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RESEARCH ARTICLE

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Spatial variation in current and historical management of Arabica coffee across forests in its indigenous distribution

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Societal Impact Statement

Arabica coffee grows in the forests and woodlands of Ethiopia. These Arabica coffee populations contain a reservoir of the highest genetic variation of this species, which is extremely valuable from a biodiversity conservation and coffee breeding point of view. Knowledge about the distribution of these populations, including how and to what extent they have been managed by local communities now and in the past, is limited. We reveal insights into the history, distribution, and management of Arabica coffee populations in the remaining forests of Ethiopia, which is essential for developing effective conservation policies for this globally important resource.

Summary

- To guide conservation of forest biodiversity in a broad sense, we need to understand the landscape-level variation in current and historical management practices of agroforestry systems.
- We collected data on coffee management practices across a large forested landscape in Ethiopia within Arabica coffee's indigenous distribution, using interviews in 11 villages and field surveys and interviews at 78 coffee sites in the forest.
- There was a gradient in coffee density (higher), liana cover (lower), and canopy cover (lower) from sites with high management intensity to sites without management. Recently, management intensity has increased in the forest edges. Interviews suggest that substantial areas of currently unmanaged coffee forests are a legacy of reforestation of abandoned (semi-) open landscapes in the late 19th century.
- Despite a dynamic history of coffee cultivation across these areas, the conservation of forest biodiversity, including unmanaged populations of genetically diverse Arabica coffee, should be a priority, given the few such remaining areas in Ethiopia and elsewhere in the world.

KEYWORDS
agroforestry, forest coffee, historical coffee management, seasonal management, Southwest Ethiopia

1 | INTRODUCTION

Most forests of the world are used in one way or another by humans, even if from satellite images they look pristine. In many landscapes, there is a clear distinction between forests and agriculture. But in other landscapes the distinction between agriculture and forests is less clear, for example, when agroforestry systems are common and crops such as coffee and cocoa are grown under shade trees (Torquebiau, 2000). It is important to acknowledge that often there are gradients in management within the agroforestry system itself. To understand such spatial variation in management intensity of agroforestry systems, on-site data are required because remote sensing has limitations (Daniel et al., 2018; Delgado-Aguilar et al., 2019). Besides, the long-term history of when agroforestry practices were introduced needs on-site data, for example, through interviews with elderly persons. Few studies have examined how management practices vary spatially across landscapes, as well as when agroforestry systems were established and how management intensity has varied over time. Such knowledge of land-use history is important in order to understand the current structure of, and spatial variation in, (agro) forests and to establish baseline conditions and develop sustainable management practices of natural resources, including biodiversity across tree-covered landscapes. In cases where the crop is native to the understories of the forests, such data is also valuable for developing policies related to the in-situ forest crop genetic conservation (Heywood & Dulloo, 2005; Meilleur & Hodgkin, 2004).

The management intensity of agroforestry systems may vary spatially, for example, with distance from farmers' houses, distance from roads, and distance from open agricultural edges, even if there are few studies on this. One example from the Indonesian coffee agroforestry system found that areas were more managed closer to houses (Hartatri & Neilson, 2021). When it comes to changes over time, the majority of studies describe management intensification, for example, from a shaded or coffee forest system to an unshaded coffee production system (see Perfecto et al., 2019 for such an example from Mexico). For cocoa farms, it is common that the shade tree density decreases over time, reducing the value for biodiversity conservation (Tscharntke et al., 2011). The history of the establishment of an agroforestry system in a place typically either involves under-canopy clearing in forests (Numbisi et al., 2021) or a conversion from open agricultural systems to an agroforestry system in which also the initial shade trees are planted (Somarriba & Turrialba, 2018).

The landscapes of south-western Ethiopia are composed of a mosaic of forests, agroforests, and open fields used for annual crops and grazing. One fascinating aspect with these forests is that Arabica coffee is believed to have its evolutionary origin in Ethiopia, and the populations of coffee in the center of the Afromontane remnant forests of south-western Ethiopia are often denoted wild coffee (Meyer, 1965; Sylvain, 1958). The management intensity in Ethiopia varies from wild coffee and managed forest coffee to semi-forest coffee, homegarden coffee, and plantation coffee (Denu et al., 2016; Schmitt et al., 2009; Teketay, 1999). Many forests in south-western Ethiopia look like dense, undisturbed forests from satellite images, but they are actually managed in many parts for coffee in the understory (e.g., Beche et al., 2022). Management activities include harvesting, slashing, undercanopy clearing, shade tree management, weeding, and pruning (Hundera et al., 2013; Zewdie et al., 2020). The presence of management is more likely towards agricultural edges than in interior forest sites (Beche et al., 2022). However, there is very limited evidence about the spatial distribution of different management systems, including both which activity is done and in which period(s) of the year (e.g., a more frequent activity is also a sign of intensification) in these forests because most studies on agroforestry systems have been conducted in accessible areas close to people's homes or in forest edges (Shimales, 2019; Shumi et al., 2019; Zewdie et al., 2020). Little is also known about how coffee management has changed over time in these forests during the last 50 years. Even less is understood regarding the history of coffee management in these landscapes a century and more ago. However, the historian James C. McCann has given a quite detailed account of the history of coffee agroforestry in part of the Gera district in south-western Ethiopia (which also is our focal landscape) based on written sources from 1859, 1880, and 1928, accompanied by interviews of elderly persons in the early 1990s (McCann, 1995). From this material, it is clear that some areas that are now covered with forests and coffee agroforests were open agricultural landscapes in the second half of the 19th century. Yet, coffee occurred in forests in the southwest of the district also during this time.

Our aim was to expand the spatial and temporal coverage and resolution in terms of our understanding of coffee management across forest landscapes in SW Ethiopia. Using a large data set consisting of a combination of inventories of forest plots and interviews with coffee managers and elderly people in the Gera district, we asked the following two main research questions:

1. Current state: How are sites with coffee in the understorey currently managed and distributed?

Using an approach of cluster analysis that divides the inventoried sites into three management clusters, we explored the following sub-questions:

a. What is characterizing the different clusters in terms of management, forest structure, and seasonal variation in management activities (as one aspect of intensification)?
b. How are different management clusters distributed spatially across the forest landscape?

2. Historic state: How has coffee been managed historically?

Based on information from interviews and site-level vegetation data, we qualitatively answered the following sub-questions:

a. For how long has coffee been known and managed in different parts of the focal landscape, and what is the history of its introduction?

