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Vascular Plant Species Composition, Relative Abundance, Distribution, and Threats in Arsi Mountains National Park, Ethiopia

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A study of vascular plant species composition, relative abundance, distribution, and anthropogenic threats to these species' survival was carried out in the Galama Mountains in Arsi Mountains National Park,

Ethiopia. An Intensive Modified Whitaker nested plot design was used to sample vegetation in disturbed and undisturbed habitats across the landscape. A total of 191 plant species (including 5 identified only to the genus level) in 56 families were recorded. The dominant family was Asteraceae, followed by Poaceae. Twenty species (about one-tenth of all species recorded) are endemic to Ethiopia. The highest overall species richness was recorded in the dry evergreen Afromontane vegetation in the undisturbed plots and in the Erica (heath) habitat in the disturbed plots. Rare plant species were less frequent in the disturbed plots than in the undisturbed ones. Regression analysis indicated a significant decrease in total

species richness with increase in elevation. It also indicated a significant decrease in species richness and average plant species ground cover with increasing amounts of fresh livestock dung. The rate of tree removal exceeds the rate of regeneration in the dry evergreen Afromontane vegetation. Myrsine melanophloeos, Schefflera abyssinica, and Juniperus procera were the dominant tree species in the lower elevations (2843 to 3200 m above sea level) and have been found to be overharvested. Based on the current anthropogenic pressures in the study area, we expect species diversity and frequency of occurrence to diminish over time. Urgent conservation measures including control of tree harvesting and livestock encroachment should be prioritized in Arsi Mountains National Park.

Keywords: Afro-alpine; Afromontane; subalpine vegetation; Erica spp.; anthropogenic disturbances; plant diversity; Intensive Modified Whitaker plot; Galama Mountains; Arsi Mountains National Park; Ethiopia.

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Introduction

Topographical and climatic conditions in Ethiopia create diverse ecosystems that support abundant floral and faunal resources (Yalden 1983; Friis et al 2010). As a result, Ethiopia is considered one of the biodiversity-rich countries in tropical Africa, especially in terms of its higher endemic plant and animal diversity (Vivero et al 2006). The country's floral diversity is ranked as the fifth largest in Africa, with an estimated 6500–7000 species of higher plants (vascular plants); 12% of these are endemic (Gebre-Egziabher 1991; Vivero et al 2006). The mountain ecosystems of Ethiopia provide diverse ecosystem services including provisioning (eg food, freshwater, wood, and

medicine) (Bussman et al 2011), regulating (eg climate regulation, flood regulation, and water purification), supporting (eg nutrient cycling, soil formation, and primary production) (Senbeta and Denich 2006; Kelbessa and Soromessa 2008), and cultural (eg aesthetic, spiritual, and recreational) services (Wesche et al 2000).

The mountains of Ethiopia are characterized by dry evergreen Afromontane, subalpine, and Afro-alpine vegetation types. Dry evergreen Afromontane vegetation occupies lower-elevation areas (2500–3000 m above sea level [masl]) and is dominated by tree species like *Afrocarpus falcatus*, *Juniperus procera*, and *Hagenia abyssinica* (Nigatu and Tadesse 1989; Hundera et al 2007; Erenso and Maryo 2014). Subalpine (heath dominated) vegetation

occupies the middle elevations (3000–3500 masl) and is dominated by *Erica arborea* and *Erica trimera* plant species (Miehe and Miehe 1994). Afro-alpine vegetation (high mountain grassland with scattered shrubs) occupies the upper elevations (3500–4000 masl) and is dominated by *Helichrysum* and *Alchemilla* species with scatter stands of the endemic giant lobelia (*Lobelia rhynchopetalum*) (Wesche et al 2000; Ahmed 2013). A number of floristic studies have been conducted to characterize the composition of dry evergreen Afromontane (Nigatu and Tadesse 1989; Hundera et al 2007; Kelbessa and Soromessa 2008; Asefa et al 2015), subalpine (Miehe and Miehe 1994), and Afro-alpine (Hedberg 1957) vegetation in Ethiopia. Many of these were concentrated in relatively well-protected areas and focused on woody vegetation (Nigatu and Tadesse 1989; Miehe and Miehe 1994; Asefa et al 2015). Other floristic studies have catalogued vascular plants and their ethnobotanical values without addressing their distribution or abundance across the landscape (Asfaw and Tadesse 2000; Luizza et al 2003; Bussman et al 2011).

A few studies have examined plant assemblages under intense and reoccurring disturbances (eg Asefa et al 2015). The floral composition and structure of the southeastern highlands (Bale Mountains) of Ethiopia are said to be threatened by disturbances including livestock overgrazing, fire, and deforestation (Nigatu and Tadesse 1989; Evangelista et al 2007; Johansson 2013). For example, deforestation driven by expansion of agriculture and settlement and by wood extraction has been found to alter vegetation composition and structure in the Bale Mountains National Park (Nigatu and Tadesse 1989). A pattern of recurrent fires is presumed to be decades old in the mountains of Ethiopia, altering the vegetation dynamics (Johansson 2013). Livestock encroachment has been common in dry evergreen Afromontane (Teketay 1992), subalpine (Miehe and Miehe 1994; Johansson 2013), and Afro-alpine vegetation types (Wesche et al 2000) in Ethiopia and has been reported to alter vegetation dynamics (regeneration) through excessive grazing, browsing, and trampling pressure on young seedlings and saplings. These disturbances have also been reported to affect the cover and food requirements of the endangered endemic mountain nyala (*Tragelaphus buxtoni*) and other wildlife species in the area, ultimately affecting their survival (Evangelista 2007; Mamo and Bekele 2011; Mamo et al 2012; Girma 2016).

