Pattern and Magnitude of Deforestation in the South Central Rift Valley Region of Ethiopia

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Pattern and Magnitude of Deforestation in the South Central Rift Valley Region of Ethiopia

The pattern and magnitude of deforestation that occurred from 1972 to 2000 in the south central Rift Valley of Ethiopia were analyzed using remote sensing change detection techniques. The results show that natural forest cover declined from 16% in 1972 to 2.8% in 2000. The total natural forest cleared between 1972 and 2000 amounted to 40,324 ha, corresponding to an annual loss of 1440 ha. The total loss was 82% of the 1972 forest cover and the annual loss was equivalent to 0.9% of the national figure. The forest decline in the area involved proximate causal factors as well as causal factors that are more spatially diffuse and are part of the long-term evolution of a region much larger than the study area. In order of importance, the major causes of change were small-scale agriculture, commercial logging, and commercial farms. Two major modes of change were observed: 1) internal, ie openings created by small farm plots, grazing lands, and villages; and 2) external, ie expansion of agriculture from the exterior into the forests. The main consequences of deforestation were habitat destruction and decline of water availability.

Keywords: *Deforestation; pattern of change; change detection; remote sensing; biodiversity; Ethiopia.*

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Introduction

Tropical deforestation has become a global concern, with an annual total forest loss of 9.4 million ha (FAO 2000a). The total forested area of Ethiopia has decreased substantially during the past half-century or so. Recent figures show that the country's forest cover has shrunk to less than 3–3.6% (Reusing 1998; WBISPP 2004). Forest loss in northern Ethiopia probably goes back many hundreds of years (Melaku 1992), with the main remaining forest now confined almost entirely to the southern part of the country (Logan 1946; Friis 1986; Friis 1992).

In the 1970s, one of the major areas with remnant high forests was the south central Rift Valley of Ethiopia, including Shashemene, Wondo Genet, and parts of Sidama (Chaffey 1979). Today only pockets of high forest remain. The Shashemene forest was one of the most commercially valuable forests in the country (Russ 1944; Logan 1946; Mooney 1954; Breitenbach 1962). The Wondo Genet forests support high biodiversity and provide important watershed services (Mooney 1954; Makin et al 1975), although both aspects are now threatened. About a century ago, early travelers (Neumann 1902; Maud 1904) reported seeing dense canopy and continuous forest covering these sites. In the past half century, the south central Rift Valley of Ethiopia has evolved as one of the core regions in the country, in terms of economy, population, urbanization, and road transport. This has caused rapid forest decline.

In Ethiopia there is a shortage of accurate information regarding the rate of deforestation and the extent of earlier forest cover. The available local level land cover and land use change studies (Kebrom and Hedlund 2000; Gete and Hurni 2001; Belay 2002; Woldeamlak 2002) are all from the northern part of the country. The objective of the present study is to detect, document, and interpret the magnitude, trend, and spatial patterns of forest cover change in the south central Rift Valley of Ethiopia between 1972 and 2000. The main research questions were: What was the rate of natural forest cover change between 1972 and 2000? What are the trends in fragmentation? What are the major causes and consequences of change?