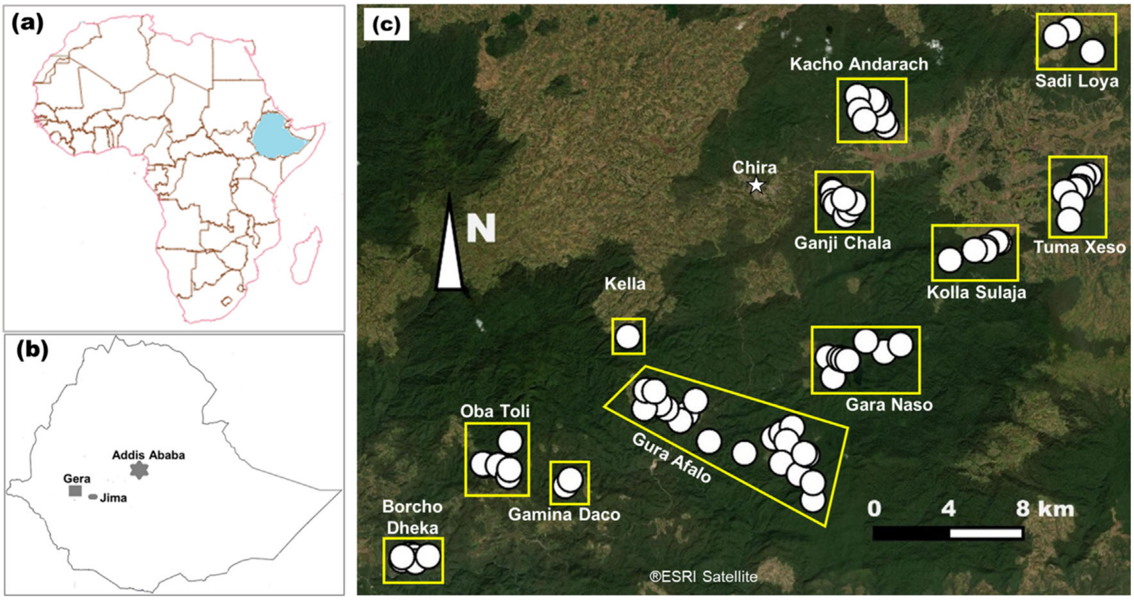

FIGURE 1 Map of the study area including its location in Africa (a) and Ethiopia (b) including the 11 main sites (kebeles) represented by yellow bordered polygons surrounding the white circle sub-sites in each main site (c).

b. How common is it that sites that were managed up to recently are now abandoned? And how do such sites look like?
c. What are the major changes in coffee management over the last few decades?

By answering these questions, we provide deeper and more nuanced background knowledge in terms of both spatial and temporal coverage regarding coffee management in a large forested landscape in Ethiopia. This increased understanding provides a new foundation for the development of policies for broader forest biodiversity conservation, in situ coffee genetic conservation, as well as sustainable coffee production.

2 | MATERIALS AND METHODS

2.1 | Study area

The study was conducted in the Gera district (7°41′–7°48′ N, 36°16′–36°25′ E) in south-western Ethiopia (Figure 1). About 60% of the district is forest land (Ango et al., 2020), mainly classified under the moist evergreen Afromontane forest type (Friis et al., 2010), and its altitude ranges from 1400 to 3000 m above sea level. The rest is open agricultural land, including fields with annual crops such as teff and maize, as well as dry or wet grasslands used for grazing. In areas outside the continuous forests, the population density is high, and people have homegardens with vegetables, fruit trees, and scattered woodlands with coffee in the understory (Lemessa et al., 2013). Coffee grown in this area is produced in different ways with less intensive management in forests, denoted forest coffee systems or semi-forest coffee systems in case of more intensive management. Outside the forests, it is cultivated with higher intensity in a few commercial coffee plantations (still with shade trees), in smaller patches of semi-forest coffee types, and in homegardens (Aerts et al., 2011; Hundera et al., 2013; Zewdie et al., 2021). Coffee management activities such as harvesting, row planting, shade management, and liana removal are commonly applied in various degrees in order to increase coffee yield and production (Aerts et al., 2011; Teferi, 2017). Coffee is an important source of income for people; besides that, it is a culturally valued crop (Sylvain, 1958; Teketay, 1999). Small-holder farmers are the dominant coffee producers in this landscape and produce coffee both for their own consumption and for the market. It is common to sell the best quality coffee to middlemen who further trade it for the international market (Stellmacher & Grote, 2011). Sometimes coffee farmers go together in cooperatives. Land tenure of the continuous forests, and hence the coffee in these areas, is less clear than close to people's settlements. Even if the land officially belongs to the government, there are traditional ways of dividing the rights to use forest resources, including coffee (Stellmacher & Gatzweiler, 2005).

The district is also historically known for its coffee production (McCann, 1995), as mentioned in the introduction. Already in the 19th century, coffee was popular, not least by the royalties. It was grown in homegardens in areas now covered by forests without any settlements (McCann, 1995). The reason that the forest cover regenerated quickly was abandonment due to depopulation after the Ethiopian emperor Menelik II conquered this area in 1881–1887 (McCann, 1995). In the first half of the 20th century, due to the increase in demand for coffee from world trade, the coffee harvest expanded by collection from the forests and also from establishing coffee plantations.

2.2 | Study design and data collection

To examine the dynamics of spatial and temporal coffee management activities across the forest landscapes, we selected 11 main forest areas (hereafter: "main sites") representing different *kebeles* (local administrative units) distributed across the coffee-growing altitudinal range. We used a mixed-methods design that combined key informant interviews, guided field walks, and field surveys to collect quantitative and qualitative data. At each main site, first and foremost, we interviewed two key informants (a total of 32 male farmers, including additional knowledgeable elders who reside even above coffee-growing altitude with a mean age of 70 years, range 40–103) about the current and historical coffee management activities in the forest landscape. The selected informants were locally knowledgeable individuals such as elders and farmers with experiences in coffee management from the surrounding forest. In this area, it is normally the men who are responsible for the maintenance of the coffee agroforestry. Second, for the most sites, we selected two other informants in each of the 11 main sites who were knowledgeable about history and coffee management and were able to walk far into the forest (a total of 24 male informants with a mean age of 54 years, range 34–81) (Figure 1). During the field walks together with these informants, we stopped at several places (denoted sub-sites) and collected quantitative data on several environmental variables as well as conducted field interviews about coffee management and historical events. The walks were organized in the following way. From each main site, we preselected one or two sub-sites that we knew from a previous project where we had inventoried trees and disturbances in randomly distributed forest plots (20 × 20 m) (see Beche et al., 2022 for details). We visited these places again, this time together with the informants. Along the way across the forested landscape to these places, we stopped at other places representative of current and historical management, suggested by the first informants in the village or by the new informants joining the walks. In each of these new sub-sites, we collected quantitative data matching the previously collected data from the random forest plots from Beche et al. (2022). In an area of approximately the same size (~20 × 20 m), we measured the size and estimated age of the oldest coffee shrub (we asked the key informants to select the oldest coffee and estimate its age), recorded coffee density, tree density, circumference of five large trees (>60 cm DBH), estimated the liana cover, canopy cover, and assessed walkability. Walkability was defined in the following scale: (1) easy to walk thought, (2) intermediate, and (3) difficult to walk through (often because of dense thickets of lianas and vines). For more information on the different types of sub-sites and the collected environmental data, see Methods S1 and S2 and Tables S1 and S2. In each of the sub-sites, including the old plots, we asked questions about present and past coffee management activities. Both for the interviews with informants in the villages and during the field walks we used questionnaires (see Methods S1 and S2), but many questions were open-ended and we allowed follow-up questions to clarify and get additional information (semi-structured interview method, Kallio et al., 2016). Answers from the interviews were noted down in a notebook and for the interviews in the villages recorded for the possibility of later verification. The interviews were done in the language Afan Oromo or, in a few cases, Amharic, both of which the first author is fluent in. The first author translated the main results from the interviews to English. In total, we collected data from 78 sub-sites where coffee occurred (Figure 1). Data was collected from February 19 to March 31, 2021.