Sustainable development and conservation of mountain ecosystems and their biodiversity requires sound qualitative and quantitative botanical data (Ren et al 2006). Unless threats such as livestock grazing, fire, and wood collection are managed in a sustainable way, rare and threatened plant species that are ecologically, economically, and culturally important could be lost without being known to the scientific community.

The newly established Arsi Mountains National Park is rich in flora and fauna diversity and a center of endemism

in Ethiopia's southern highlands. A study by Girma (2016) identified 4 dominant vegetation types: Afro-alpine (3576–4008 m asl), *Erica* (3202–3985 m asl, heath-dominated), dry evergreen Afromontane (2843–3756 m asl), and mixed plantation (indigenous and exotic trees) (3181–3340 m asl). However, the complete floral composition of the Park and how biophysical factors such as elevation and disturbances (livestock encroachment and tree felling evidenced by stump count) affect plant diversity and distribution have not been investigated. To help fill this gap, our study investigated the species composition, relative abundance, distribution of, and threats to vascular plants in the Galama Mountains in the Arsi Mountains National Park to provide inputs for the preparation of the Park's management plan and to guide future conservation strategies.

Methods

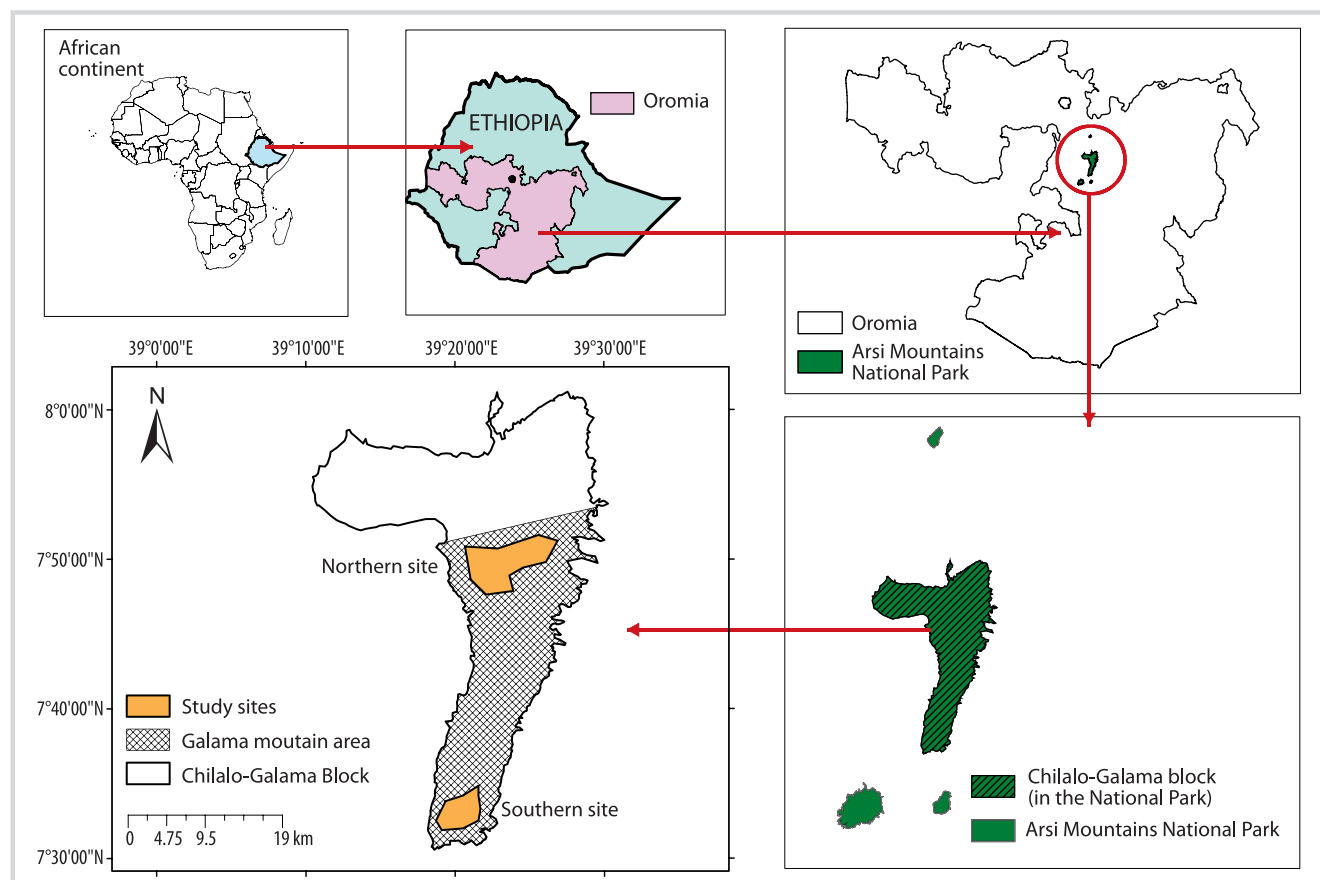
Study area

Arsi Mountains National Park was established in 2011 to protect the area's unique and threatened biota and for watershed conservation (OFWI 2015). It is located in Oromia state in Ethiopia, approximately 200 km southeast of Addis Ababa, and 15 km from the town of Asella (APEDO and ABRDP 2004) (Figure 1).

