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Regeneration Response of *Juniperus procera* and *Olea europaea* subsp *cuspidata* to Exclosure in a Dry Afromontane Forest in Northern Ethiopia

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The Afromontane forests of northern Ethiopia have been degraded and fragmented for centuries. Recently, efforts have been made to restore these forests by protecting them from livestock interference. In this study, the natural regeneration of Juniperus procera *Hochst. ex Endl. and* Olea europaea *L. subsp* cuspidata *(Wall. ex G. Don) Cif. is investigated under protected conditions after 3 years of enclosure and under open management systems in a dry Afromontane forest in northern Ethiopia. Data on the floristic and structural compositions of the vascular plants were collected using 32 randomly selected plots (20 m × 20 m), while nested plots (10 m × 10 m) were used to investigate the seedling bank at the protected and adjacent open sites. The results reveal that there was a significantly higher regeneration of* O. europaea *on the protected site than on the open site (*$P = 0.01$*). However, there was no significant difference between the 2 sites for* J. procera *(*$P = 0.16$*). Thus, protecting the degraded forest in northern Ethiopia seems to be an appropriate management option for the regeneration of* O. europaea*. The regeneration status of* J. procera *at both sites is poor, which indicates that protecting the forest from livestock and human disturbance is unlikely to lead to regeneration of this species. Further investigation of other factors that hinder the regeneration of* J. procera *is therefore recommended.*

Keywords: *Dessea; dry forest; forest restoration; natural regeneration; succession; exclosure; Ethiopia.*

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Introduction

In many tropical forests, excessive deforestation has hampered natural regeneration and seedling establishment and affected the diversity and structure of plant communities (Denslow 1980, 1987; Runkle 1982; Bussmann 2001). Similarly, forests in Ethiopia have been affected by climatic and anthropogenic factors for centuries (Friis 1992; Machado et al 1998; Tekle and Hedlund 2000; Zeleke and Hurni 2001; Dessie and Kleman 2007). Historically, soil erosion as a result of vegetation clearing in the highlands of Tigray, for instance, is recorded in the Middle Holocene (Bard et al 2000; Darbyshire et al 2003). The vascular plants of the Afromontane forests of Ethiopia maintain their population through natural regeneration (Teketay 1997). However, large-scale degradation of natural forest in Ethiopia has created a major challenge with respect to the regeneration of key native tree species (Wassie 2009a) while favoring herb and shrub colonizers. For instance, Dessea Afromontane forest, which was dominated by *Juniperus procera* and *Olea europaea* prior to disturbance, has been gradually replaced by encroaching light-demanding shrubs such as *Cadia purpurea* L. and *Tarchonanthus camphoratus* L. In response to such disturbances, area exclosures have been introduced in some Afromontane forests in northern Ethiopia in recent years (eg Yayneshet et al 2009).

Natural regeneration is a site-specific ecological process, and it is usually difficult to characterize the factors that control the regeneration processes (Schupp 1988; Khurana and Singh 2001). Protecting areas from livestock intervention—a practice termed exclosure—is an assisted natural regeneration strategy to restore degraded forests in the tropics (Parrotta et al 1997; Shono et al 2007). Many degraded sites have been managed as exclosures in northern Ethiopia, and attempts have been made to document the regeneration and ecology of the plants in these exclosures.

Although it is difficult to generate a specific management plan for exclosures (Mengistu et al 2005a; Muys et al 2006), many studies have indicated that vegetation recovery in the exclosures is quick, particularly in the younger stages (Mengistu et al 2005a; Abebe et al 2006). Assefa et al (2003) and Yayneshet et al (2009) found that exclosures do not significantly contribute to the diversity and biomass of plants after 8 years of exclosure, suggesting the need to introduce additional management measures to restore key native species. Some studies on vegetation restoration in Ethiopia have suggested that the