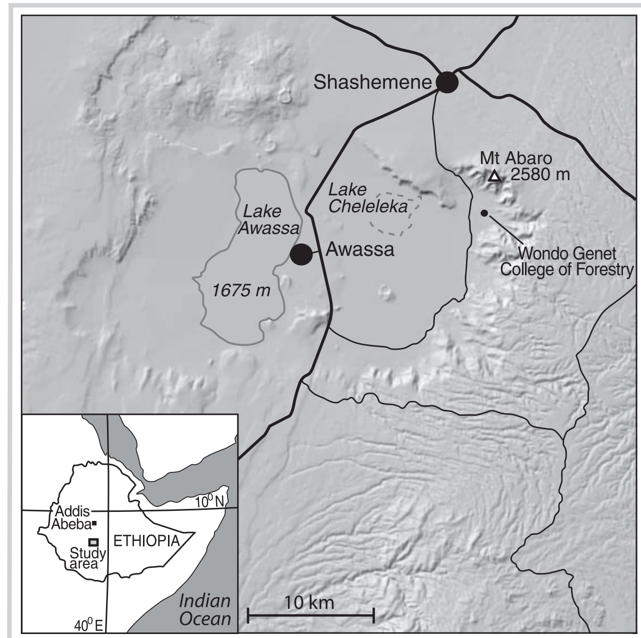
Material and methods

The study area

The study area (Figure 1), which comprises 3060 km^2, lies at 6°45' N to 7°15' N latitude and 38°15' E to 38°45' E longitude. It is located 280 km south of Addis Ababa, and forms part of the south central Rift Valley of Ethiopia. The area has a highly dissected topography draining into 4 different watersheds. The altitude varies between 1675 and 2900 m. The climate is transitional, between a well-defined bimodal pattern to the south and a single rainy season to the north. The eastern half gets annual rainfall reaching 1200 mm, whereas the rainfall on the western side subsides to around 900 mm at Lake Awassa. Within the area, the mean annual temperature varies between 17°C and 19°C.

The forest is upland rain forest (Friis 1986), sometimes termed submontane seasonal rain forest (Chapman and White 1970) or, more recently, Afromontane rain forest (White 1983; Friis 1992). It contains a mixture of *Podocarpus falcatus* and broad-leaved species at low elevations and in sheltered valleys, while patches resembling dry single-dominant Afromontane forest (White 1983; Friis 1992) with *Juniperus procera* as the most prominent species are found on ridges and at higher elevations. A survey of the forest cover in the region was done by Chaffey (1979). Figures 2A to 2D show representative land use types in the study area; the different types also represent a sequence of deforestation and land use transformation. The population in

FIGURE 1 The study area. Digital terrain model showing the main physiographic features, including Lakes Awassa and Cheleleka on the Rift Valley floor, and the eastern escarpment (south of Mt Abaro) of the Rift Valley. (Map by authors)



the study area is around half a million, about a third of which lives in the 2 major towns, Shashemene and Awassa. The area is comprised of parts of Oromya Regional State, and Southern Nations and Nationalities Peoples' Regional State.

Registration of images

Landsat images were registered to the Universal Transverse Mercator (UTM) geographic projection, using modified Clarke 1880 spheroid, datum Adindan (Ethiopia) and zone 37 (see Table 1 for data source). Four topographic maps covering the area were scanned in Tag Image Format (TIFF) on a high-resolution scanner at 1200 dots per inch. The maps were then rectified (rectification error 0.3 pixels) and converted to image format. The image registration was done using distinctive and easily identifiable features such as road intersections and stream confluences.

Image classification

We used a supervised maximum likelihood classification method to classify satellite images. Training areas were identified and defined as follows: for the entire study, the FAO definition of forest was adopted (FAO 2000b). Forest included natural forest and established plantations >30% crown cover and >1 ha in area. Representative forest cover types for MSS images were identified through stereoscopic and digital interpretation of aerial photographs. For the ETM image, training areas were identified based on knowledge of ground conditions acquired through extensive multi-year fieldwork in the area. The most homogenous portion of each sample type was marked as a training area, after which the histogram of each signature was checked for spectral separability. The size and shape of the training areas were readjusted until reasonable classification was attained. To accommodate variability of forest cover types we used 80 training areas for the MSS and 50 for the ETM images.