The Park contains the second largest expanse of Afro-alpine habitat in Ethiopia (Gottelli and Sillero-Zubiri 1992; Malcolm and Sillero-Zubiri 1997). It is divided into 4 blocks (ie mountain areas once historically known to be connected each other): Dera Dilfaqar, Chilalo-Galama, Kaka, and Hunkolo (Young 2012). This study focused on the mountainous Chilalo-Galama block, the largest (about 793 km²) of the 4 blocks (OFWI 2015)—and specifically on the Galama Mountains (7.48–7.88° N; 39.27–39.51° E), which make up about two-thirds of the block (524 km²) and form a diverse landscape with elevations ranging from 2000 to more than 4000 masl (Malcolm and Sillero-Zubiri 1997). Many rivers and streams emanate from this area and flow in different directions (APEDO and ABRDP 2004); the mountains also contain Afro-alpine lakes and swamps (OFWI 2015).

The average annual rainfall in the study area ranges from 778.7 to 1089.7 mm. It has a mean monthly maximum temperature of 22.4°C and minimum of 11.1°C (Girma 2016). Soils in the study area consist primarily of Pellic Vertisols in lower elevations (2500–2700 masl), Orthic Luvisols at mid elevations (2700–3000 masl), Chromic Luvisols at higher elevations (3000–3500 masl), and Eutric Nitosols at peak elevations (3500–4000 masl) (Tekle 1984). Vegetation is primarily Afro-alpine at higher elevations (3276–4008 masl), *Erica* (heath dominated) at middle elevations (3202–3985 masl), dry evergreen Afromontane vegetation at elevations of 2843–3756 masl, and mixed-species tree plantations at lower elevations (3181–3340 masl) (Girma 2016).

FIGURE 1 Map of the study area. (Map by Mikias Biazen)



Due to the area's cool climate and relatively fertile soil, it is among the most populous in Ethiopia; more than 90% of the population lives in rural areas surrounding the Galama Mountains (Girma 2016). Agriculture and human settlement are dominant land uses around the Galama Mountains, often affecting the forest landscape (Evangelista et al 2007; Girma et al 2012). Local livelihoods rely on cultivation of crops, livestock rearing, and subsistence extraction of forest resources (Girma et al 2012).

Field sampling

Stratified random sampling was used to lay out sampling plots over the 4 vegetation types that are the focus of this study: Afro-alpine, *Erica*, dry evergreen Afromontane, and mixed plantation. Due to the nature of the sampling, some plots were located in more or less undisturbed areas and others in disturbed areas (Table 1). Sampling plots in each habitat type were randomly chosen using ArcGIS software v. 10.1 (ESRI 2012) in 2 areas, 1 in the northern and 1 in the southern Galama Mountains, chosen because they contained all 4 vegetation types described above. Before the end of the data collection period, a species accumulation curve was plotted to confirm that the

majority of plant species in the study area were captured by our sampling methods.

A total of 104 sample plots (18 in Afro-alpine vegetation, 53 in *Erica* vegetation, 24 in dry evergreen Afromontane vegetation, and 9 in mixed plantation vegetation) were established to study the plant species composition, relative abundance, and distribution in the study area. Of these, 75 plots (13 Afro-alpine, 40 *Erica*, 19 dry evergreen Afromontane, and 3 mixed plantation) were on disturbed land. In the *Erica* and Afro-alpine vegetation, a disturbed plot was defined as having at least 2 of the following 3 criteria: <40% ground cover, having been burned, and >3 fresh livestock dung piles. In the dry evergreen Afromontane and mixed plantation plots, a disturbed plot was defined as having at least 2 of the following 4 criteria; <10% ground cover, >3 fresh livestock dung piles, having been burned, and a stump count >2. Mixed plantation forests were established in the area in an attempt to restore dry evergreen Afromontane vegetation degraded or lost due to human influences such as wood collection, agriculture, and settlements. Hence, both habitats were considered together when defining disturbed and undisturbed plots. Since the proportion of disturbed to undisturbed plots varied, all comparisons of

TABLE 1 Biophysical characteristics of disturbed and undisturbed sampled plots. Values in parentheses refer to the undisturbed plots.

Characteristic	Habitat			
	Afro-alpine	Erica	Natural forest	Mixed plantation
Total area sampled (m ²)	1300 (500)	4000 (1300)	1900 (500)	300 (600)
No. of plots	13 (5)	40 (13)	19 (5)	3 (6)
Elevation (m) mean	3649 ± 78.05 (3670.1 ± 92.08)	3524.5 ± 44.24 (3570.1 ± 77.21)	3299.73 ± 65.92 (3037 ± 76.64)	3265 ± 33.85 (3271.83 ± 67.06)
Elevation (m) range	3305–4008 (3276–3958)	3202–3985 (3230–3974)	3161–3756 (2843–3183)	3217–3328 (3181–3340)
Slope ^{a)}	Flat (flat)	Moderate (moderate)	Moderate (moderate)	High (high)
Percentage	74.3 (75.7)	47.2 (50.3)	54.5 (59.7)	42.3 (47.3)
Species richness	78 (80)	114 (119)	108 (126)	101 (90)
Vegetation height (m) mean	0.32 ± 0.56 (1.82 ± 1.01)	1.91 ± 0.45 (1.94 ± 0.63)	6.84 ± 1.07 (2.7 ± 1.04)	4.7 ± 0.33 (5.7 ± 0.64)
Vegetation height (m) range	0.12–0.35 (0.1–2.8)	0.1–1.4 (0.32–1.7)	0.35–17 (0.35–5)	2.8–6 (5–6)
Average vegetation ground cover (%)	52.6 ± 0.21 (65.1 ± 1.64)	24.4 ± 0.84 (36.5 ± 1.07)	4.3 ± 0.51 (12.6 ± 0.51)	5.2 ± 2.12 (16.6 ± 1.54)
Average no. of felled trees (stump count)	Stump count not conducted	Stump count not conducted	8.2 ± 0.16 (2.8 ± 1.61)	Stump count not conducted
Average no. of livestock (dung pile count)	22.2 ± 2.33 (4.46 ± 3.62)	14.25 ± 1.98 (2.38 ± 2.41)	8.05 ± 0.96 (1.6 ± 1.57)	7.67 ± 1.45 (0.83 ± 3.39)

