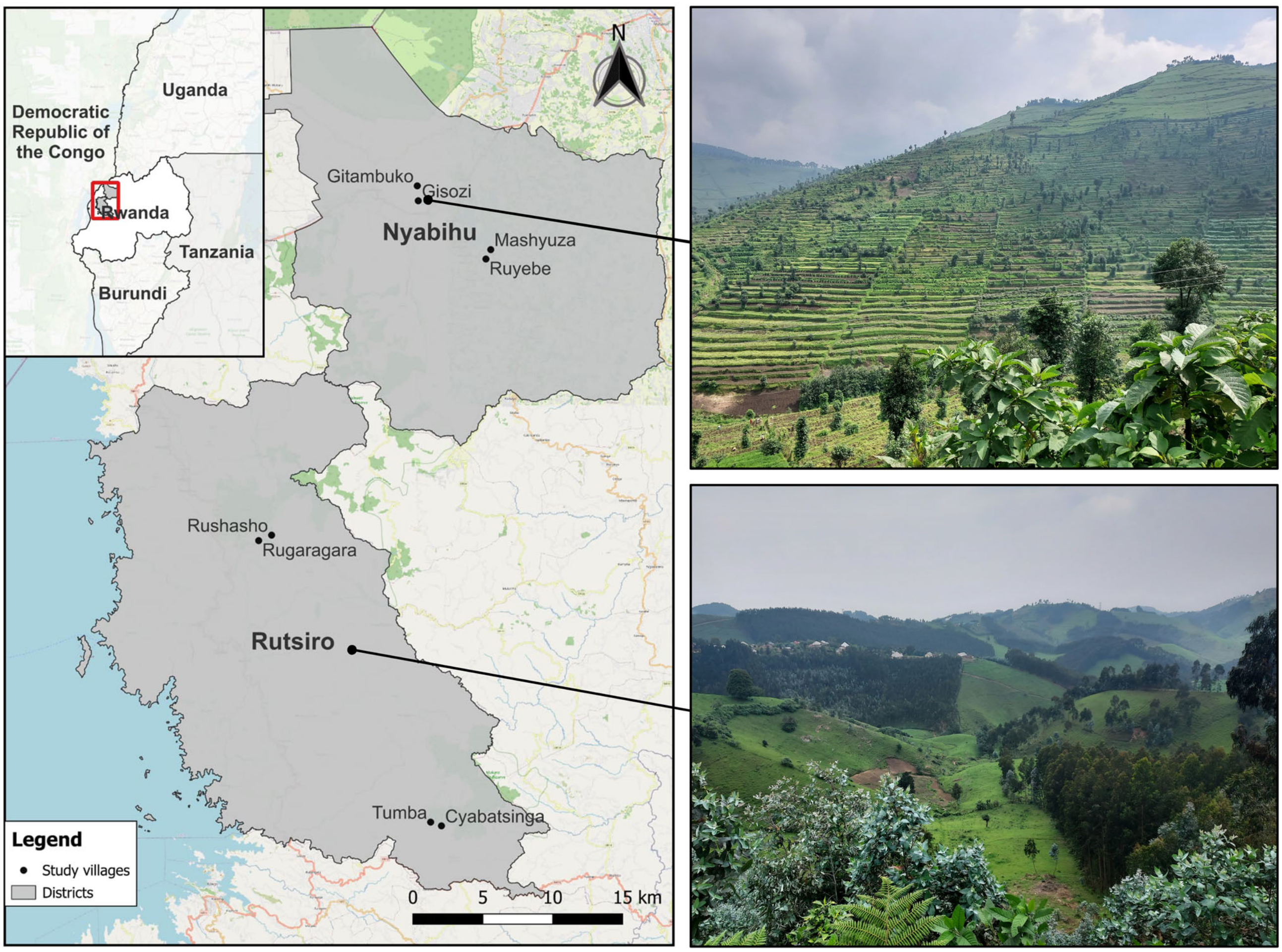

Figure 1. Locations of the study villages in the districts of Nyabihu and Rutsiro in Western Rwanda. Source: Own data and Open Street map (left), and examples of the restoration landscapes in the study districts with terraced farmlands in the Nyabihu district and pasture lands and woodlots in the Rutsiro district (right). Photo by Gaelle Ndayizeye, January 2024. Map data: Open Street Map.

Table 1. Study area description. [a]Remote villages, not accessible to the district roads. [b]Villages near the district roads.