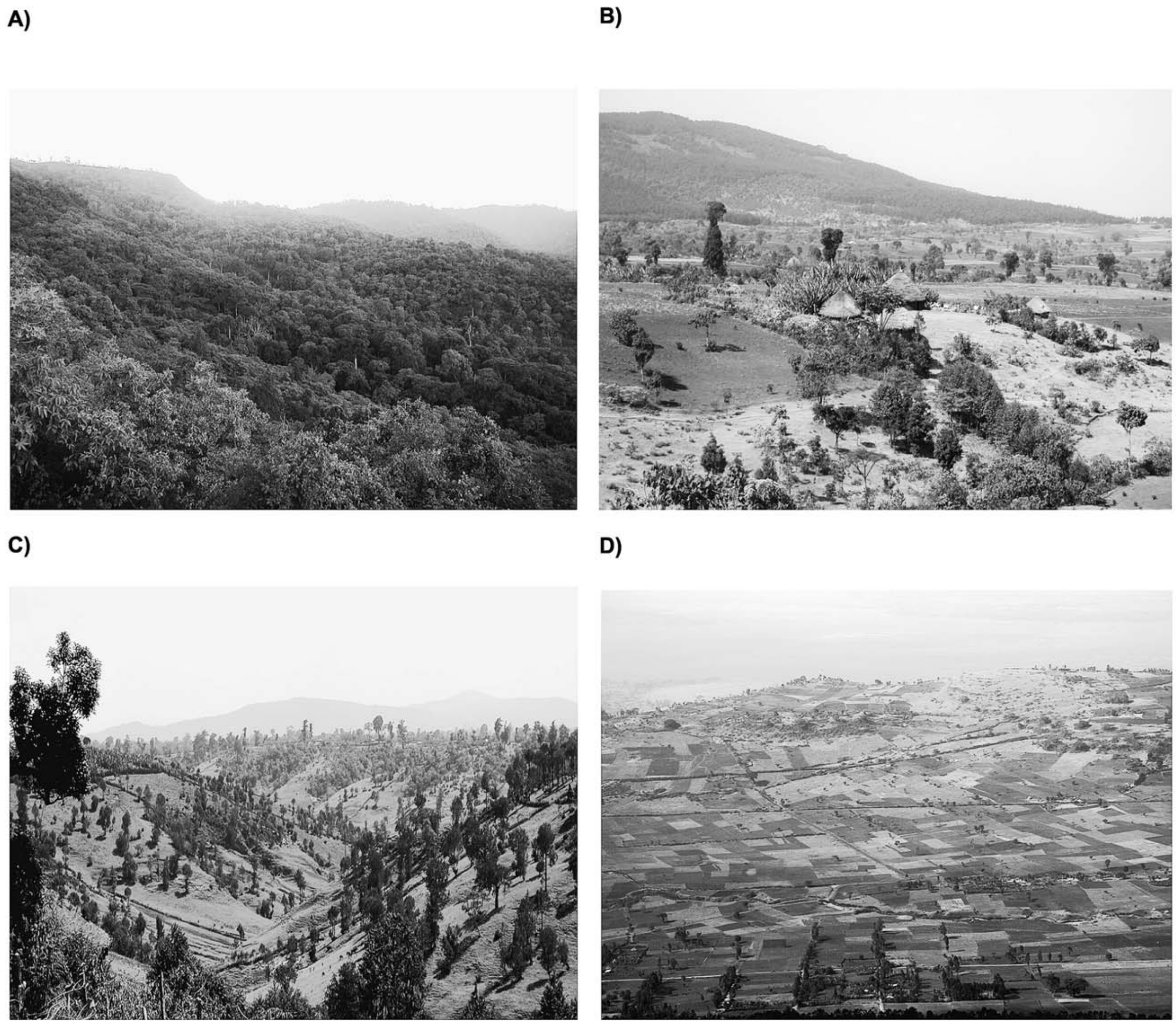
Classification accuracy

Classification accuracy was tested by overlaying grids on the aerial photographs (Quirk and Scarpace 1982; Rembold et al 2000) and the IKONOS image. Three sets of aerial photographs representative of forest conditions in 3 different parts of the study area were selected for verification of the 1972 classified image,

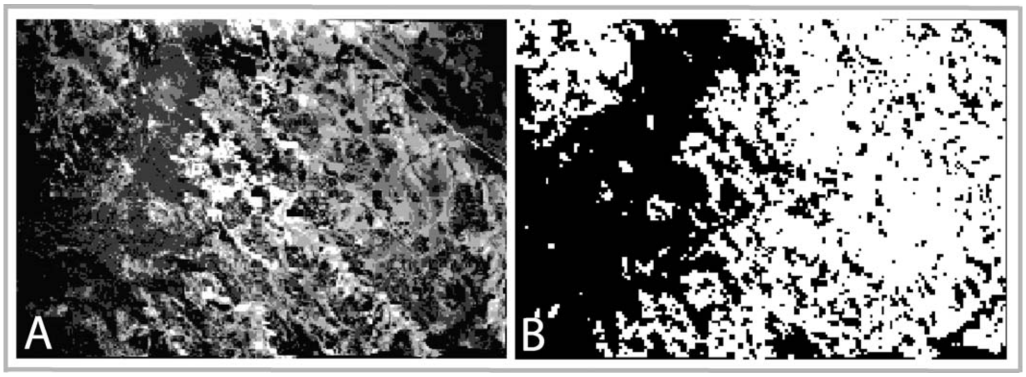
TABLE 1 Data sources and description.