2.3 | Data analysis

2.3.1 | Characterization of current coffee management types

From the interview answers, different management activities could be identified, such as harvesting, pruning, and planting (see Table S1). To characterize different coffee management types (i.e., recurrent combinations of different activities), we (i) converted each of the coffee management activities per site to presence/absence, (ii) ran a principal component analysis (PCA) using presence/absence of coffee management activities per site (Table S1), and (iii) used a cluster analysis (see for details Figure S1) to illustrate and analyze the different coffee management practices in the dataset. All analyses were run using the statistical program R 4.1.3 (R Core Team, 2022). We compared the following characteristics between sites belonging to the different delineated clusters: tree circumference, estimated age of oldest coffee, circumference and height of oldest and thickest coffee shrubs, the density of coffee shrubs above 1.5 m height, coffee seedling density, tree density, canopy cover, liana cover, and walkability (see Table S2). Seasonal variation in management activities is also part of the characteristics of coffee management. To describe differences between clusters, we qualitatively summarized which activities were done at different times of the year for the different clusters.

The spatial distribution of the different coffee management types was examined by linear models comparing the clusters in terms of distance to forest edge, distance to road, and elevation using the functions "lm" and "anova," and Tukey's test for comparison of means using the function "TukeyHSD" (Tukey's honest significant difference).

2.3.2 | Historical changes in coffee management

For each main site, we sifted through the answers from key informants in the villages as well as from the guided field walks and then identified and summarized the emerging patterns (Bryman, 2012) of how coffee first entered different parts of the forest landscape, to what extent it has been managed historically, which areas that have been particularly important historically, and other aspects of changes in land use that are relevant to understand the history of coffee management in this landscape. The notes on the historical times were converted from the Ethiopian calendar to the Gregorian calendar. We looked for accounts as far back as possible, even into the 19th century, bearing in mind that such accounts should be interpreted with much caution.

TABLE 1 Description and characterization of the three clusters representing different coffee management types based on 76 coffee sites collected during guided field walk[a] (see also Table S2).

Variables	Categories/levels	Cluster 1	Cluster 2	Cluster 3
Number of sites in each cluster	Number[a]	36	20	20
Average number of management activities per site	Average	5.3	2.5	0.05
Maximum and minimum number of management activities per site	Range	3–9	2–4	0–1
Number of sites in which different coffee management activities were practiced (only show for the most frequent practices).	Slashing	36	20	0
	Harvesting	36	20	0
	Under canopy clearing	31	0	0
	Shade tree management	18	3	0
	Enriching	15	1	0
	Planting coffee	13	0	1
	Removal of lianas	2	2	0

[a]Coffee occurred in 78 sites, but we excluded the two sites in this particular analysis where coffee previously was managed but where the management has been recently abandoned.

To describe the dynamics of coffee management over the recent past, defined as (∼5–50 years ago), we categorized all visited sites into the following four categories: (1) currently not managed nor in the recent past, (2) currently not managed but managed in the recent past, (3) currently managed but not in the recent past, and (4) currently managed and also in the recent past.

Lastly, to assess how coffee management has changed over approximately the last 50 years, we summarized interviews on how different coffee management activities have changed (i.e., modified, intensified, or reduced) over time.

3 | RESULTS

3.1 | Characterization of current coffee management types

We identified three main coffee management clusters using cluster analysis of the sites along one major axis of variation (shown by an initial PCA, Figure S1). The first cluster included 36 sites that were intensively managed, with a mean number of management activities of 5.3 per site that were applied at least once a year (Table 1). These sites typically have an active management of the shade trees, removal of competing small trees and shrubs, and enriching with coffee seedlings (i.e., planting extra seedlings in-between established coffee), slashing of weeds, and harvesting. The second cluster included 20 sites with mainly weeding and harvesting as management activities, with a mean number of management activities of 2.5 per site (Table 1). Finally, the third cluster contains 20 sites with basically no current management activity (not even harvesting) (Table 1).

The thickness of the oldest and largest coffee shrubs, respectively, seem to be slightly larger in sites with the highest management (Cluster 1) even if there is much variation ($F > 7.5$, $p < .001$, Figure 2a,c). Coffee density was highest in the most managed sites (Cluster 1), intermediate in Cluster 2, and lowest in Cluster 3 (chi-squared = 29.3, $p < .001$, Figure 2d). The cluster with basically no management (Cluster 3) was further characterized by high canopy cover (chi-squared = 11.6, $p = .020$, Figure 2f) and high liana cover (chi-squared = 31.1, $p < .001$, Figure 2g). These sites were also, in general, more difficult to walk through (chi-squared = 35.1, $p < .001$, Figure 2h). For differences in more structural and environmental variables among the clusters, see Table S3.

Farmers visited the highly managed coffee sites (Cluster 1) 2–5 times per year for different management activities (Figure 3a). Coffee is harvested from October to January. Often the sites are visited several times to collect the berries when they sequentially become red and ripe, but finally they also pick dropped berries from the ground (Table S4). Slashing of weeds is often done any time of the year. However, slashing is especially frequent just before the main harvesting season in September and October to ease the walking during harvesting and just after harvesting is completed (e.g., especially for farmers who temporarily settle in the forest) (Figure 3a). Digging around individual coffee shrubs or the whole farm is done during most of the time of the year, but mainly in the dry season (September–May), enriching of coffee seedlings and planting of new sites with coffee is done in the rainy season (May–August, Figure 3a). Follow-up or visits to the coffee forest to inspect the flower and fruit setting and weed conditions or to protect the coffee from wildlife (e.g., baboons that eat coffee berries and break coffee branches) are done any time of the year. In the sites with little coffee management intensity (Cluster 2), the sites are visited only 1–2 times a year and then only for harvesting and slashing (Figure 3b). If a site is visited a second time, it is often during the dry season (February–April) and then only for slashing (Figure 3b).