Characteristics	*Districts*	
	Nyabihu	*Rutsiro*
District area	531 km^2	1,159 km^2
Elevation range	1,500–4,500 m	1,460–2,600 m
Rainfall	1,200–1,500 mm mean annual precipitation	1,200–1800 mm mean annual precipitation
Population density	600 people/km^2	319 people/km^2
Landscape features characteristics	• Terraced hills with arable land (croplands and tea plantations) • Pastures lands • Agroforestry systems and woodlots	• Steep hills with arable land • Pasture lands • Forested hills • Agroforestry systems and woodlots
Soil	Andosols derived from volcanic parent material, with naturally high nutrient content	Andosols and Acrisols
Villages included in this study	Mashyuza[a], Ruyebe[a], Gitambuko[b], Gisozi[b]	Rushasho[b], Rugaragara[b], Cyabatsinga[a], Tumba[a]
Restoration types	• Agroforestry • Progressive terraces • Radical terraces • Wetlands • Woodlots	• Agroforestry • Pasture lands • Reforestation of natural forests • Woodlots
Urban/rural	Mainly rural (75%) and remote	Rural but not remote
Protected areas	Volcanoes National Park	Gishwati-Mukura National Park

Western Rwanda (Baumann et al. 2025) and that have been implemented under Rwanda's national landscape restoration strategies (Mukuralinda 2016; Mugabowindekwe et al. 2024) (Table 1, Fig. 1B):

(1) *Establishment of terraces*, designed to reduce soil erosion and enhance agricultural productivity on steep slopes;
(2) *Development of agroforestry systems*, which integrate predominantly exotic trees, such as *Grevillea robusta*, *Pinus* sp., *Eucalyptus* sp., and *Alnus* sp., along with occasional native species, including *Markhamia lutea* and *Croton megalocarpus*, planted with crops to enhance ecosystem services and diversify rural livelihoods;
(3) *Wetland restoration*, which includes the replanting of native wetland vegetation, control of invasive species, and hydrological modifications, such as water retention measures to enhance biodiversity and water regulation;
(4) *Pastureland restoration* through reseeding with native and adapted forage species, rotational grazing management, and soil conservation practices to sustain fodder production and reduce land degradation;
(5) *Restoration planting in degraded natural forests*, involving the enrichment of native tree species such as *Entandrophragma excelsum*, *Poliscias fulva*… to recover forest structure, ecosystem functions and biodiversity; and
(6) *Planting of woodlots*, predominantly *Eucalyptus* plantations, which are widely promoted for their economic and functional value, including providing fuelwood, timber, and controlling erosion.

Identification of Place-Specific Landscape Values Through Focus Group Discussions

In June 2024, we conducted two focus group discussions (FGDs) to identify locally relevant landscape values for use in our PPGIS survey. One FGD took place in Rugaragara village, a restoration area adjacent to Gishwati forest, and the other in Mashyuza village, a culturally and ecologically important site near a wetland.

Before conducting the research, we obtained a research permit from the Rwandan National Commission for Science and Technology (NCST). Further, we obtained permission from the local district and village authorities to carry out this research. Participants were selected to ensure diversity in gender and age (18 years and above) to capture a wide range of perspectives. Each FGD included 10–12 participants, equally divided between men and women. To encourage balanced participation, we actively facilitated discussions by directing questions to female participants and more reserved individuals to ensure that all voices were heard.

For each FGD, we explained the purpose of the study to the participants and obtained and recorded informed consent to participate. Two facilitators conducted the FGDs: one was responsible for asking questions and taking notes on the flipcharts, while the other handled the audio recording. After each session, participants were compensated for their time and contribution. The FGDs consisted of a series of open-ended questions designed to gather participants' perceptions of their landscapes and the benefits they derive from them. The discussions followed a four-step process. First, participants were given a locally contextualized explanation of restoration, described as the effort to improve degraded land, forests, wetlands, and pasturelands to enhance ecosystem functions, support livelihoods, maintain biodiversity, and provide more landscape values for the community. Second, we asked participants about the types of restoration efforts in their villages to set the context. Then, they brainstormed different landscape values, which we recorded on flipcharts in the local language (Kinyarwanda) to ensure clarity and inclusivity. Finally, participants ranked these values according to their importance in daily activities, encompassing aspects related to livelihoods, culture, and environment.

To facilitate discussions, we provided A3 printed imagery maps designed in ArcGIS Pro 3.3.3 as visual references. These maps helped participants to better identify and relate to specific areas of importance in the village landscapes, making it easier to discuss landscape values and restoration efforts. Each FGD lasted 30–45 minutes. Our focus group discussions were designed to ensure that the subsequent PPGIS survey was informed by the input of community members, rather than being shaped solely by the research team's assumptions about which values were most important.

The transcription process began with a review of the list of values identified during the FGDs in both villages. This list, initially generated in the local language, was translated into English. A thematic analysis was conducted to identify the most frequently cited values across the two sites. This process involved coding participants' statements inductively, without using pre-existing categories, to allow local perceptions to shape the classification of landscape values. We analyzed the full audio recordings to capture nuances or values that may have been mentioned but were not explicitly listed during the group discussions. This step ensured completeness and refined the initial dataset. To refine the classification process, we selected 40 representative responses and coded them in a table to facilitate discussion of possible value categories. These responses were chosen based on their recurrence, contextual richness, and relevance to participants' landscape experiences, rather than by frequency alone. During the final classification, similar responses were either merged or reworded, and less clearly defined or overlapping entries were eliminated. This resulted in a consolidated list of 34 distinct responses grouped into 13 landscape value categories, which reflect both widely recognized and culturally specific values (e.g., hot springs in Mashyuza village) (Table 2).