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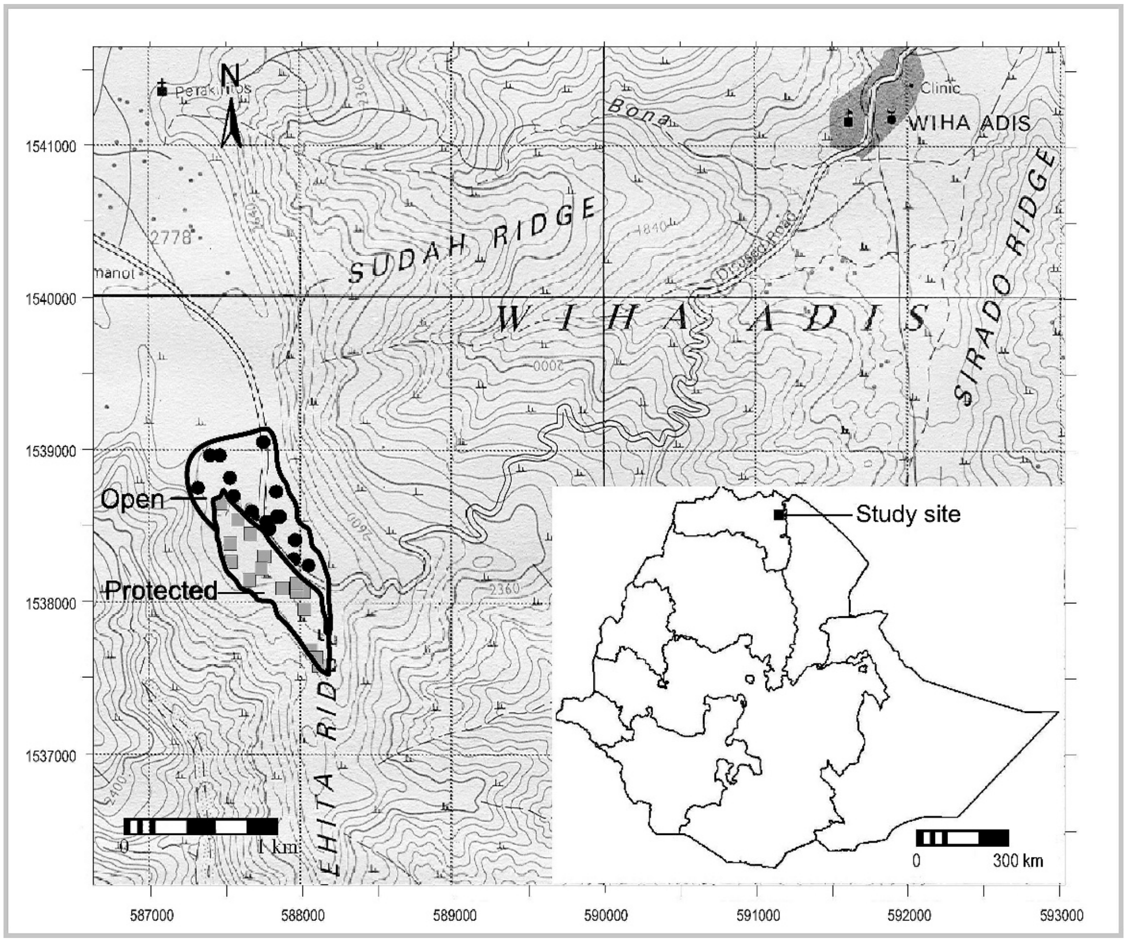
FIGURE 1 Location of the study plots used in the protected and open sites at Dessea forest in northern Ethiopia (Map projection: UTM Zone 37N, Datum: Adindan); the topographic map (EMA 1998) is used as background. (Map by authors)



presence of matured trees as useful seed sources (Tekle and Bekele 2000), plantations (Senbeta and Teketay 2001; Yirdaw 2001; Lemenih et al 2004), and minimization of livestock pressure (Aerts at al 2007) create favorable environments for the regeneration of native species.

Although some studies exist regarding the regeneration and ecology of *J. procera* and *O. europaea* in the northern Ethiopian highlands (Aerts et al 2006b; Wassie et al 2009a) and other parts of Ethiopia (Senbeta and Teketay 2001; Tesfaye et al 2002; Bekele 2005), little is known about regeneration in the degraded Afromontane forest in northern Ethiopia. Thus, the aim of this study is to investigate the ways in which exclosure, protecting forests from livestock and human interference, affects restoration of the degraded forests in this region. Specifically, we studied the seedling abundance of *J. procera* and *O. europaea* in a forest that had been protected for the past 3 years in comparison to an open-management system.