Sites of Cluster 1 are generally found closer to forest edges and roads than sites from Cluster 2, and sites from Cluster 3 are even

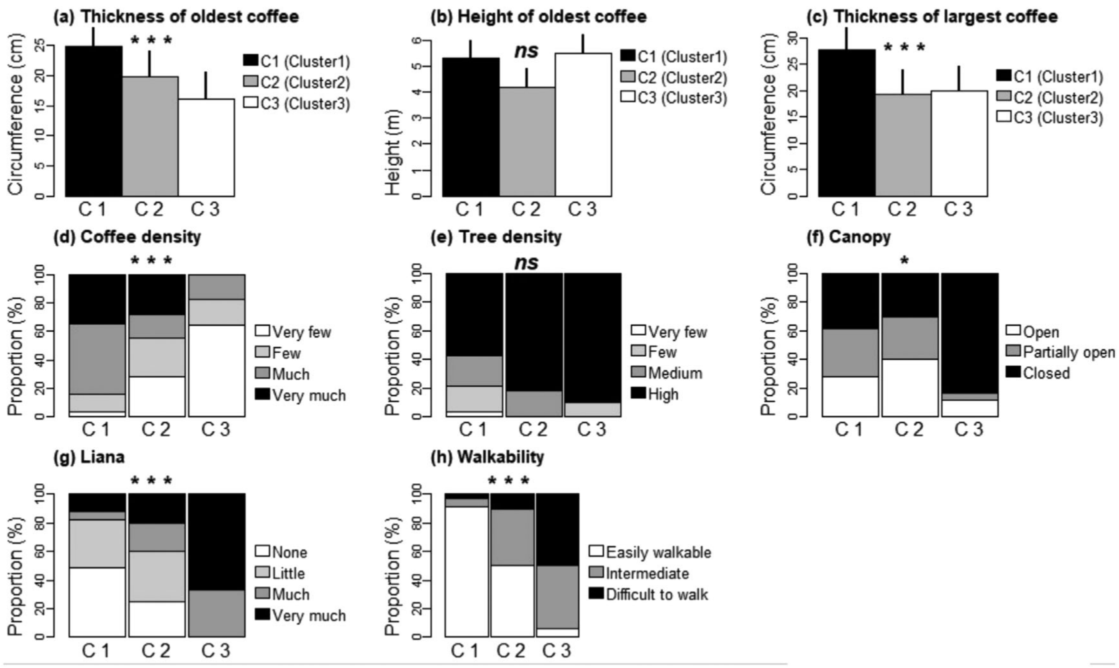

FIGURE 2 Coffee management clusters and their characteristics. Coffee clusters represent different management intensities that vary from intensively managed (C1), little managed (C2), to unmanaged (C3). Shown are (a) circumference and (b) height of the oldest coffee shrub, (c) thickness of the largest coffee shrub, (d) coffee density, (e) tree density, (f) canopy cover, (g) liana cover, and (h) walkability. The error bars in panels (a–c) are standard errors, and significance is indicated by asterisks (ns = not significant, * = $p < .05$, ** = $p < .01$, and *** = $p < .001$) based on analysis of variance (a–c) and chi-square tests (d–h).

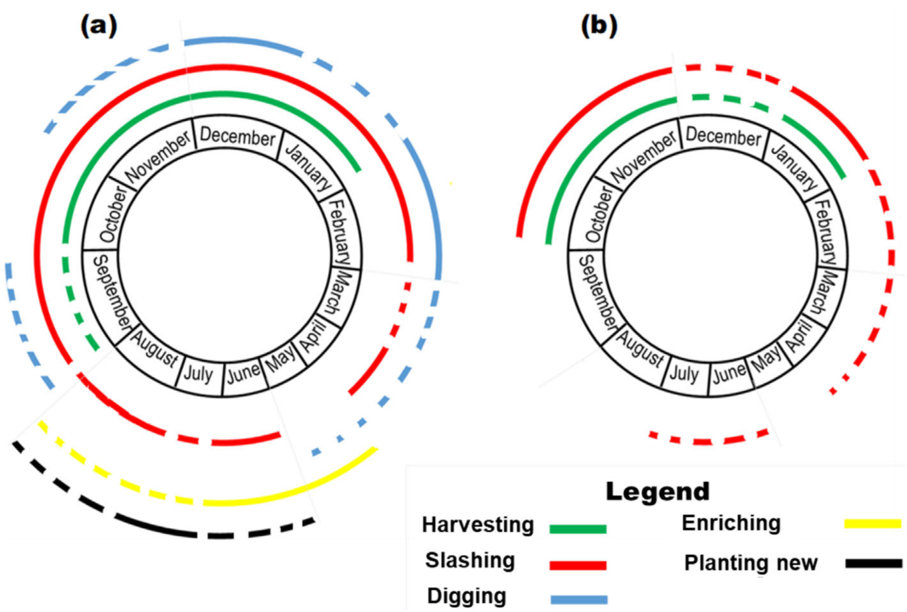

FIGURE 3 Main coffee management activities and the time (season) of the year when they are practiced for (a) Cluster 1 (i.e., the intensively managed sites) and (b) Cluster 2 (i.e., little managed sites). The management activities reported from many sites (i.e., three or more sites) at the specified time was represented by solid lines while broken lines were used to show management from fewer sites (i.e., ≤2 sites). Note that the harvesting indicates collection of coffee beans from the shrubs, as well as picking of dry beans from the ground or leftovers after the main harvesting season. As there is no management (even no harvesting) (except one site with coffee planting) in the Cluster 3 sites, we did not show a seasonal diagram for those sites.

found further into the forests (Figure 4a,b, Table S5). However, there is a lot of variation, and sometimes also heavily managed sites are found far from edges or roads, as seen on the map (Figure 4d). There were no distinct patterns observed in how the different clusters were distributed in relation to elevation, except Cluster 2 was found at somewhat lower elevation (Figure 4c).

3.2 | Historical changes in coffee management

One informant told us that coffee production was known even as far back as 300 years ago (Gura Afalo, Table S6). However, most informants referred back to stories about coffee management in many parts of the area during the 19th century (Table S6, Figure 5). Often it