The values gathered from the discussions were categorized into several themes consistent with human–nature relations (Diaz et al. 2015) and previous PPGIS studies (Fagerholm et al. 2016, 2019), which used participatory methods to assess landscape perceptions and the different ways in which people value their environment. This structured approach captured both general and localized perspectives, providing a comprehensive understanding of how communities perceive and value their landscapes. As with many qualitative studies, logistical constraints

Table 2. Landscape values and their sub-categories in the context of rural Western Rwanda.

Landscape Values	*Overarching Value*	*Subcategories*
Aesthetic value	Beautiful places in the landscape	• Enjoyment of green environments • Value for culture and tourism
Recreation	Sites for enjoyment, relaxation, and leisure time	• Enjoyment of fresh air • Enjoyment of quietness and relaxation place.
Cultural heritage value	Sites for spiritual significance and traditional practices, local culture, and history	• Religious significance and beliefs • Cultural and traditional healing
Social relations	Sites for social gatherings in the community	• Community meetings • Meeting friends to play games • Meetings with relatives
Sense of place	Ancestral and cultural attachment	• Place identity • Place attachment
Construction materials	Resource-rich construction site	• Natural construction materials extraction • Handicraft materials collection
Benefits from trees	Tree-based benefits	• Charcoal production • Firewood and timber harvesting • Honey production • Mulch supply
Crop production	Cultivation benefits	• Manure provision • Fertile and moist soils • Favorable microclimate for crops
Water	Fresh water collection site	• Drinking water source
Grazing and fodder	Collection and production sites of fodder	• Tree fodder and medicinal plants for livestock harvesting • Grazing sites • Cowshed locations (e.g., near Gishwati)
Source of income	Place sustaining livelihoods and financial well-being.	• Jobs in development projects • Sale of tree products or cash crops • Sites of (farm) labor
Regulating values	Sites that maintain environmental stability and well-being.	• Erosion control • Comfortable microclimate • Air, soil, or water production, cleaning and provision • Disease regulation sites
Nutrition	Sites that provide essential food resources	• Vegetable provisioning • Milk collection • Fish harvesting

limited participant feedback on coding and interpretation. The FGDs, though valuable for identifying locally grounded landscape values, were brief (30–45 minutes) and focused on selected open-ended questions to inform the PPGIS survey. Mixed-gender groups reflected local norms but may have limited gender-specific perspectives.

PPGIS Survey

In July 2024, we conducted a face-to-face PPGIS survey, using the Survey 123 Field app, to assess perceptions of the 13 identified landscape values across a larger respondent group. The survey was designed using a semi-structured online questionnaire consisting of four parts: first, socio-demographic characteristics such as gender and age, followed by spatially explicit questions, some open-ended questions, and another set of questions about socio-demographic characteristics. We obtained ethical approval for the study from the University of Göttingen human resources ethics committee. We designed and coded the survey in English and carried it out in the local language, Kinyarwanda. Each survey session lasted between 30 and 40 minutes. When recruiting participants, we clearly explained the aim and purpose of the survey, the intended use of the results, and assurances that responses would remain anonymous and confidential. Participation was voluntary, and participants could withdraw at any time during the survey.

Due to the limited internet access in the study area, we designed offline base maps using ArcGIS Online and Field Map Designer, which were uploaded to the Survey123 Field app for field use. The data collected offline were uploaded to the survey platform at the end of each day. For the mapping exercise, we used four maps, each encompassing two neighboring villages with an additional 5 km radius, and a minimum scale of 1:5,000. These maps were also used for selecting respondents, with one household chosen from every third household, starting from the designated household, depending on the layout of the houses. This resulted in a sample of 20–30 informants per village and a minimum of 50 households surveyed per study site (two adjacent villages), totaling 210 informants for the eight villages. To capture diverse perspectives, representativeness in terms of gender, age, and other socio-demographic characteristics was monitored daily.

Like in the FDGs, before starting each survey, we recorded informed consent to participate, and each participant was provided with a brief, locally contextualized explanation of restoration. This introduction provided participants with a clear understanding of "restoration," which also helped them respond meaningfully to later questions on how restoration contributes to household well-being. To ensure respondents understood the maps, they were first asked to indicate the location of their fields and homes before proceeding to the mapping exercise of the landscape values. For spatial questions, each respondent could map up to five locations for each landscape value, while for the open-ended questions linked with mapping, respondents could give a maximum of three answers. Each point mapped represented a specific location or area. The point mapping technique is often used in PPGIS studies (Brown & Fagerholm 2015). The spatially explicit part of the survey was followed by some open free-listing questions about (1) the contribution of restoration to the respondent households' well-being, and (2) potential conflicts arising from current restoration practices and their future preferences. As these questions were open-ended, the responses referred to the importance and impacts of restoration on people's daily lives and, thus, applied an integrated, holistic approach to values in landscapes as applied in Fagerholm et al. (2020). The final survey questions focused on the socio-demographic characteristics of the respondents, which could significantly influence perceptions of landscape values and well-being (García-Martín et al. 2018).