^{a)} Flat = 0–2%; moderate = 2–5%; high = 5–10%; steep > 10%.

TABLE 2 Plant families recorded in the Galama Mountains.

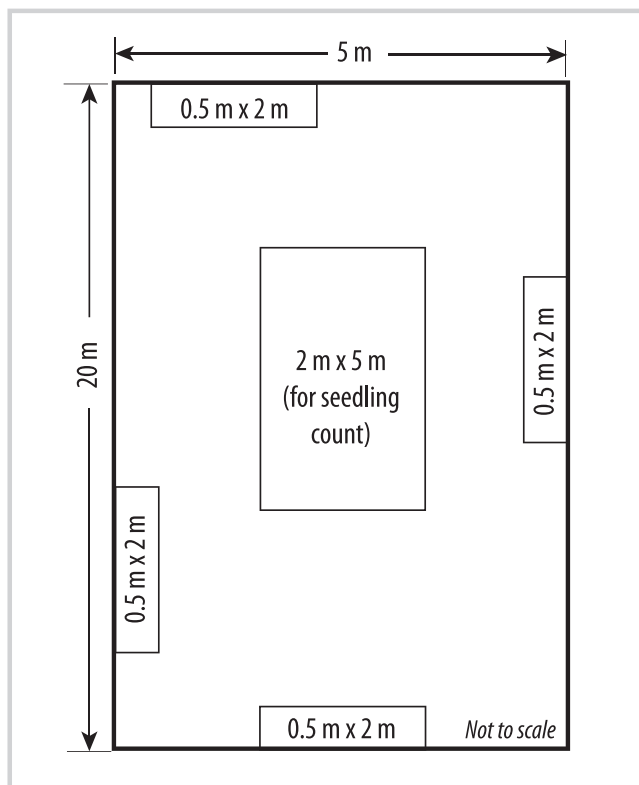
Family	No. of genera	No. of species	Family proportion (%)
<i>Asteraceae</i>	21	32	17
<i>Poaceae</i>	11	23	12
<i>Rubiaceae</i>	7	10	5
<i>Apiaceae</i>	9	9	5
<i>Lamiaceae</i>	6	9	5
<i>Fabaceae</i>	5	7	4
<i>Scrophulariaceae</i>	4	6	3
<i>Rosaceae</i>	3	5	2
<i>Lobeliaceae</i>	2	4	2
<i>Cyperaceae</i>	3	4	2
<i>Apocynaceae</i>	2	3	2
Others	40	79	41

species richness among disturbed and undisturbed plots considered the variations in overall species richness (gamma diversity) to highlight how disturbances have affected the overall distribution of vascular plants in the study area.

The study used an Intensive Modified Whitaker nested plot design, which has proven effective in sampling vegetation in mountainous terrain, especially where herbaceous vegetation dominates (Barnett and Stohlgren 2003). In this design, an outer plot measuring 20 × 5 m contains 4 subplots along its edges measuring 0.5 × 2 m and 1 subplot in the center measuring 2 × 5 m (Figure 2). Each plot was situated with its longest edge aligned with the slope of the land in an attempt to represent subtle ecotones and capture the greatest number of plant species.

For each of the four 1 m² subplots, all vascular plant species were recorded with their height, percentage of ground cover, and burn history. For the 100 m² outer plot, we recorded only the number of species that were not recorded in the 1 m² subplots, to produce a complete species checklist. For the 100 m² outer plot, we also recorded the number of fresh livestock dung piles (a dung

FIGURE 2 Design of the intensive Modified Whitaker nested plot following Barnett and Stohlgren (2003).



pile is defined as having 2 to 5 pellets dropped together at a close distance) and the number of tree stumps. The central 10 m² subplot was used to count tree seedlings. (The latter 2 counts were carried out only in the dry evergreen Afromontane and plantation vegetation plots; the Afro-alpine and *Erica* plots were above the treeline.) The percentage of bare ground or exposed rock cover was also recorded in the four 1 m² subplots where applicable. Ancillary data such as elevation, latitude and longitude, and slope were recorded with a GPS (Global Positioning System) device and clinometer. The time since last burn of the 100 m² outer plot, where applicable, was estimated with the aid of park staff. An attempt was made to identify all plant species in the field; samples of each species were also collected, pressed and oven-dried, and taken to the Ethiopian National Herbarium, located in the Department of Plant Biology and Biodiversity at Addis Ababa University, for verification. The identification process was guided by *Flora of Ethiopia and Eritrea* (FEE 1989–2009) and *Flora of Tropical East Africa* (FTEA 1996–2010), and by comparison with archived specimens from the collection housed at the National Herbarium, and followed the Angiosperm Phylogeny Group (APG III) system (Chase and Reveal 2009). About 3% of the specimens were identified only to the genus level.