Material and methods

Study site

The study was conducted in the Dessea forest, which is one of the Afromontane (White 1983) forest remnants in northern Ethiopia. The site is located at 13°55′3″N, 39°48′46″E at an altitude of 2700 m above sea level (Figure 1). The physiographic units map of the forest vegetation of eastern and northeastern Africa (Friis 1992) illustrates that the study site is located on the Tigrean Plateau, which lies immediately above the escarpment of the Rift Valley in northern Ethiopia. A large part of the site is located on shale, limestone, and sandstone of the Tertiary and Mesozoic era (TFAP 1996). Based on the diverse geological formations, the soils are variable; the dominating soil types in the study region are Leptosols, Cambisols, Vertisols, Regosols, and Arenosols (TFAP 1996).

TABLE 1A List of overstory species recorded in the protected and open sites in Dessea forest, northern Ethiopia. (Table continued on next page.)

Overstory species	Family	Abundance		Frequency	
		Protected	Open	Protected	Open
Juniperus procera Hochst. ex Endl.	Cupressaceae	642	814	100	100
Olea europaea L. subsp *cuspidata* (Wall. ex G. Don)	Oleaceae	57	42	94	81
Solanum schimperianum Hochst. ex A. Rich.	Solanaceae	120	268	88	100
Maytenus senegalensis (Lam.) Exell.	Celasteraceae	35	22	88	63
Dodonaea viscosa Jacq.	Sapindaceae	84	5	19	13
Rhus sp	Anacardiaceae	13	11	25	31
Clutia lanceolata Forssk.	Euphorbiaceae	10	16	19	31
Carissa edulis Vahl	Apocynaceae	14	0	13	0
Acacia etbaica Schweinf.	Fabaceae	1	0	6	0
Cassipourea malosana (Bak.) Alston.	Rhizophoraceae	1	3	6	13
Ficus palmata Forssk.	Moraceae	1	0	6	0
Canthium setiflorum Hiern	Rubiaceae	1	0	6	0
Solanum adoense Hochst. ex A. Rich.	Solanaceae	1	0	6	0
Canthium oligocarpum Heirn	Rubiaceae	2	1	5	8
Erica arborea L.	Ericaceae	1	0	0	0
Cadia purpurea (Picc.) Ait.	Fabaceae	3	1	3	4
Pappea capensis Eckl. & Zey	Sapindaceae	2	0	1	0

Study species

The forests of eastern and northeastern Africa are categorized into 9 major floristic groups (see Friis 1992). Accordingly, the Dessea forest is categorized as a dry single-dominated Afromontane forest, which is characterized by a dry climate (annual precipitation less than 1000 mm) and *Juniperus procera* Hochst. ex Endl (Cupressaceae) in the canopy and *Olea europaea* subsp *cuspidata* (Oleaceae) in the understorey as dominant species. *Juniperus procera* is widely grown from Arabia to Zimbabwe (Hall 1981). Due to heavy pressure on this species, the Food and Agriculture Organization (FAO) has listed it as a threatened species that requires in situ conservation priority beginning 1985–1989 (FAO 1975). James Bruce first documented *J. procera* as a common forest tree species in the highlands of northern Ethiopia during his expedition to trace the origin of the Blue Nile (1768–1773) (Bruce 1790, cited in Friis 1992). *Juniperus procera* has a slow germination rate (Yirdaw and Leinonen 2002) and low germination capacity, which are mainly attributed to seed dormancy (Tigabu et al 2007).

The genus *Olea* has 33 species, and *Olea europaea* subsp *cuspidata* is one of the subspecies that was previously named *Olea africana*. The species is commonly called the African olive and is widely distributed from Arabia to southern Africa. Although it is a useful tree species in its natural habitat, it is categorized as an invasive plant in countries like Australia (Cuneo and Leishman 2006) and Hawaii (Santos et al 1992). *Olea europaea* is a common species in the highlands of Ethiopia. The natural regeneration of the species in Ethiopia has been studied and documented by many authors (eg Bekele 2005; Teketay 2005; Aerts et al 2006a).

Sampling design

A small part of the Dessea forest has been protected from human and livestock interference for the last 3 years in order to restore the degraded forest (hereafter referred to as protected forest). The area is protected by forest guards. We mapped the protected site and the adjacent open forest, which has similar geology, soils, and vegetation to the protected site, using a global positioning system (GPS). Later, the GPS data were

TABLE 1A Continued. (First part of Table 1A on previous page.)