Survey Data Analysis

We conducted spatial analysis using geographic information system (GIS) software, specifically ArcGIS Pro 3.3.3 and QGIS 3.34.6. We used kernel density analysis to identify high and low spatial point intensity areas. High-intensity areas represented hot spots, while low-intensity areas represented cold spots. We adjusted the kernel density estimation (KDE) parameters to the mapping scale, using a cell size of 20 m and a search radius of 200 m to ensure adequate resolution given the small size of the villages. These maps generated continuous density surfaces for each value category, allowing us to identify the spatial intensity and variation between villages. The spatial distribution of mapped landscape values was further analyzed using nearest neighbor (NN) statistics to assess random distribution and clustering patterns. This tool measures the average Euclidean distance between each point and its nearest neighbor points. It divides it by the average distances in a random distribution, where a NN ratio below 1 indicates spatial clustering and a ratio above 1 suggests dispersion (Ebdon 1985). Statistically significant patterns were identified based on z-scores and p-values, with extreme z-scores and small p-values signifying meaningful clustering or dispersion. To better understand how the perceived values may change with distance to key landscape features, we calculated the Euclidean distance from each mapped point to respondents' homes, main roads, water bodies or wetlands, and forests, and summarized these across respondents by calculating the mean distance of each landscape value.

For the open-ended questions, we first translated the responses from Kinyarwanda to English, coded them using keywords, and identified frequently used keywords. We categorized the responses according to the main themes identified as in the first stage of coding; we systematically identified recurring words and concepts. These were then grouped into broader thematic categories to ensure that key ideas were captured consistently. For the restoration contribution well-being responses, we categorized them according to the 13 identified landscape values, while for other open-ended questions, we developed an emergent coding list by analyzing common responses and relations between responses. In addition, insights from the focus group discussions (FGDs) helped to refine our categories and ensure that the themes were consistent with local perspectives. In the next stage of coding, the categories identified in the first stage were either eliminated, combined, or subdivided into subcategories, paying particular attention to common ideas and overarching themes. Then, we used cross-tabulation and chi-square tests to assess whether particular themes differed significantly between different sites.

Results

Characteristics of Respondents

A total of 210 respondents took part in the survey, with a balanced gender distribution (52% female and 48% male respondents). Age categories were divided into three categories, with the middle age group (36–60 years) being the most represented with 54%, while the other two categories were: 18–35 years (27%) and ≥60 years (19%). Almost all respondents (93%) identified themselves as farmers, with 74% mainly dependent on agriculture for their livelihood, while 14% were landless (Table S1). Thirty-five percent of respondents had no formal education, 31% had less than primary education, 30% had completed primary school, and 4% had completed secondary school. Six percent of respondents were elderly and dependent on family support or government assistance programs. The survey results showed that household sizes were distributed into three categories: 1–4 members (26.6%), 5–7 members (58.6%), and 8–10 members (14.8%).

Spatial Patterns of Mapped Landscape Values

In total, 210 respondents mapped 3,047 locations for the 13 selected landscape values. The average number of places mapped per respondent was 14.4 ± 2.8 (arithmetic mean ± standard deviation). The most frequently mapped values were regulating values (1.50 ± 0.88), benefits from trees (1.38 ± 0.67), and crop production (1.30 ± 0.76). Grazing and fodder (1.0 ± 0.5), cultural heritage value (0.9 ± 0.3), and sense of place (0.8 ± 0.4) were less frequently mapped.

Kernel density calculation showed that the six most commonly mapped values were not equally distributed both in the villages and between the two districts. For both districts, social relations sites were dispersed (Fig. 2). In the Rutsiro district, regulating value and crop production were clustered in the forest, while Mashyuza nutrition sites were the most clustered in the wetland. When aggregated across both study sites, however, the three most clustered values were those for construction materials, followed by the places for grazing and fodder, and sources of income. Conversely, the most randomly distributed values overall were crop production, followed by social relations and regulating values. In both districts, the landscape values were mostly close to the respondents' homes, with the mean distance mostly less than 500 m. However, mapped values were on average far from the main roads, the woodlots, and the wetlands, considering the four studied sites (Table S2). The spatial distribution of some values was significantly clustered, while others showed more random patterns (Fig. 2).