Data analysis

Vegetation data were summarized per plot using Microsoft Excel 2013. Plant species were summarized by family, habitat type, and occurrence on disturbed and undisturbed plots. A linear regression model was fitted to assess the relation between species richness and elevation data as well as the amount of fresh livestock dung per plot (Hundera et al 2007) (Equations 1, 2). A linear regression model was also fitted to assess the relation between average percentage of ground cover and amount of fresh livestock dung (Equation 3).

$$\begin{aligned} \text{Species richness} &= 108.6 - 0.024 \times \text{elevation} \\ (S = 5.55, R^2 = 59.8\%, F = 151.90) \end{aligned} \quad (1)$$

$$\begin{aligned} \text{Species richness} &= 24.8 - 0.4093 \times \text{fresh livestock dung} \\ (S = 8.67, R^2 = 12.9\%, F = 16.2) \end{aligned} \quad (2)$$

$$\begin{aligned} \text{Average ground percentage cover} \\ &= 5.9 - 0.098 \times \text{fresh livestock dung} \\ (S = 3.87, R^2 = 3.4\%, F = 4.65) \end{aligned} \quad (3)$$

For the dry evergreen Afromontane forest, a linear regression model was fit to assess the relation between species richness and stump count (Equation 4).

$$\begin{aligned} \text{Species richness in the dry evergreen Afromontane forest} \\ &= 36.53 - 1.655 \times \text{stump count} \\ (S = 5.58, R^2 = 42.1\%, F = 17.73) \end{aligned} \quad (4)$$

All linear regression models were derived using Minitab 17 software.

Tables were created to summarize the proportion of each plant family in the plot, to summarize the biophysical characteristics of both undisturbed and disturbed plots, to estimate regeneration status and tree cut (fall) rates for tree species (for dry evergreen Afromontane forest), and to compare the percentage frequency of occurrence of plant species per plot/habitat/growth form using Microsoft Excel 2013.

The frequency of occurrence of each plant species was calculated using the formula below (Equation 5).

$$\begin{aligned} \text{Species percentage frequency of occurrence (FO)} \\ &= \frac{\text{Total species count in the plots in the landscape (SC)}}{\text{total number of plots in the landscape (n)}} \times 100, \\ &\text{where } n = 104 \text{ plots} \end{aligned} \quad (5)$$

Results

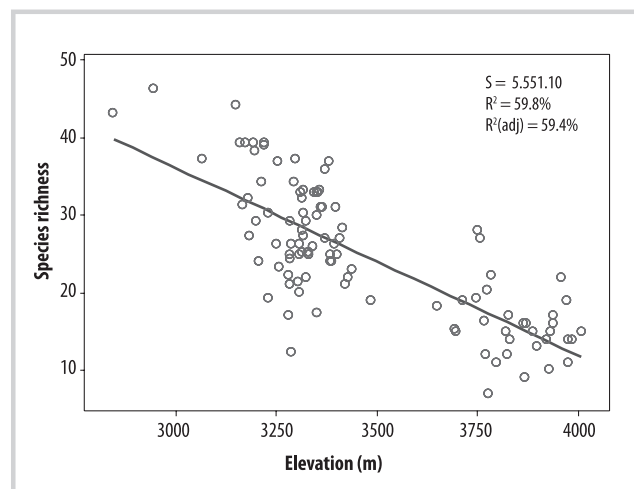
The highest overall species richness was recorded in the dry evergreen Afromontane vegetation in the undisturbed plots and in the *Erica* vegetation in the disturbed plots. The least overall species richness was recorded in the

Afro-alpine vegetation type in both disturbed and undisturbed plots.

We recorded 191 plant species (including 5 only identified to the genus level) in 56 families (*Supplemental material*, Table S1: <http://dx.doi.org/10.1659/MRD-JOURNAL-D-17-00006.S1>). The dominant family groups were *Asteraceae* (*Compositae*), with 32 species (16.8% of the total species recorded), and *Poaceae*, with 23 species (12.0% of the total species recorded). Eleven families represented approximately 60% of the total species recorded (Table 2); 21 families were represented by a single species each. Trees accounted for 7.32% (14 species), shrubs 12.04% (23 species), herbs 76.45% (146 species), and climbers 4.19% (8 species) of the species recorded. Of these, 20 species (10.5%) are endemic to Ethiopia. About 45% of the endemics (9 species) belong to the family *Asteraceae*; more than half (12 species) were herbs. Two endemic species are considered endangered and 3 near threatened (IUCN 2012). The most common endemics were *Micromeria imbricata* (40%) and *Clinopodium paradoxum* (34%); the least common were *Festuca gilbertiana*, *Festuca macrophulla*, and *Vernonia rueppellii* (1% each) (*Supplemental material*, Table S1: <http://dx.doi.org/10.1659/MRD-JOURNAL-D-17-00006.S1>).