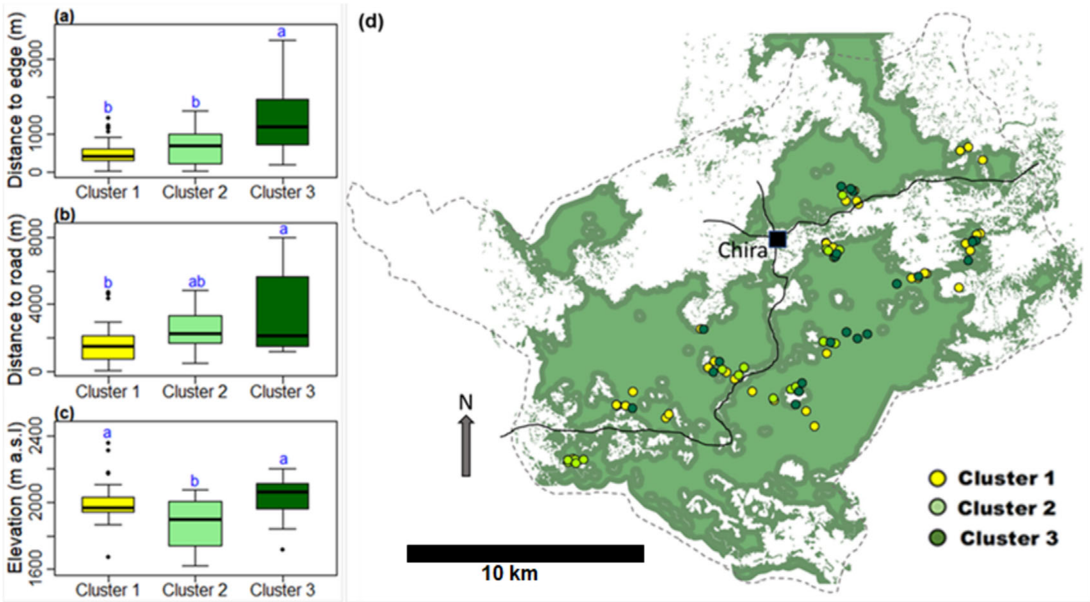

FIGURE 4 Spatial distribution of coffee management types (Cluster 1: intensively managed, Cluster 2: little managed, and Cluster 3: unmanaged) across a forested landscape in SW Ethiopia shown for (a) distance to edge, (b) distance to road, and (c) elevation (see also Table S5 for statistical tests). The horizontal bar in the boxplot represents the median, the lower and upper parts of the box represent the first and the third quartiles, respectively, the whisker lines represent the lower and upper limits of the data, and the black dots represent outliers. Different lower case letters above the boxplots denote significant differences, p < .05, based on Tukey multiple comparisons of means (a–c). (d). Map indicating the distribution of clusters (management types) across the landscape. The green, grey, and white areas represent forest, a buffer of 500 m from the edge (i.e., geographical point where an open field ends and the forest begins) of the forest and into the forest, and agricultural lands (including villages), respectively. The border of Gera district is indicated by a dashed line.

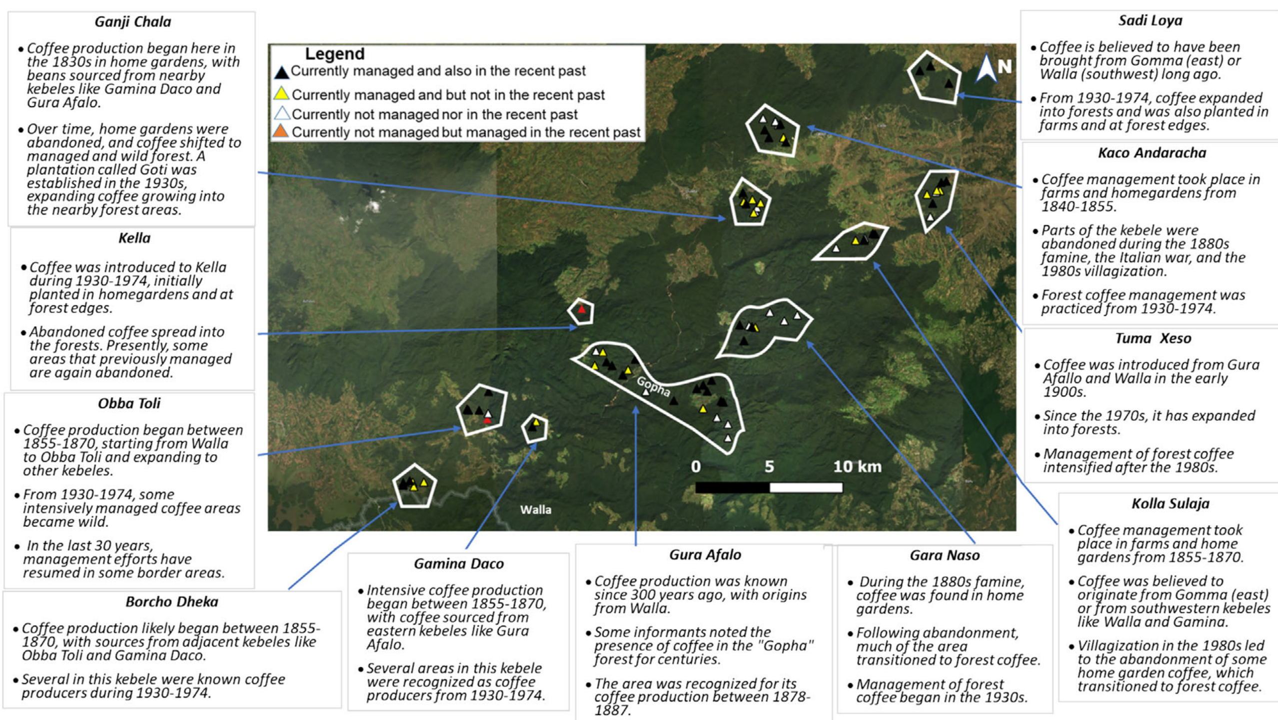

FIGURE 5 Visited coffee sites with an indication of current (0–5 years) and recent past (5–50 years) management. The visited sub-sites in each main site (kebele) are surrounded with a white border. A short summary of the historical occurrence (including accounts centuries back) and management of coffee in the 11 main sites are given in the text boxes surrounding the map (see Table S6 for more details).

was mentioned that coffee was managed in farms (still with shade trees and sometimes almost forest-like) owned by rich persons, including local governors or royal families such as the king or queen of the Gera kingdom. Such farms were present before 1870 in kebeles such as Obba Toli, Borcho Dheka, Gura Afalo, and Gamina Daco (Table S6, Figure 5). Coffee was also reported to have been present in homegardens of richer people and the royal family as early as in the 1840s in many kebeles, for example, Ganji Chala, Gura Afalo, and Kaco Andaracha (Table S6, Figure 5). Currently, coffee is managed by thousands of smallholder farmers across the landscape. However, our informants told us that during the 19th century, coffee was mainly grown by the royal family and rich people with permits from the rulers. Also, drinking coffee was prohibited for ordinary people in some areas. Even if coffee seems to have been known and managed at least since mid-19th century in many parts of the landscape, there were reports in some kebeles that coffee cultivation and even the presence of coffee in the forest were not known before 1940, for example, in Tuma Xeso (Table S6, Figure 5). There was sometimes contradictory information about when coffee started to be managed, if it was present or not in the forest long ago, and from where it was introduced to farms or homegardens.

In many kebeles, the informants told us that people who started cultivating coffee got the coffee from another place. Putting things together, it seems as a common source of coffee for starting cultivation were areas in the central and south-western part of the forest landscape, such as from Gura Afalo or Walla (Figure 5). Often it is unclear if the coffee was taken from wild sources in the forest or from already established farms. In the north-eastern part of the study landscape, the introduction of coffee management seems to have a different source from the other coffee-growing kebeles. Here we were told that it was introduced from an eastern neighboring district named Gomma (see, e.g., Sadi Loya, Figure 5). However, other informants in these kebeles claimed that both the coffee in Gomma and in the north-eastern kebeles in Gera came from Walla and Gura Afalo kebeles in the southwest (Figure 5, Table S6).