Mapped Landscape Values and Socio-Demographic Characteristics of Respondents

Land ownership and age categories were the most strongly socio-demographic characteristics associated with perceptions and mapping of landscape values. A Kruskal–Wallis test revealed significant differences in crop production values between land ownership categories ($\chi^2 = 74.15$, $df = 3$, $p < 0.001$). Post hoc Dunn's tests showed that the upper-class landowners mapped fewer locations related to crop production than the middle class and the group with small land. Interestingly, participants without land identified more locations associated with crop production than participants in any other group ($p < 0.001$). Significant differences in water resource value were also found between the upper-class landowners and the groups with small land and without land ($p < 0.001$), as the upper-class landowners mapped significantly more water resource value sites than the two other groups. This was similar to the nutritional value described in Table 2. Livestock owners mapped statistically significantly more places for benefits from trees and crop production compared to non-owners (Table S3).

Age also significantly influenced crop production value ($\chi^2 = 17.59$, $df = 2$, $p < 0.001$). Older people valued crops more than young people, while middle-aged adults valued them less than young people. Findings have also indicated that older people mapped grazing and fodder significantly higher than young people ($p < 0.001$), while middle-aged adults mapped significantly fewer places than young people ($p < 0.001$), with no significant difference between the middle-aged and older people groups. Age and gender groups also revealed statistically significant associations with sense of place value, with men and elders showing a strong connection to their landscape. The household size variable generally showed limited or no significant associations with most landscape values (Table S3).

Contribution of Restoration to Well-Being

A total of 164 out of 210 respondents (78%) answered the open-ended question about the contribution of landscape restoration to the well-being of their households. Of the 13 landscape value categories (Table 2), nine were identified as related to restoration, with a total of 168 responses. The most highly valued were regulating values, with participants particularly valuing terraces for their role in this category (Fig. 3). The comparison between the two most valued restoration types—natural forests and terraces—revealed highly statistically significant differences in the landscape values associated with each ($\chi^2 = 64.589$, $df = 8$, $p < 0.001$). Woodlots were included in the results for descriptive purposes, but were only mentioned in relation to two landscape values, while other restoration types (e.g., agroforestry systems, wetlands, pasturelands) were mentioned too infrequently to be included in the statistical analysis.

The open-ended question on preferences for potential values in future restoration practices was answered by 158 out of 210 participants (75%), while the question on possible conflicts arising from restoration practices received fewer responses, with only 93 participants (44%) providing input. In terms of restoration-related conflicts, respondents predominantly identified exotic