Purpose	Data/specifications	Acquisition date/source	Resolution/scale
Classification	MSS Image Path/raw 181/55	26 Dec 1972 (dry season) USGS	57-m pixel
	ETM Image Path/raw 168/55	5 Dec 2000 (dry season) USGS	30-m pixel
Verification	Aerial photo 133ET1-133ET15	Nov–Dec 1972 Ethiopian Mapping Agency	1:50,000
	IKONOS Wondo Genet	10 Dec 2000 Wondo Genet College of Forestry	4-m pixel
Registration	Topographic maps 0738 C4,0738 D3, 0638 A2, 0638 B3	1976, 1988 (prepared) Ethiopian Mapping Agency	1:50,000

FIGURES 2A–2D Pattern of deforestation. A) Unchanged forests located on the slopes protected by Wondo Genet College of Forestry. The upper canopy trees are *Aningeria adolfi-friderici*, *Podocarpus falcatus*, and *Prunus africanus*. These species are rare and have a high market value. B) Land use transformation in what was originally the unbroken Shashemene forest. A plantation of mainly *Cupressus lusitanica* is seen in the background. The foreground shows small-scale farming, mainly maize mixed with grazing land and settlement. C) Pattern of change from forest to grazing land at high elevation >2500 m in Wondo Genet forest; the dominant tree species is *Juniperus procera*, a durable construction wood with high market value. D) A landscape of farm plots that have completely replaced the forest, as a result of encroachment from the exterior. (Photos by Gessesse Dessie)



and one available IKONOS scene was used for verification of the 2000 classified image. Digital orthophoto sets were created from the aerial photographs to eliminate topographic and other distortions and to enable direct comparison with the classified 1972 image. The orthophoto representing the true forest area and the classified image representing forest area were then compared (Figures 3A and 3B). The 2 units were printed at a scale of 1:50,000; thereafter, the amount of forest falling on the grid points was counted for both prints using a square grid (4-mm^2 unit). The accuracy of classification was calculated by dividing the proportion of forest in the image by the proportion of forest in the orthophoto (percentage correct). A similar procedure was followed for the year 2000 ETM image using the IKONOS image. Above 87% correct classification was attained for the 2 classifications. The change detection accuracy (0.87*0.87) was 0.76. Percentage correct is a simple measure of accuracy and well suited to a classification where only a few broadly defined classes are used (Campbell 1996). Various sources of error were recognized, including resolution and format difference between MSS and ETM images, shadows in high-relief terrain, localized haze, and the occurrence of restricted areas of other vegetation types (eg papyrus grass) that were occasionally classified as forest. We regard the >87% correct as a classification accuracy which is fully satisfactory for the purpose of this study, where the total magnitude of change between the 2 dates is large (see below).



FIGURES 3A AND 3B A) 1972 orthophoto compared to the 1972 classified image (B) for the estimation of classification accuracy. The site shows part of the Shashemene forest. Percentage correct of the classification (100b/a) is >87%.

Results and discussion

Quantitative trend

The areas under forest in 1972 and 2000 are presented in Table 2 (for spatial coverage, see Figures 4A and 4B). A closer investigation of the changes revealed that of the 48,924 ha of forest in 1972, less than 1% remained unchanged. The forest loss of 1440 ha/yr is equivalent to 0.9% of the national annual forest cover loss (163,000 ha) reported by Reusing (1998).

The rate of deforestation in the study area can be compared with results from studies elsewhere in Ethiopia. Northern Ethiopia is generally regarded as heavily deforested, but some data exist for areas with remaining pockets of forest. In a study area of 11,000 ha in northeast Ethiopia (1958–1986 study period), forest cover declined from 7.8% to 5.4% (Kebrom and Hedlund 2000). A similar study in northwestern Ethiopia (covering 27,103 ha for the period 1957–1995) documented a drop in natural forest cover from 27.1% to 0.3% (Gete and Hurni 2001).

The trend of forest decline in the study area correlates with the general pattern of forest decline in Ethiopia over the last few hundred years (Kebrom and Hedlund 2000; Belay 2002). However, there are a few examples of forest cover gain (Crummey 1998; McCann 1999). There is an increasing trend of homestead exotic (non-indigenous trees) planting. A similar trend has been reported elsewhere in Ethiopia (Woldeamlak 2002).