In several areas, coffee has continued to be managed over at least the last 150 years (e.g., old plantation coffee at Dacha and Gopha in Gura Afalo kebeles, Table S6). However, in most places, it seems like the intensity of cultivation has varied over time. For example, informants told that coffee farms, homegardens, as well as the open fields were abandoned because of the outmigration of people during the 1880s because of war and famine, for example, in Ganji Chala, Gura Afalo, Obba Toli, and Gara Naso (Table S6, Figure 5). According to them, the abandoned open landscapes were then overgrown by forests, and the coffee remained or spread into new secondary forests, which is the reason for the current dense cover of coffee in many forests. Later, during Haile Sellasie's time (1930–1974), new coffee farms were established in Sadi Loya, Gura Afalo, Gara Naso, and Kaco Andaracha, where forests with or without coffee were converted to more intensively managed farms (Figure 5, Table S6). Other political events that caused changes in land ownership and management were the fall of Haile Selassie and the rise of the Derg regime (e.g., Kolla Sulaja), which opened up the land for smallholder farmers, as well as the villagization program during the Derg that sometimes moved smallholders away from coffee resources in the forests (e.g., Kolla Sulaja) (Table S6).

Of the 78 sub-sites visited by us, only two sites of the managed forest coffee were now abandoned (Figure 5, Figure S2). It is difficult to make any generalizations about the characteristics of the abandoned sites because there are only two. However, both had low coffee density, and they lacked coffee seedlings. The canopy cover was low, and the sites were overgrown by lianas and vines. However, 48.8% of all sites with coffee had continuous management from before (at least 5 years) into the current situation (Figure S2). When plotted on a map, it is clear that coffee management in the recent past has been widespread (Figure 5). It seems like there is a current intensification of coffee management because as much as 20% of all coffee sites were classified as having a recent history of intensification of management within the last 5 years (probably moving from Cluster 2 to 1 according to our terminology above) (Figure S2).

Common management activities in the more closely managed sites have changed over time (say, the last 50 years), even if large parts of the forest landscape are still very little managed. For example, the traditional planting of coffee seedlings in these forests was to directly plant them into a hole made by a stick in a random pattern, while farmers now often plant with regular spacing using seedlings that have been raised on seed beds in plastic bags filled with enriched soil (Tables 2 and S7). Coffee harvesting is also modified towards the production of high-quality coffee from only ripe berries instead of the previously common harvesting of a mixture of dry black, ripe red, and unripe green berries. The drying is changed from drying on the ground to drying on coffee drying beds in the most managed sites (Table 2). Weeding herbs by machete is in very rare cases replaced by the use of herbicides (Table 2). Often there has just been a slight increase in management intensity over time rather than an abrupt change in practice. For example, slashing is done more often in many places nowadays. In the past, farmers were provided with machetes (e.g., during the Derg government period in the 1980s) and encouraged to intensify coffee management (Table 2). According to Proclamation no. 542/2007, most coffee management practices are formally prohibited in protected states and communal forests, except harvesting (FDRE, 2007). Even if farmers have been practicing the management for many years, more recently (c. the last 5 years), the prohibition of management seems to be more strongly implemented by Oromia forest and wildlife enterprise (Tables 2 and S7).

4 | DISCUSSION

We show that the large forested study area in south-western Ethiopia, known for being part of coffee's indigenous distribution with remnants of wild coffee, in fact is heavily utilized for harvesting coffee from the understory deep into the forests. Currently, there is a strong gradient in management intensity spanning from intensive

TABLE 2 Commonly reported changes in coffee management activities during the last decades (∼50 years).

Management activity type	Historical management (during the last 50 years) and some notes when it was changed	Current management in the most highly managed sites of the studied forest coffee
Planting of coffee when establishing a new site and enriching the existing coffee forest	Coffee was planted randomly, with holes prepared using a stick ("horda") and spaced 0.6 m apart. Most areas have practiced row planting since 2017, though some have done so since 1949 under Haile Selassie. After 1988, the Derg government introduced planting through well-prepared holes, raising seedlings on seed beds, and using plastic poles for hole creation. Most farmers collected local coffee variety seedlings from the forest for new farms or to enrich existing ones. In a few areas, improved coffee varieties were used as early as 1958.	Sometimes coffee is now planted in rows. Often the hole is large, with spacing either 0.5 m or 1.5 m. Seedlings are raised on regularly prepared seed beds and in plastic bags. It is common to use new or improved coffee varieties to establish a new site but also for enriching already existing sites.
Harvesting	Before, a mixture of ripe, unripe, and dry black beans was commonly collected and dried on the ground. "Duguga" (collecting ripe and unripe berries together) was abandoned 10 years ago in most areas in favor of red berry collection. Drying beans on beds has been practiced since 2008. The shift to red bean collection is linked to the establishment of the first coffee grinding mill in the district in 1948.	Collecting coffee beans by picking one by one separately for red and dry beans, then drying on beds
Slashing	Often minor slashing, in which very few shrubs and tree saplings were removed. However, slashing more than two times per year was commonly applied after the fall of the Derg regime (*c.* 1991).	Most frequently, regular slashing is practiced two to four times per year.
Under canopy clearing	Under canopy clearing is practiced mostly once per year, and it is assumed to be known since the beginning of coffee cultivation.	Under canopy clearing is mostly practiced 3–4 times per year.
Weeding	Removal of weeds such as herbs and seedlings by hand. Herbicide application was introduced by the Derg but rarely applied in a few coffee sites.	Removal of weeds, and in very rare cases, by herbicides
Digging	Digging (if applied) was done only around individual coffee shrubs once per year or once in 2 years. It is assumed to have been known since the beginning of coffee cultivation, but some farmers have begun practicing it since 1981.	Digging the whole coffee farm (especially for highly intensified coffee farms) 2–4 times per year
Permissions	Coffee management was not legally restricted during this time, unlike earlier. Instead, it was promoted by the government, such as the Derg regime, which provided tools like machetes for management.	Coffee management in some states and communal forests is legally restricted. In the last 3–5 years, there has been stricter enforcement of forest protection legislation (Proclamation No. 542/2007, FDRE, 2007), which prohibits all coffee management activities except for collecting forest coffee beans or harvesting in protected forests.