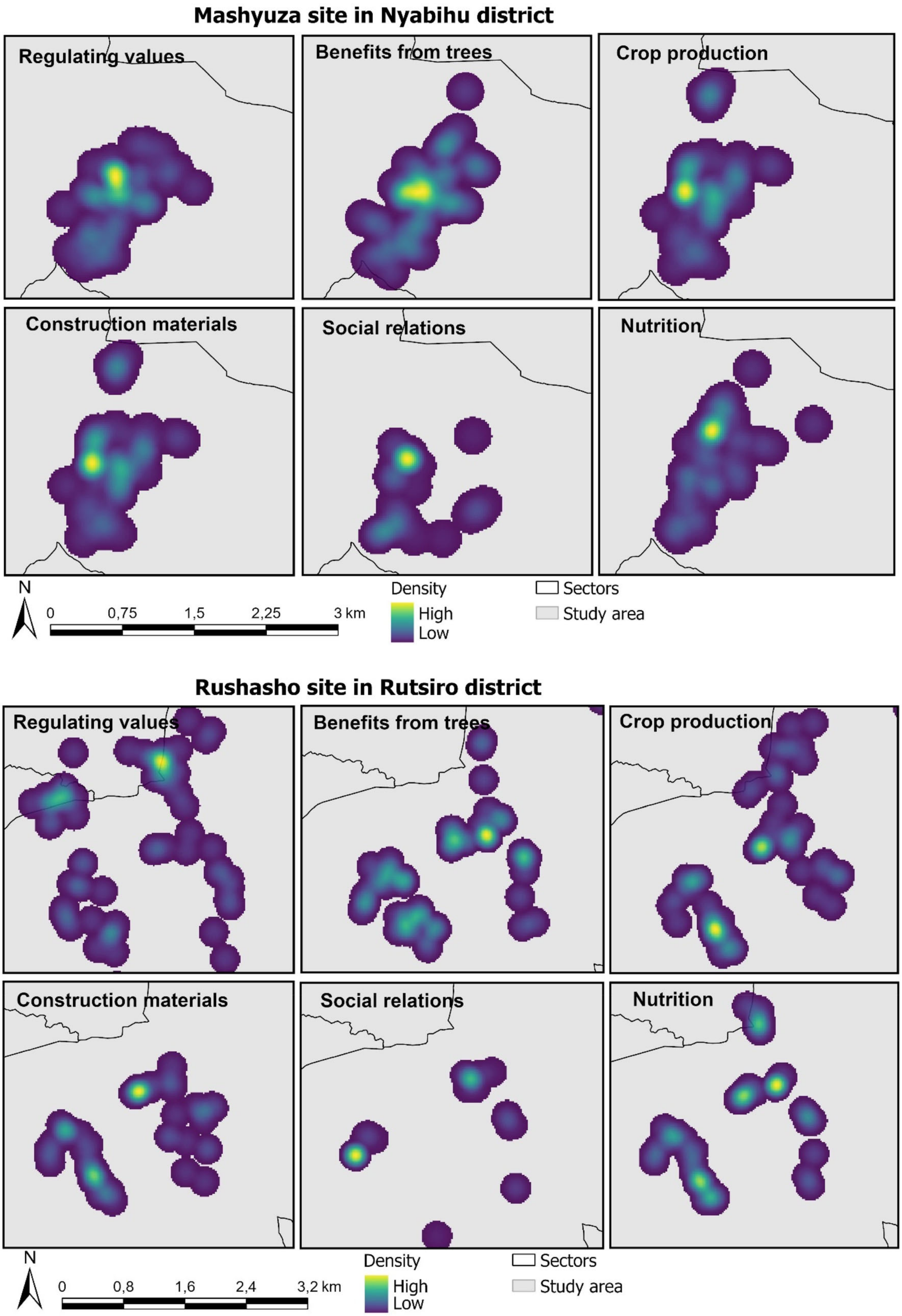

Figure 2. Kernel density heatmaps of the first six mostly mapped landscape values in two sites. The intensity increases from dark purple to green to yellow. The two sets of maps contain three landscape values from two sites of two villages: Rushasho site is near Gishwati forest in Rutsiro district, and Mashyuza site is near a wetland in Nyabihu district.

tree plantations as a source of concern (Fig. 4). Many expressed that while exotic species are important, they are problematic due to their high-water consumption levels, soil depletion, and potential allelopathic effects that hinder agricultural productivity. One female respondent, 42 years old, shared, "We like exotic species for their benefits, but they are degrading our soil." Another concern was about the need for context-specific planning, with one example pointing out, "We have many woodlot plantations in fertile and suited areas to grow crops, male, 39 years old."

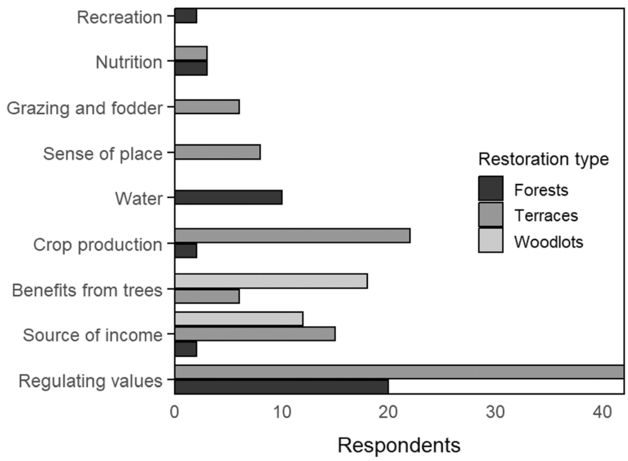

Figure 3. Local communities' perceptions of the contribution of different landscape values to household well-being, as influenced by different types of restoration. Dark gray bars represent values associated with terraces, black bars correspond to values associated with continuous forests (national parks), and light gray bars represent values associated with woodlots.

Conversely, when asked about preferred future restoration practices, many respondents strongly expressed the use of terracing in their landscapes (Fig. 4). This preference reflects the local communities' recognition of the benefits of terracing, such as soil conservation, erosion control, and improved agricultural productivity.

Discussion

Our study emphasizes the importance of integrating local knowledge and landscape values into restoration planning through participatory methods such as Public Participation GIS (PPGIS), which can provide critical insights into restoration priorities that might be overlooked in conventional ecological assessments (Sieber 2006; Brown & Fagerholm 2015). Our results showed that regulating values, benefits from trees, and crop production were most frequently mapped, underscoring the essential role of landscapes in sustaining agricultural livelihoods, resource security, and resilience to environmental change. This is consistent with findings from other locations within the Global South (Sears et al. 2018; Fagerholm et al. 2019; Ndayizeye et al. 2020). These patterns reflect both material dependence on landscapes and broader issues of access, scarcity, and vulnerability, especially in densely populated or land-limited regions. This contrasts with several studies performed in the Global North, where non-material values such as recreation, aesthetics, and identity are typically more prominent (Plieninger et al. 2013; Tasser et al. 2025), highlighting regional differences in landscape priorities and human–nature relationships. These findings reinforce the need for context-specific restoration planning, which accounts for local social-ecological realities.