Overstory species	Family	Dominance		IV (%)	
		Protected	Open	Protected	Open
Juniperus procera Hochst. ex Endl.	Cupressaceae	9.53	11.35	161.01	170.54
Olea europaea L. subsp *cuspidata* (Wall. ex G. Don)	Oleaceae	2.19	2.46	41.71	39.01
Solanum schimperianum Hochst. ex A. Rich.	Solanaceae	0.03	0.06	29.36	45.64
Maytenus senegalensis (Lam.) Exell.	Celasteraceae	0.13	0.08	21.64	16.50
Dodonaea viscosa Jacq.	Sapindaceae	0.12	0.03	13.04	3.43
Rhus sp	Anacardiaceae	0.35	0.33	8.99	10.30
Clutia lanceolata Forssk.	Euphorbiaceae	0.00	0.00	4.66	8.40
Carissa edulis Vahl	Apocynaceae	0.04	0.00	4.16	0.00
Acacia etbaica Schweinf.	Fabaceae	0.00	0.00	1.32	0.00
Cassipourea malosana (Bak.) Alston.	Rhizophoraceae	0.00	0.00	1.32	3.07
Ficus palmata Forssk.	Moraceae	0.00	0.00	1.32	0.00
Canthium setiflorum Hiern	Rubiaceae	0.00	0.00	1.32	0.00
Solanum adoense Hochst. ex A. Rich.	Solanaceae	0.00	0.00	1.32	0.00
Canthium oligocarpum Heirn	Rubiaceae	0.01	0.02	0.61	0.42
Erica arborea L.	Ericaceae	0.01	0.00	0.50	0.00
Cadia purpurea (Picc.) Ait.	Fabaceae	0.02	0.03	0.40	0.60
Pappea capensis Eckl. & Zey	Sapindaceae	0.01	0.00	0.31	0.00

transferred to a geographic information system (GIS) environment for further mapping. The protected and open sites have a size of 33 and 43 ha, respectively. Regeneration at the two sites was compared using a total of 32 randomly selected plots, ie 16 from each site. A plot size of 20 m × 20 m was used to collect data on floristic compositions of woody species and structural composition of *J. procera* and *O. europaea*, while nested plots (10 m × 10 m) were used to identify and record seedlings. Emphasis was placed on the 2 key native target species (ie *Juniperus procera* and *Olea europaea*).

Data analysis

The relative dominance of all woody species was determined using the importance value index (IVI) (Mueller-Dombois and Ellenberg 1974). The IVI of a species was computed by summing up the relative density, relative dominance, and relative frequency of individual species. Dominance is the basal area of each species (sum of the basal area of each plant: $g = \pi[\text{Dbh}^2/4]$, where Dbh is the diameter at breast height), and frequency is the percentage of plots in which a species is recorded. Species diversity was determined using the Shannon Wiener diversity index and Simpson's Index of Diversity given by Magurran (1988).

The generalized linear model (GLM) with quasi-Poisson distribution (with log link) was used to determine the effect of management on seedling abundance of *J. procera* and *O. europaea* using R software version 2.7.0 (R Development Core Team 2008). The family quasi-Poisson distribution was used because there were overdispersions when Poisson distribution was run (Crawley 2007). For a better visualization and consideration of spatial correlations (Webster and Oliver 2001), the spatial distribution of seedling density (number of seedlings per plot) was mapped using the ordinary kriging interpolation method with the Integrated Land and Water Information System (ILWIS 3.3) GIS software (ITC 2001).

Results

Floristic compositions

In total, 17 vascular plant species (with measured Dbh) belonging to 12 families were recorded at the open and protected sites, and *J. procera* Hochst. ex Endl. was the dominant species with the highest relative importance

TABLE 1B List of seedling species recorded in the protected and open sites in Dessea forest, northern Ethiopia.

Seedling species	Family	Abundance		Frequency	
		Protected	Open	Protected	Open
Olea europaea L. subsp *cuspidata* (Wall. ex G. Don) Cif.	Oleaceae	498	232	100	100
Juniperus procera Hochst. ex Endl.	Cupressaceae	25	44	63	75
Maytenus senegalensis (Lam.) Exell.	Celasteraceae	33	54	63	69
Solanum schimperianum Hochst. ex A. Rich.	Solanaceae	12	0	19	0
Ficus palmata Forssk.	Moraceae	1	2	6	6
Sageretia thea (Osbeck) M.C. Johnston	Rhamnaceae	2	0	6	0
Dodonaea viscosa Jacq.	Sapindaceae	11	0	13	0
Dovyalis abyssinica (A. Rich.) Warb.	Flacourtiaceae	1	0	6	0
Plectranthus ornatus Codd	Lamiaceae	1	0	6	0
Carissa edulis Vahl	Apocynaceae	1	0	6	0

value (Table 1A and 1B). This species, together with *Olea europaea* L. subsp *cuspidata* (Wall. ex G. Don) Cif., *Solanum schimperianum* Hochst. ex A. Rich., and *Maytenus senegalensis* (Lam.) Exell., was the most common species, found in more than 75% of the plots, while *Erica arborea* L. was among the rare species, recorded only once in a plot.