Alchemilla haumanii Rothm. and *E. arborea* had the highest overall frequency of occurrence in the Afro-alpine and *Erica* vegetation, respectively, in both disturbed and undisturbed plots; in disturbed plots, the percentage cover of each species was greatly reduced. *Rubus steudneri* and *Alchemilla pedata* occurred with highest frequency in the dry evergreen Afromontane and mixed plantation vegetation, respectively, in undisturbed plots. However, *A. pedata* was rare in disturbed plots in mixed plantation vegetation. In the overall study area, *A. pedata*, *E. arborea*, *Crassula alsinoides*, *Geranium arabicum*, and *Haplocarpha rueppellii* were the 5 most abundant species in that order. *E. arborea*, *Andropogon abyssinicus*, *M. imbricata*, and *R. steudneri* favored disturbed plots more than undisturbed ones. Some species were not recorded in the disturbed plots at all. In the disturbed Afro-alpine vegetation plots, *Festuca abyssinica* and *Juncus dregeanus* were absent. In the disturbed *Erica* vegetation plots, *Luzula abyssinica*, *Oldenlandia monanthos*, *Parochetus communis*, *Swertia fimbriata*, and *Androcymbium schimperianum* were absent. In the disturbed plots of dry evergreen Afromontane vegetation, *Maesa lanceolata*, *Momordica foetida*, *Umbilicus botryoides*, *Nuxia congesta*, *Senecio fresenii*, *Dombeya torrida*, *Arundinaria alpina*, *Urera hypselodendron*, *Jasminum abyssinicum*, *Hypoestes triflora*, *Conyza pyrhopappa*, *Barleria orbicularis*, *Gerbera piloselloides*, *Eragrostis tenuifolia*, *Anagallis serpens*, *Veronica glandulosa*, *Scabiosa columbaria*, and *Sanicula elata* were not recorded. Similarly, *Vernonia glandulosa*, *Plectocephalus varians*, *Schefflera volkensii*, *Holothrix squamata*, *Oenanthe palustris*, *Helictotrichon elongatum*, *Myrsine africana*, *Buddleja polystachya*, *Thalictrum rhynchocarpum*, *Polygala steudneri*, and *Hypoestes triflora* were not recorded in the disturbed plots of mixed

FIGURE 3 Results of a regression analysis comparing species richness and elevation.



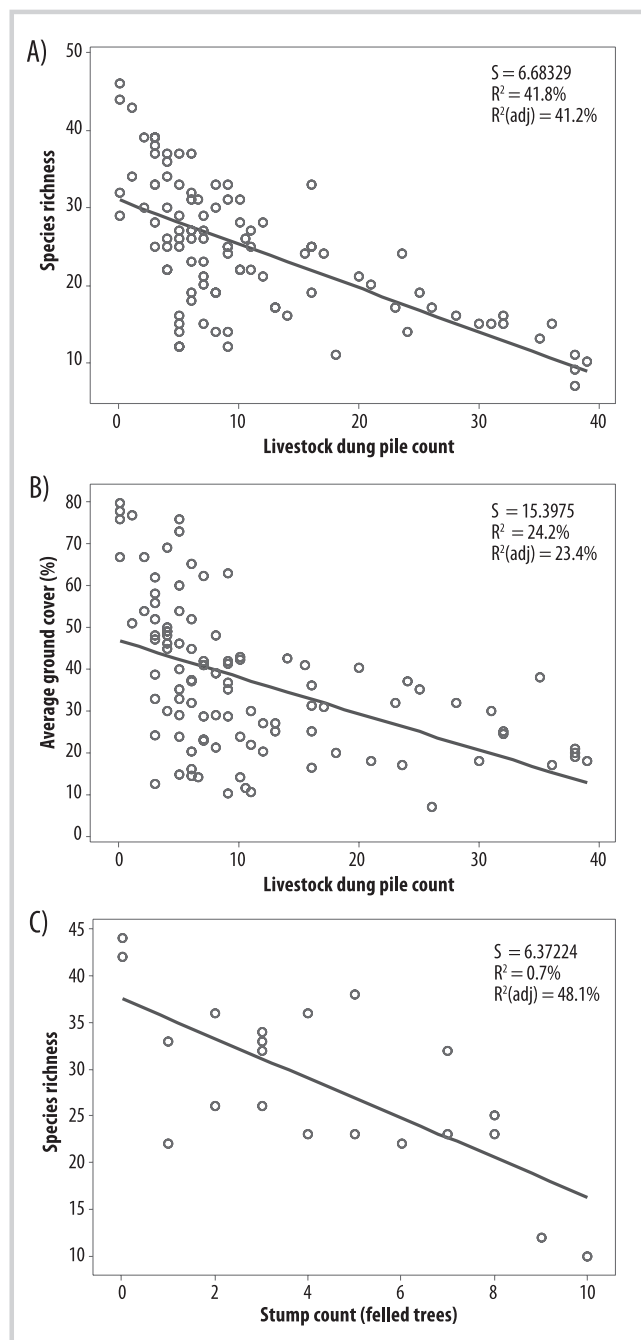
plantation vegetation (*Supplemental material*, Table S1: <http://dx.doi.org/10.1659/MRD-JOURNAL-D-17-00006.S1>).

The regression analysis indicated a significant decrease in species richness with increasing elevation ($P < 0.001$) (Figure 3). Regression analysis also indicated a significant decrease in species richness ($P < 0.001$) (Figure 4A) and average ground cover ($P < 0.001$) (Figure 4B) with increasing fresh livestock dung piles. In the dry evergreen Afromontane vegetation, regression analysis indicated a significant decrease in species richness with increasing tree stump count ($P < 0.001$) (Figure 4C).