Note: Note that historically there might have been quite little management in some sites, and also at the present time coffee is very little managed in some areas (Figure 5). Thus, based on the key informant responses, the management activities described in the column under "current management" rather describe the context of management activities practiced in the most intensively managed coffee forest area (see also Table S7).

management, via very little management with mostly harvesting and weeding, to what seems to be totally unmanaged areas with even no harvesting, according to our respondents. Such sites can thus in some sense be denoted "wild coffee." The management gradient correlates to distance from forest edges and roads, but there are also quite heavily managed sites in more remote areas. The interviews suggest that only very few sites have been abandoned recently and that there is instead currently a trend of intensification going on in this landscape. Our respondents told us that coffee management started centuries ago in some areas and more recently in others. The management has been dynamic, and in many places, coffee has spread into secondary forests after abandonment of agriculture (homegardens, coffee plantations). Our study suggests that large areas of what now look like forests on satellite imagery could rather be classified as an agroforestry landscape. However, there is a smooth and not easy to delineate transition into little managed forests that also contain coffee. To what extent such "wild coffee" has its roots in coffee populations from the forest itself or from abandoned coffee farms and homegardens is difficult to know and probably varies from area to area. In any case, coffee is the key species of this fascinating social-ecological forest landscape (Fashing et al., 2022).

4.1 | Characteristics of current coffee management types

Current coffee management intensity across the forest landscape differed much along a gradient from no management to quite intensive management. We illustrated this by dividing this gradient into three clusters corresponding to no management, little management, and intensive management. Common management practices in the most intensively managed group of sites were removal of small trees and shrubs, slashing, weeding, planting, and enriching of coffee seedlings, which is similar to how farmers generally manage their coffee in the mosaic part of the landscape outside the larger forest areas (Teferi, 2017; Wariyo et al., 2022). Also in terms of the structure of these sites with little cover of lianas, easy to walk, and high density of coffee shrubs, they would likely cluster together with sites in the landscapes that in the Ethiopian literature are called semi-forest coffee systems (Aerts et al., 2011; Senbeta & Denich, 2006; Shimales, 2019; Zewdie et al., 2020). The improvement of coffee management over the last 50 years in the more intensively managed part of the landscape has been supported by both the government (e.g., distributing improved varieties during the Derg period) and by non-government organizations. Even if we, in this paper, call them heavily managed, it is thus important to realize that they are still less managed than what is often the case for agroforestry systems.

The sites with little management focusing on harvesting and slashing were also a common type of site. This type of forest coffee system with seasonal visits only for harvesting has been reported from other Ethiopian Afromontane forest landscapes (Schmitt & Grote, 2006; Senbeta & Denich, 2006). As expected, we found a lower coffee density, higher canopy cover, and more lianas than in the more managed parts of the gradient (Beche et al., 2022). However, less intuitive was the finding that the thickness of the largest coffee shrubs was lower in sites with little or no management. A similar finding was reported earlier in the same landscape (Zewdie et al., 2022). We do not know if this has to do with that coffee management activities in intensively managed sites might enhance coffee growth, for example, by reducing competition (Aerts et al., 2011; Senbeta & Denich, 2006) or if it rather reflects that the sites with the thinner coffee are more recently established coffee, even in remote forested areas (see below the discussion on the history of coffee in the forests of these landscapes).

In a previous study from the same forest landscape, we found that the presence of coffee management was more likely close to agricultural edges and roads than deep into the interior forest (Beche et al., 2022). We here confirm that, but also quantify what management activities are applied at different distances. Most studies on coffee management in Ethiopia are from the mosaic agricultural landscape setting and from intensively managed forest edges (e.g., Abafita, 2010; Shimales, 2019), except a few studies on coffee forests of Bonga, Yayu, Berhane-Kontir, Harrena, and Belete-Gera that confirm our observations of sometimes an abundance of coffee even far from edges (Gole, 2003; Hundera et al., 2013; Schmitt et al., 2009; Senbeta & Denich, 2006). From the interviews and field walks, we learned that the farmers visit intensively managed sites during different months of the year for different management activities such as harvesting, under-canopy clearing, and enrichment by planting of new seedlings. Making frequent visits to coffee sites is obviously easier in places that are accessible, and especially so if it is close to the place where you live. That coffee farmers whose coffee forests are far from their houses often apply less management than farmers with nearby farms has also been shown elsewhere. For example, farmers of Flores and Toraja areas in Indonesia reside far from their coffee farms, and as a result, they rarely practice coffee pruning, fertilizing, weeding, and controlling disease that is common among farmers in the Simalungun area, where farmers live closer to their farms (Hartatri & Neilson, 2021). It is not strange that harvesting is the management practice that penetrates deepest into the forest, and other authors have also reported that forest coffee in some other Ethiopian areas is harvested in seemingly undisturbed forests (Schmitt et al., 2009). It is difficult to know whether other management activities are also occasionally practiced in sites that are classified as little managed sites. Interestingly, slashing was the only other management practice that was frequently found in the little managed category of sites. Normally slashing of weeds is done before harvesting to ease walking and picking (even if it is regularly done in the most intensively managed sites year around), but in the little managed sites some reported slashing activities also outside the harvesting time when they visit for some other main activity such as honey collection.

Seasonal visits and camping in some coffee forest areas for management such as slashing, harvesting coffee, and honey are also sometimes practiced mainly by farmers from adjacent *kebeles* and districts who previously had lived closer but now had migrated to other areas but still retained their coffee (Ango et al., 2020, 2022; personal observation). The unexpectedly high management of coffee in some areas deeper into the forest might also be due to camping deep into the coffee forest or a result of differences among the individual farmers in their management decisions.

4.2 | Historical coffee management and its change over time

Our informants told us that coffee has been known and managed for at least one and a half centuries in many areas in Gera. This information agrees with other sources also pointing out the long history of coffee production in south-western Ethiopia. For example, coffee from farms in Gera was the main commodity from the "Gibe states" in the second half of the 19th century (Hassen, 1990; McCann, 1995; Zewde, 1991). Even before that, Ethiopia was a supplier of coffee to markets outside Ethiopia, but to what extent that coffee came from this region is less known (e.g., Morris, 2019). Within Gera, it seems like coffee has been known and managed for the longest period in the south-west, but this would need further investigations because there are some contradicting answers and suggestions that coffee came to some parts of Gera from east instead of from south-west. The spread of coffee and coffee cultivation across the forest landscape is probably linked to the governance structure at each time, and our results, also told by McCann (1995), indicate that the royal family directed the coffee management dynamics in the 19th century and a similar top-down governance appeared during the second expansion period in the 20th century under Emperor Haile Selassie.

Most global forests, including some agroforestry systems, may look like wild, untouched nature from a satellite image, but when historically and empirically investigated, they actually have been utilized by people for a long time (Chokkalingan & Jong, 2001; FAO, 2020). Thus, the forests that superficially look like pristine forest that has never been disturbed might turn out to be forest that has regrown on historically managed non-forest land after many decades of abandonment (Chokkalingan & Jong, 2001; Josefsson, 2009). In some of the seemingly "wild forest" areas like Gera, the historical data actually suggest that the multi-layered forests with understory coffee in many areas actually are a legacy of naturalized coffee that initially were introduced by people (see also McCann, 1995). Because of the fast ecological succession following abandonment in the 1880s, these forests give the impression that coffee has been there for centuries and is truly wild. This result corroborates McCann (1995), who has shown that areas of open agriculture in Gera, specifically in the Afalo area, were abandoned because of depopulation after famine and Emperor Menelik II's war of conquest during the 1880s and that these areas were quite fast reforested.