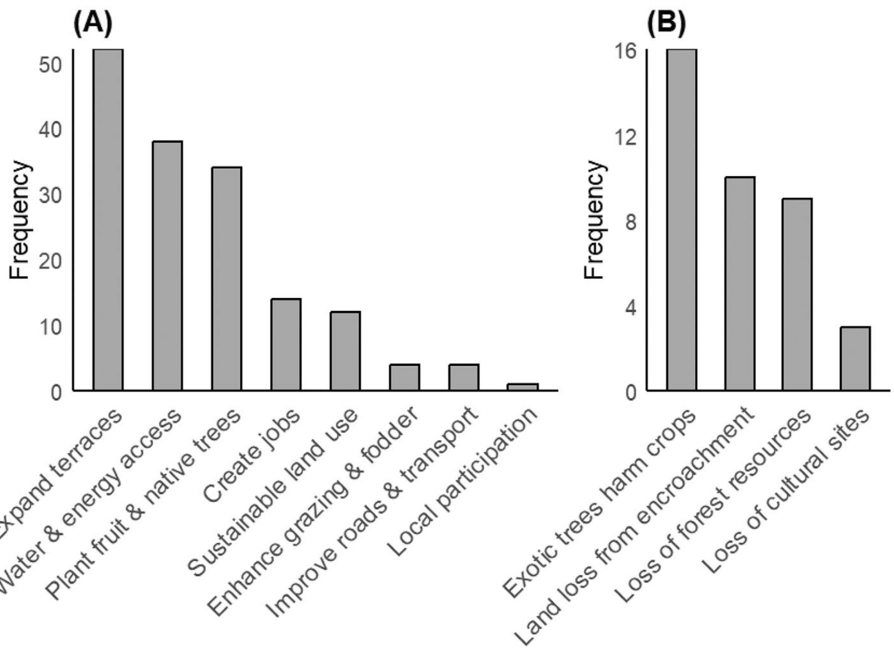

Figure 4. Preferences of landscape values from restoration for future planning (A) and perceived conflicts around restoration practices (B).

The spatial distribution of mapped values revealed clear patterns influenced by land use and accessibility. In Rutsiro, regulating values and crop production value (e.g., favorable microclimate for crops) were clustered around native forests, supporting findings on the role of forests in improving soil fertility, preventing erosion, and increasing agricultural productivity (Miller et al. 2021). In contrast, people in Nyabihu primarily mapped regulating values and crop production on terraced farmlands, highlighting the different reliance on landscapes across districts. These differences demonstrate how landscape values are shaped by the proximity of critical resources to local communities, with proximity to basic needs often influencing mapping patterns (Plieninger et al. 2023). This trend is consistent with other participatory mapping studies (Fagerholm et al. 2012; Brown & Fagerholm 2015).

However, accessibility remained a challenge. In several sites, landscape values were often mapped far from wetlands, forest areas, and main roads, highlighting spatial inequalities in the distribution of benefits. Similar results have been observed in restoration projects in Tanzania and Ghana, where access to key features influenced who benefits from diverse restored landscapes (Brown et al. 2020). Brown et al. (2020) found that forest-related values are often mapped near national parks, highlighting the importance of protected areas in providing vital benefits such as water supply. People living near forests tend to be more aware of these benefits (Plieninger et al. 2023), further highlighting potential inequalities in access. Although distance from main roads was included as an accessibility indicator, its influence on the distribution of mapped values is limited. This contrasts with many studies from the Global North, where road proximity is a strong predictor of mapped landscape values due to greater car dependency and formal infrastructure (Brown & Raymond 2007; Henningsson et al. 2015; Fagerholm et al. 2016; Brown et al. 2020). In our context, limited road infrastructure and reliance on informal mobility, such as the use of walking paths, likely explain why mapped values were often far from main roads (Fagerholm et al. 2012, 2019; Morales et al. 2019). Future interventions should consider accessibility to relevant local key features and equity in planning to ensure that restoration sites are ecologically optimal and socioculturally inclusive. These findings highlight the need to address disparities in access to landscape resources and ensure equitable distribution of restoration benefits.

Socio-demographic characteristics, such as land ownership, age, and gender, significantly influenced perceptions of landscape value and restoration preferences. For example, landless respondents prioritized crop production, grazing, and fodder for income, while wealthier landowners emphasized water supply and nutrition values. These findings are consistent with research highlighting how resources and land access influence preferences for nature-based benefits (Cuni-Sanchez et al. 2016). These patterns may reflect daily needs, with landless people often depending more directly on common or marginal resources for subsistence and income, such as working for wealthier landowners' farms for income. In contrast, landowners benefit from greater control over productive landscapes and infrastructure. These differences may indicate a scarcity hypothesis, in which people assign higher value to resources they lack (Martín-López et al. 2012; Milcu et al. 2013), or they may be related to spatial inequalities in access to restoration benefits (Iniesta-Arandia et al. 2014).