The pattern in terms of growth forms is summarized below and shown in detail in the *Supplemental material*, Table S1 (<http://dx.doi.org/10.1659/MRD-JOURNAL-D-17-00006.S1>):

- Herbs occurred from 2843 to above 4000 masl. *A. pedata* (80%), *C. alsinoides* (68%), and *Geranium arabicum* (68%) were the dominant herbs, while *Holothrix squamata* (1%), *P. communis* (1%), and *Swertia fimbriata* (1%) were among the rarest. Overall herb species richness was less abundant in disturbed plots than undisturbed ones. Shrub species were relatively common at 2843–3900 masl and infrequent above that elevation. *E. arborea* was the most frequently occurring shrub, with 73% overall frequency of occurrence, and was dominant at 3402–3985 masl, while *E. trimera* dominated in elevations from 3200 to 3400 masl. *Myrica salicifolia*, *A. alpina*, *Eriocaulon schimperi*, *Halleria lucida*, *N. congesta*, and *V. rueppellii* were the rarest shrub species (*Supplemental material*, Table S1: <http://dx.doi.org/10.1659/MRD-JOURNAL-D-17-00006.S1>).
- Climbers were the rarest growth form, representing only 8 species (4.19%); they occurred in close association with trees, predominantly in the dry evergreen Afromontane vegetation. *Dregea stelostigma* and *Clematis hirsute* were dominant, while *Momordica foetida* was the rarest among the climbers.

FIGURE 4 Results of regression analyses comparing (A) species richness and livestock dung piles; (B) average percentage of ground cover and livestock dung piles; (C) species richness and tree fall/stump count (dry evergreen Afromontane forest only).



- Tree species predominated at 2843 to about 3500 masl and were rare above that. *Myrsine melanophloeos*, *Schefflera abyssinica*, and *J. procera* were the dominant tree species, while *Bersama abyssinica* subsp. *abyssinica*, *D. torrida*, *M. lanceolata*, *S. volkensii*, and *Afrocarpus falcatus* were the rarest. The rate of disturbance expressed in terms of tree felling was very high in the dry evergreen Afromontane vegetation.

In the dry Afromontane vegetation, 9 tree species were recorded, of which 5 were found to be harvested. About 95.6% of the stumps (65) were recorded in the disturbed plots; only stumps of *S. abyssinica* and *H. abyssinica* were recorded in the undisturbed plots. *Hypericum revolutum* had been highly harvested in all of the disturbed plots, while *S. abyssinica* was least harvested.

Only a few tree species reproduced. *M. melanophloeos* was the most frequently reproducing species, mostly in undisturbed plots, while *S. abyssinica* and *H. abyssinica* had reproduced the least. The rate of tree recruitment was below the rate of tree felling (as indicated by stumps) in most cases (Table 3).

The species accumulation curve (Figure 5) suggests that our sampling on 104 plots detected a large majority of the plants in the study area. The shape of the species curve indicates the expected pattern of initial exponential increase in species with increasing sampling, then gradually slowing as more samples are added until the curve flattens out. Hence, the 191 plant species recorded in the study area were considered to be within the third quartile of total richness. The species accumulation curve indicates that the majority of plant species in the study area were captured by our sampling efforts.

Discussion

Compared to other natural ecosystems such as tropical rainforests, those investigated in this study—the Afro-alpine, subalpine, and dry evergreen Afromontane vegetation types—are considered species poor (Hedberg 1971; Whitmore 1996; Ahmed 2013). Asteraceae and Poaceae were dominant families in the study area. A number of factors probably contributed to the success of these 2 families. The parachute-like structures in *Helichrysum*, *Senecio*, and other genera of Asteraceae improve air flotation and contribute to their widespread dispersal, especially when strong winds are prevalent in the Afro-alpine zone (Hedberg 1971). Poaceae have tiny seeds capable of being windblown for long distances; this can lead to colonization of bare rock during and after mountain formation (Hedberg 1957). Wind has aided the long-distance dispersal of many Afro-alpine plants in East African mountains (Hedberg 1964).

Anthropogenic fire is frequent in the subalpine and Afro-alpine zones and can foster the spread and dominance of grasses in these areas (Wesche et al 2000). Grasses quickly regenerate after a burn, giving them an advantage over other species. *Erica* species also benefit from fire, sprouting from portions of the lignotuber that had been buried under moist humus, as Johansson (2013) found in the Bale Mountains National Park in southeastern Ethiopia for *E. arborea* and *E. trimera* (Johansson 2013). Similar studies carried out across East Africa mountains—Mounts Kenya, Elgon, Kilimanjaro, Ruwenzori, Bale, and Simen (Ahmed 2013)—also suggest

TABLE 3 Tree felling and regeneration in dry evergreen Afromontane natural forest.

Species	Seedlings/saplings			Tree stumps		
	No. of plots occurred in	No. of individuals	Density	No. of plots occurred in	No. of individuals	Density
<i>Myrsine melanophloeos</i>	12	24	0.0100	7	25	0.0104
<i>Hypericum revolutum</i>	7	19	0.0079	9	28	0.0117
<i>Juniperus procera</i>	2	5	0.0021	4	12	0.005
<i>Schefflera abyssinica</i>	1	1	0.0001	1	1	0.0001
<i>Hagenia abyssinica</i>	1	1	0.0001	2	2	0.0008

that Asteraceae and Poaceae are dominant in Afro-alpine vegetation. Asteraceae was also found to be the dominant family in Dodola dry evergreen Afromontane forest in the Bale mountains (Hundera et al 2007).