Of the high forest lost (approximately 40,300 ha) in the study area, more than 82% was lost to mainly agricultural land and about 17% was reforested and/or afforested. Studies elsewhere in Ethiopia likewise reported that forests were replaced mainly by cultivated land (Gete and Hurni 2001; Kebrom and Hedlund 2000).

Spatial patterns

Examination of forest maps (Figures 4A and 4B) and analysis of the topography revealed that the natural pattern of forest distribution is governed by topographic conditions and surface moisture states. The evergreen forests have glades of edaphic grasslands on seasonally waterlogged sites and marshes (Tewolde Berhan 1990). The pattern is further shaped into linear form by a dendritic drainage pattern (see Figure 1). This linear structure is still apparent in Figure 4B, although substantially encroached and thinned. Location and distribution in the upstream parts of catchments make these forests hydrologically important to the region. The non-linear fragmented patches are mainly located on slopes and in inaccessible valleys. These isolated patches are key habitats and harbor rare and threatened animal and plant species.

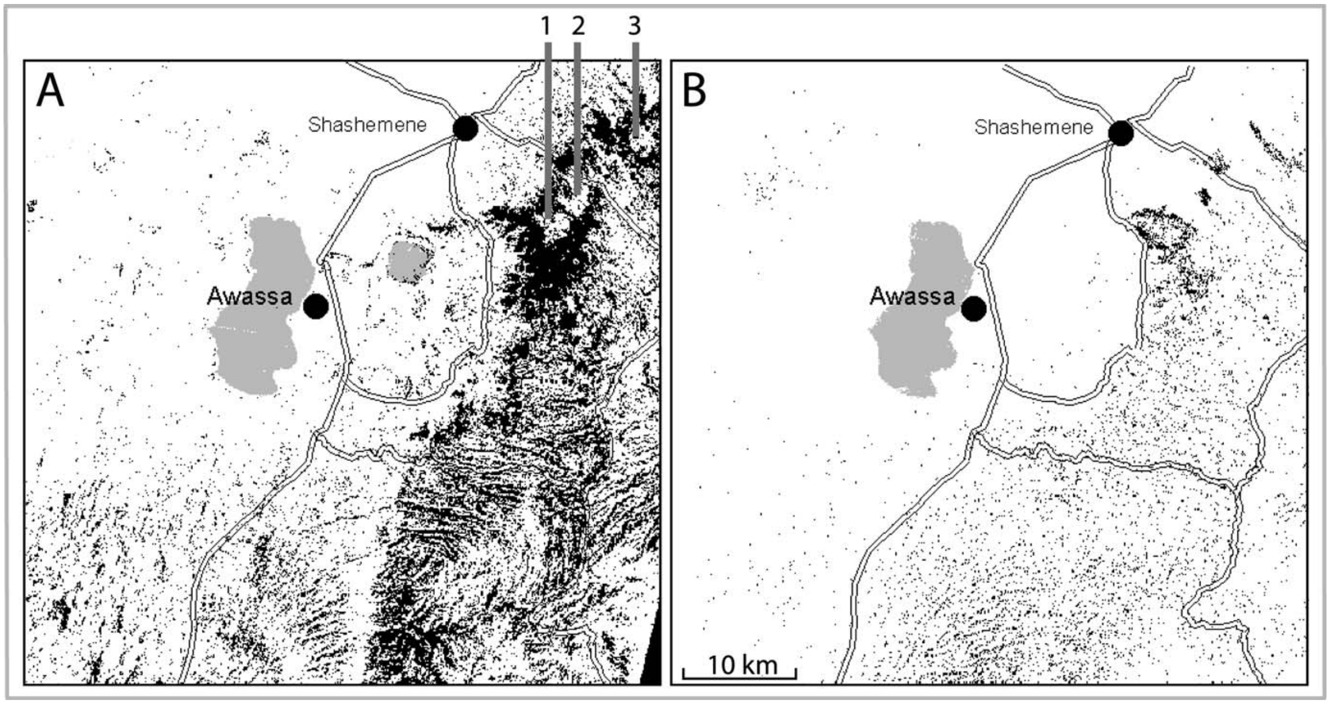
Figure 4B depicts a speckled spatial pattern formed of non-connected small forest patches. Fragmentation generally resulted in a landscape that consisted of remnant areas of native vegetation surrounded by a matrix of agricultural or other developed lands (Saunders et al 1991). A closer look (Figures 2B and 2C) shows a pattern consisting of small farm plots and grazing land units. This pattern is in contrast to the large regularly shaped openings in the Shashemene and Wondo Genet forests (Figure 4A). These openings are located near 3 commercial sawmills. The spatial pattern is not only shaped by perforation and fragmentation inside the forests but also by changes on the exterior (Figure 5). Figure 2D shows complete replacement of border forests by agricultural land.