McCann (1995) also documented that to increase coffee export in the first half of the 20th century, coffee harvest expanded by collection from the forests as well as from established coffee plantations. The establishment of several coffee farms in different parts of this forest landscape, which latter expanded to adjacent districts including Gomma and Manna during Emperor Haile Selassie's era, stemmed from the significant revenue generated by exporting coffee from this region (Hassen, 1990). A second occasion of abandonment of coffee farms in favor of annual crops such as maize occurred in the 1980s due to coffee berry disease, low coffee price, land reform, and the villagization program, as also reported by McCann (1995). Thus, one of the main conclusions by McCann (1995) that forest cover and coffee cultivation in the area have been dynamic in space and time is corroborated by our study, which covered a larger area than McCann (1995). Besides, the current study added new insights to the history of coffee production in the region regarding the complex pattern of introduction and expansion of coffee to different parts of the Gera forest landscape in multiple directions and at different historical periods, which is coupled with evolving coffee management practices over time.

Given the fast secondary succession in tropical forests and the complex dynamic history of coffee management within the forest landscape, it is difficult to say which areas with coffee deep into the forests have always been unmanaged and thereby truly represent "wild coffee areas" and which areas have (part of) their roots in abandoned cultivated coffee that has naturally spread into these areas. Some of our informants claimed that some places in Walla, Obba Toli, and Gura Afalo had forest coffee for centuries. Similarly, McCann (1995) stated that there were limited areas along the borders between districts that had remained pristine forest and that likely most of Gera was covered by forest before the year 1800. The remnants of Afromontane forests in Ethiopia are widely recognized as the shelter of some of the last populations of wild coffee (Meyer, 1965; Senbeta et al., 2007). Even if our study suggests that it can be difficult to know the history of coffee that is found deep into current forested areas, several studies show that the forest coffee in Ethiopia displays the highest genetic diversity of Arabica coffee in the world, thus likely having at least some temporal connectivity to old wild populations (Alemayehu, 2017; Zewdie et al., 2022). Thus, in order to reduce the risk of reduction in genetic variation of Arabica coffee due to climate and land use changes (Davis et al., 2019), scholars have been urging for in situ genetic conservation of forest coffee (Iriondo et al., 2007; Krishnan, 2011). In our study landscape, the information from the informants suggests that perhaps the longest history of coffee management and persistence over time of wild coffee is in the southwestern part of this landscape. Genetic studies could be used to find hotspots of genetic variation using this information as a starting point.

Because coffee is an important export product for Ethiopia, even from the remote areas, the local prices have been affected by global market prices that have continued to fluctuate much (Koehler, 2017). This can lead to a strategy of keeping a relatively low management activity that prevents a fast intensification during periods of high prices. However, because drinking coffee is also culturally important for the local community, the falling of prices will not lead to abandonment either. Despite these considerations, there is currently a quite distinct intensification trend. For example, management activities such as harvesting high-quality coffee by picking only ripe coffee beans, drying beans on drying beds, and planting coffee with regular spacing have increased instead of harvesting a mixture of ripe and unripe coffee beans, drying beans on the ground, and planting coffee in a random pattern. The coffee forest management expansion and intensification across this vitally unique biodiversity-rich forest landscape is predicted to have a long-term negative impact on biodiversity, including reducing woody vegetation diversity and related ecosystem services (Geeraert et al., 2019), reductions of areas of forest with unmanaged coffee, and loss of coffee genetic resources.

5 | CONCLUDING REMARKS

From this study, we can conclude that even though coffee is present everywhere in the forest landscape at its favorable altitudinal range, the current coffee management across the coffee forest landscape varies in management intensity (i.e., number and frequency of management per site or per year). The small-holder farmers intensively manage, frequently visit, and harvest coffee in more accessible areas around the edge. From a long historical time perspective, coffee has been produced here for centuries, but the extent of management has varied much across space and time. This makes it difficult to judge what is truly wild coffee or not. However, that should not be the focus, but rather the question of how to protect the forests and natural processes of the currently unmanaged coffee populations for a mutual benefit of biodiversity conservation in a broader sense and to protect the unique global coffee genetic variation in these landscapes (Hylander et al., 2024). Yet, it is important to value this landscape, including its forests, as a cultural landscape with a rich, dynamic history of coffee management. It is impossible and unwarranted to distinguish between wild and human-modified forests, but given the decline of forests, biodiversity, and Arabica coffee genetic diversity, it is important to be aware of the risks of large-scale intensification of coffee management (e.g., planting improved varieties) that might come with better accessibility to global markets.

AUTHOR CONTRIBUTIONS

All authors contributed to the manuscript development and review. Design of the research was done by (Kristoffer Hylander, Ayco J. M. Tack, Dinkissa Beche, Sileshi Nemomissa, Tola Gemechu Ango, Debissa Lemessa, Bikila Warkineh); field data collection (Dinkissa Beche); data analysis (Dinkissa Beche, Kristoffer Hylander, Tola Gemechu Ango, Ayco J. M. Tack); interpretation (Kristoffer Hylander, Dinkissa Beche, Tola Gemechu Ango, Sileshi Nemomissa, Ayco J. M. Tack, Debissa Lemessa, Bikila Warkineh); writing the manuscript (Dinkissa Beche), and reviewing the manuscript (Sileshi Nemomissa, Ayco J. M. Tack, Tola Gemechu Ango, Debissa Lemessa, Bikila Warkineh).

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CONFLICT OF INTEREST STATEMENT

The authors declare that they have no conflict of interest.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are openly available in DRYAD at http://doi:10.5061/dryad.ns1rn8q2p.

ETHICS STATEMENT

Fieldwork was led by Dinkissa Beche. Interviewees were told about the aims, potential outputs, and methodology of the study, and prior informed consent (PIC) was gained verbally before interviews. The process for PIC followed guidelines provided by Stockholm University's research ethical policy (dnr: SU FV-1.2.1-4285-20) that is grounded in "The European Code of Conduct for Research Integrity" (All European Academies, ALLEA, 2017). After the interview, we asked if we were allowed to publish his/her name or if he/she wanted to remain anonymous. Linking a statement to a named person can strengthen the quality of the data and help other researchers to verify the results. We have indicated in the footnotes of Table S6 whether an interviewee wanted to be anonymous or not, and no other data than this from the interviews is published. The research permit from the Jimma Zone Coffee, Agriculture and Natural Resource Development Office to Gera district has the number J/30280/8-97 and was issued on 12/06/2013 (Ethiopian Calendar).

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SUPPORTING INFORMATION

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

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