Similarly, older and male respondents more frequently mapped sense of place values, reflecting strong cultural ties to ancestral land and inheritance, a pattern commonly observed in agricultural and pastoral societies (Hay 2009; Raymond et al. 2009; Plieninger et al. 2023). Such values often stem from long-term, intergenerational relationships with land where landscapes serve as economic and symbolic assets. This pattern is partly rooted in patrilineal land tenure traditions, where men typically inherit land and remain in their place of origin, while women move to their husband's village after marriage. As one woman noted, "I am not from this area and I come from very far; I don't have any deep attachment to this land." Such mobility, shaped by cultural norms, can weaken women's emotional and symbolic connection to land, even in the context of progressive land laws that formally guarantee equal inheritance rights (Djurfeldt 2020). These socio-cultural dynamics help explain gendered attachments to land and differing perceptions of restoration. Although Rwanda's legal reforms have promoted gender equity, customary practices and patrilineal traditions may still limit women's influence over land-related decisions and their sense of belonging. To be more inclusive and equitable, restoration planning must move beyond legal frameworks and actively engage with the cultural and historical context that shapes people's relationships with the landscape. While PPGIS captures value differences between social groups (Sieber 2006), it is crucial to ensure that young people and women are considered. These groups play an important role in resource management and community resilience (Basnett et al. 2017; Lauman et al. 2023), and their input is essential to achieving more inclusive restoration outcomes. By integrating local socio-economic factors, cultural ties, and lived experiences, PPGIS can guide policymakers in addressing local inequalities in restoration. Restoration efforts can improve human well-being by increasing access to food, water, and income-generating resources. Our results show that terraced farmland contributes to well-being through regulating values, crop production, and nutrition, while forests are primarily associated with water supply. This supports previous research on ecosystem services' multiple roles in human well-being (Chan et al. 2012). Interestingly, respondents near national parks often associated forests with water security, reinforcing the role of protected areas in maintaining benefits from nature (Brown et al. 2020). However, since these benefits were primarily recognized by those living near forests, there is an accessibility gap highlighting the need for equitable restoration practices to ensure that benefits are fairly distributed.

In addition to providing material benefits, restoration also contributes to subjective well-being by fostering cultural and place-based connections. Many respondents mapped their sense of place around specific landscape features, highlighting their importance to social cohesion and cultural identity, a finding consistent with other participatory mapping studies (Brown & Fagerholm 2015) and other studies on the restoration of forests (Constant & Taylor 2020). However, not all perceptions of restoration were positive. Many respondents expressed concerns about reforestation with non-native species, fearing that it would reduce access to key resources, reduce crop productivity, and disrupt traditional uses. These concerns highlight the importance of integrating both ecological and landscape values into restoration strategies (Fagerholm et al. 2019).

Respondents also expressed concerns about trade-offs in restoration, particularly regarding the growth of exotic trees, which were perceived as a threat to crop yields and soil fertility. This aligns with findings from other studies showing the unintended negative impacts of exotic tree species on local livelihoods (Shackleton et al. 2019; Desta et al. 2023). Conflicts over the perceived negative impacts of restoration practices highlight the need for context-specific and participatory approaches (Castillo et al. 2021). To address these trade-offs, stakeholders must be involved in restoration planning to balance ecological goals with livelihoods and cultural values (Fox & Cundill 2018; Burnett et al. 2019).

The success of global restoration efforts, such as those under the Bonn Challenge and the UN Decade on Ecosystem Restoration, hinges on context-sensitive and socially inclusive strategies. This study from Rwanda demonstrates how participatory approaches, such as public participatory geographic information systems (PPGIS), can help identify diverse landscape values and support restoration planning that aligns with ecological priorities and community needs. The findings show that various restoration practices, such as terracing, woodlots, and natural regeneration, are linked to specific landscape values, highlighting the potential of mixed approaches to enhance landscape multifunctionality. Agroforestry, although a nationally recognized restoration practice in Rwanda, was infrequently reported by participants in our study sites, likely because it is mostly integrated within terraces and not perceived as a distinct practice. This suggests that while agroforestry plays an important role at the national level, its local recognition may be context-dependent, particularly in landscapes dominated by terracing. While provisioning and regulating services are frequently emphasized, cultural values, such as spiritual connections and sense of place, also play meaningful roles and should be better integrated into restoration planning. These values vary across landscapes, reinforcing the need for spatially differentiated and culturally grounded interventions. The Rwandan case offers insights that can be applied in other regions seeking to incorporate human dimensions into restoration efforts. Embracing inclusive, multifunctional, and participatory strategies can strengthen the legitimacy and resilience of restoration initiatives worldwide.

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Supporting Information

The following information may be found in the online version of this article:

Table S1. Socio-demographic characteristics of respondents.
Table S2. Frequency of points mapped, spatial clustering, and mean distances.
Table S3. Relationship between locations mapped and socio-demographic characteristics.

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