TABLE 2 Forest cover change between 1972 and 2000 estimated from satellite image analysis with 76% change detection accuracy.

Forest area	1972	2000
In hectares	48,924	8600
In percent	16.0	2.8

Causes of change

Analysis of the satellite images and ground observation revealed that small-scale permanent agriculture is the major cause of deforestation. This result is in line with



FIGURES 4A AND 4B Deforestation 1972–2000 in the study area. A) Classified MSS 1972 image showing the forest cover during 1972. The forest is found at altitudes above 1800 m on upstream catchment areas and covers 16% of the total study area. The regularly shaped openings (1, 2, 3) are due to commercial logging. B) Classified ETM image showing the forest cover in 2000. The forest covers 2.8% of the total study area. Regularly shaped patches and strips are mainly plantations of *Cupressus lusitanica*, *Pinus patula*, and *Eucalyptus* spp. Lake Cheleleka has dried out.

previous studies (Russ 1944; Mooney 1954) and a recent comprehensive study (WBISPP 2004). The other causes of forest cover change are commercial logging and commercial agriculture. Commercial wood extraction was begun in the mid-1930s by 3 sawmills logging in Shashemene and Wondo Genet forests (Mooney 1954). Cleared areas were immediately occupied by settlers and converted to farmlands (Mooney 1954; Zerihun 1988). The sawmill in Wondo Genet was closed in the early 1970s, while the other 2 remained in operation until the mid-1980s. Only a minor fraction of the supply during the final period of operation came from the study area. During the period 1950–1975, establishment of commercial farms (coffee and cereal crop farms) contributed to deforestation primarily through clearance of forest and through the secondary effect of in-forest settlement of evicted farmers (Ståhl 1974; Makin et al 1975; Benti 1988).

The changes taking place are related to the gradual emergence of the region as one of the core centers in Ethiopia. In south central Ethiopia, particularly around Awassa and Shashemene, the population grew fast, settlements increased and expanded rapidly, road networks improved, and economic sectors developed (Ståhl 1974; Bjerén 1985). The forest decline in the area therefore involves a combination of specific and proximate causal factors, including causal factors that are more spatially diffuse and are part of the long-term evolution of a large surrounding region. According to Lambin et al (2001) various human–environment conditions react to and reshape the impacts of drivers differently, leading to specific pathways of land use change.

Forest decline in the period of 1972–2000 is not an isolated event, but rather a continuation of past trends. The forests of southern Ethiopia have been subjected to human influence for centuries. Pollen analysis (Bonnefille and Hamilton 1986) has revealed that the onset of major disturbances, including mountain forest destruction, occurred around 850 BP. In the study area, soil carbon analysis (Zewdu and Högberg 2000) has revealed more recent major land cover change. Travelers' accounts at the beginning of the 20^{th} century (Neumann 1902; Maud 1904) indicate that at that time the study area was heavily forested. Our data show that by 1972 forested area was already down to 16%, suggesting that a great deal was lost in the period 1900–1972. During the study period, the main causes of change were the increasing expansion of small-scale farming, particularly cash crops, and the factors that drove it. Another persistent cause was selective cutting and forest fires.