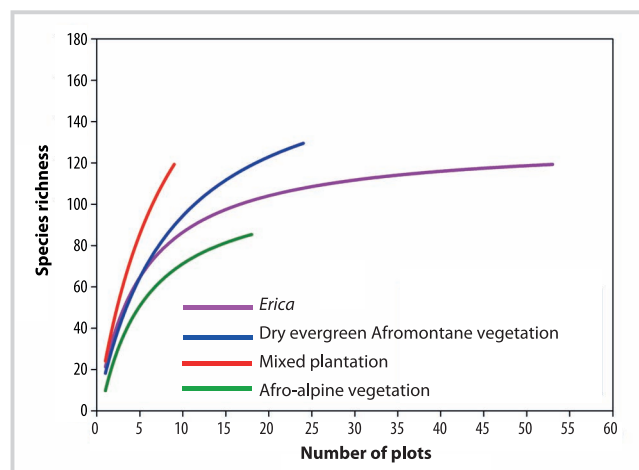
The dominance of the shrub *R. steudneri* and herbs like *A. pedata* and *C. alsinoides* in the dry evergreen Afromontane forest could be due to elevation, soil, and climate factors that support the growth of these species. Other studies in dry evergreen Afromontane forests in Ethiopia have reported similar findings (Abate 2003; Hundera et al 2007).

The decrease in total species richness and number of tree species with increasing elevation is likely due to ecological and physiological constraints, such as reduced growing season, low temperature, and low ecosystem productivity (Miehe and Miehe 1994). In higher elevations (above 3600 masl), the temperature often falls below the freezing point of water, which decreases the available water to the plants and leads to chilling; only plants that are adapted to such climatic conditions grow, reducing species diversity at higher elevations (Afro-alpine vegetation) (Hedberg 1964). For example, Afro-alpine vegetation species have developed xenomorphic

characteristics like stem reduction (eg *Haplocarpha* and *Haplosciadium* species) and tussock forming for insulation and protection of vascular tissue (eg *Carex* and *Festuca* species) (Hedberg 1964; Ahmed 2013).

The soil type of the study area varies from Pellic Vertisols in lower elevations to Eutric Nitosols on the mountain summits (Tekle 1984), which directly affects the type of vegetation. Soil type and texture have been reported to affect plant species composition, abundance, and structure in the mountains of Ethiopia (Tekle 1984; Woldu et al 2002; Friis et al 2010). Particularly, Nitosols are acidic and nutrient poor, which can reduce species diversity at higher elevations (Tekle 1984). Mountains resemble islands in their reduced accessibility to colonization by plants and animals. As elevation increases, the isolation of slopes from pathways of migration increases linearly. With a reduction in the channels available for dispersal, there is a reduction in the number of species that occupy high-elevation sites. Studies in similar mountain localities have pointed out that tree species richness decreases with increasing elevation, since elevation affects light, soil, and climate factors that influence the growth and development of plants and the distribution of vegetation (Hedberg 1964; Miehe and Miehe 1994; Senbeta and Teketay 2003; Hundera et al 2007; Schmitt et al 2010; Erenso and Maryo 2014).

Human activities (wood collection, fire, and livestock grazing) have altered the vegetation composition and structure in the study area, resulting in highly disturbed secondary vegetation, especially in the dry evergreen Afromontane forest. Overgrazing and wood collection can threaten the survival of highly palatable grazed plants and timber trees. This is probably the reason for the absence of rare species in the disturbed plots. The dominance of herbaceous plants in the dry evergreen Afromontane forest, especially in the disturbed plots, could be an indication that most of the trees have been logged and shrubs cut for fuel and fencing. For example, the Jibat humid Afromontane forest was dominated by herbaceous plants (34.5%) following human disturbances (Burju et al 2013). Invasive species that are favored by degradation of habitats were more abundant in the moderately disturbed habitat of dry evergreen Afromontane vegetation in the

FIGURE 5 Species accumulation curves for all species in the 4 vegetation types.

Bale Mountains National Park (Asefa et al 2015). This could be the reason some rare species are absent from most disturbed plots in most habitat types. Other studies have found changes in forest diversity and structure as a result of human-induced disturbances (Kumar and Ram 2005; Chown 2010).

Some disturbances, such as the selective logging of trees, can create canopy openings that actually promote biodiversity. Studies elsewhere in the world have indicated that forest gaps favor the germination and growth of light-demanding understory vegetation and thus ultimately increase plant diversity (Mishra et al 2004; Senbeta et al 2005; Bongers et al 2009). Nevertheless, disturbances in our study area (since it is above the threshold required for normal canopy openings) can threaten its endemic and endangered species and can ultimately transform it into a human-dominated landscape.

This study has investigated the composition and distribution of plant species in the Galama Mountains in Arsi Mountains National Park, Ethiopia, where severe anthropogenic threats (wood collection, fire, and livestock encroachment) and inaccessibility play a stronger role, as is the case in other mountains in Ethiopia and eastern Africa. Hence, the methods used to study the vegetation in

this mountain region can be replicated in similar inaccessible and highly threatened mountain ecosystems. The findings of the study will be an important input for sustainable conservation of mountain ecosystems in Ethiopia and all of East Africa. The methods presented in this paper can be used for other monitoring studies of mountain plant species.

Conclusion

The Galama Mountains harbor diverse plant species including species endemic to Ethiopia. Plant species diversity and structure vary across environmental gradients such as elevation, slope, and level of disturbance. Threats like wood collection and livestock encroachment have affected species diversity and distribution. This study has provided important information on floral composition and distribution in the Galama Mountains that can help inform the management plan for the Arsi Mountains National Park and can be used as a baseline for further detailed vegetation studies in the park's Afro-alpine, subalpine, and dry evergreen Afromontane ecosystems.

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Supplemental material

TABLE S1 Species abundance ranking by habitat and for the whole study area (listed according to their overall rank).

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