Causes of abrupt change have also been identified. According to local residents in Wondo Genet, 2 periods known to be times of abrupt change are 1974–75 and

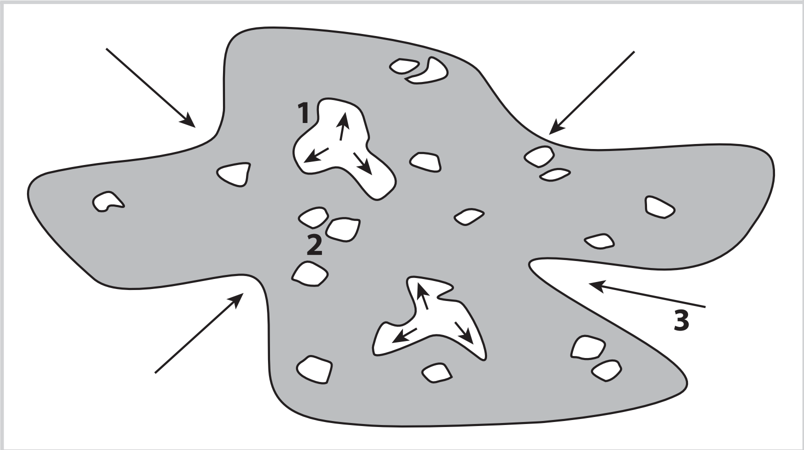


FIGURE 5 Modes of change. The three primary modes of change (reduction) in forested areas: internal (1 and 2) and external (3). The internal modes appear as openings created by small farm plots, grazing, and settlements, while the external mode results from expansion of agriculture from the exterior into the forest.

1991–92. These periods correspond with the 2 most recent changes of government in Ethiopia. Farmers point out that during periods of disorder and transition between governments, more trees are cut and more forestland is settled. The other explanation is a lack of clear forest property rights. Melaku (2003) reported that state-owned forests experienced huge losses after the change of government in 1991.

Consequences

Habitat loss and habitat fragmentation create loss and/or decline of species (Darren et al 1998). According to Saunders et al (1991) the influence of physical and biogeographic change is modified by the size, shape, and position in the landscape of individual remnants, with larger remnants being less adversely affected by the fragmentation process. The high biodiversity of forests in the study area has been identified in many studies (Makin et al 1975; Lorna 1979; Cross 2003). Earlier, Makin et al (1975) proposed to establish a wildlife reserve in the Abaro and Wondo Genet area. Forest change leads to habitat destruction and threatens to make rare tree species such as *Aningeria adolfi-friderici*, *Podocarpus falcatus* and *Prunus africanus* extinct. Already in the mid-1980s, the mountain nyala (*Tragelaphus buxtoni*), one of the mammals endemic to Ethiopia, was extinct in the study area.

Another consequence may be a decline in availability of water. For example, Lake Cheleleka dried up during the study period (Figure 4B). Local sources reported that during the past 30 years a number of streams previously feeding the lakes have dried up and/or the flow of water has substantially decreased. There are 3 possible causes for the lake drying up: 1) lowering of the outlet threshold; 2) sedimentation in the lake basin; 3) reduced streamflow. There are no indications of downcutting of the outlet, and there is little erosional or depositional evidence to suggest a major increase in sediment supply. It therefore appears probable that drying up is caused by reduced streamflow related to deforestation and increased use of streamwater for irrigation purposes.

While deforestation contributes to the decline of water resources, it indirectly contributes to a decrease in agricultural productivity and also affects people's health. The people of Wondo Genet are heavily dependent on irrigation agriculture, and Awassa and Shashemene towns (with a combined population of about 200,000) rely on potable water drawn from the area. Additionally, forest loss has affected practical forestry training at Wondo Genet College of Forestry. The college, the only one of its kind in the country, is heavily dependent on this forest for outdoor exercises and experiments.

Conclusion

In addition to the severe loss in forested area, deforestation in the study area has also created a highly fragmented pattern with a multitude of small patches. The patches are shaped by the expansion of permanent cultivation and grazing by smallholders. Small patch size, lack of connectivity, and permanent agricultural activities have seriously undermined the resilience/regeneration potential of the forest.

In the long run, plantations may ease the energy, feed, and construction needs of the people, but will not contribute to any significant recovery of biodiversity. Loss of natural forest has already caused substantial damage to biodiversity and watershed services. To revive some of these services, it is important to conserve remnant patches before it is too late.

The present study, by examining a nationally important site during a dynamic period, indicates the magnitude, causes, and consequences of upland deforestation in Ethiopia. The major proximate cause is expansion of smallholder agriculture. The consequences are far-reaching in terms of environmental, livelihood, and even academic impacts.

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