Species richness and diversity of woody plants were higher at the protected than at the open site (Table 2). The stem density (number of stems per hectare) of *J. procera* was higher at the open (1272 ± 170, mean ± SE) than at the protected site (947 ± 252). In contrast, the density of *O. europaea* was higher at the protected (87 ± 19) than at the open (67 ± 22) site. The average density of all woody plants at the open site (1853 ± 75) was higher than at the protected site (1499 ± 264). The mean basal areas of the woody plants at the protected and open sites were 19.4 and 21.1 m^2 ha^{-1}, respectively.

Structural compositions of *J. procera* and *O. europaea*

The diameter distribution of *J. procera* indicates that the number of individuals in the lower-diameter class, including seedlings, is very low (Figure 2). The highest numbers of *J. procera* individuals were found in the diameter class of 2–6.9 cm, declining with increasing diameter. Although the number of individuals at the open site was a bit higher than at the protected site, the population structure in both sites followed a similar trend. The seedling population of *O. europaea* was much higher than the subsequent higher-diameter classes. Although the number of individuals was low, more *O. europaea* saplings were recorded at the protected than at the open site.

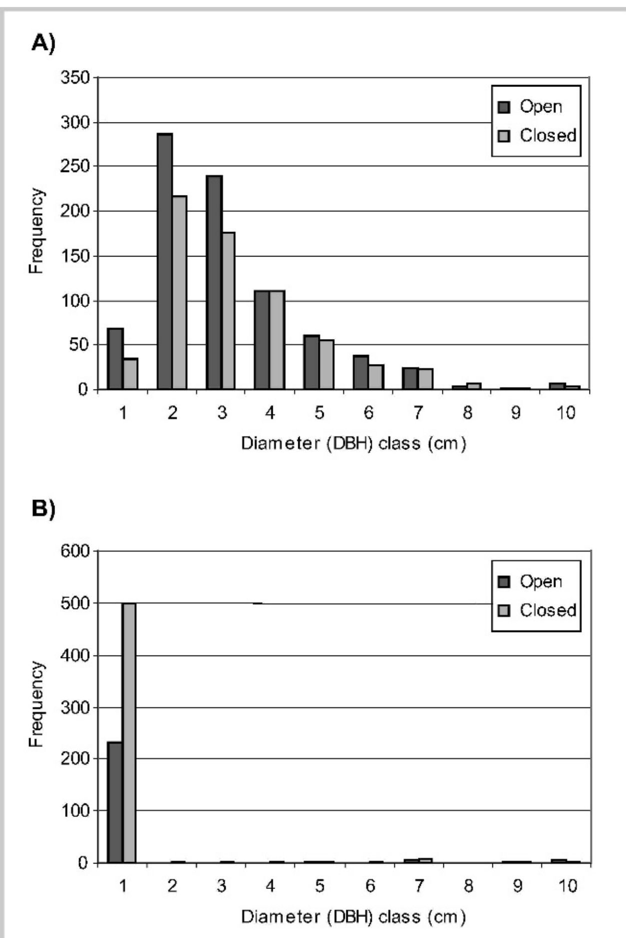
Natural regeneration

In total, 10 species of vascular plants were recorded in the seedling bank. As for the overstory plants, *O. europaea*, *J. procera*, and *M. senegalensis* seedlings were the most dominant species and were recorded in more than 65% of the plots (Table 1B). The seedling density (number of seedlings per hectare) of *O. europaea* was significantly higher at the protected site (3113 ± 1852, mean ± SE) than at the open site (1450 ± 929) ($F_{1,30} = 7.29$, $P = 0.01$). The seedling density of *J. procera* was slightly higher at the open site (275 ± 156) than at the protected site (156 ± 104), but the difference was not statistically significant ($F_{1,30} = 2.1$, $P = 0.16$) (Table 3).

TABLE 2 Summary of vegetation attributes (mean ± SE) of all woody species and densities (number of stems per ha) of *J. procera* and *O. europaea* in protected and open sites in Dessea forest, northern Ethiopia.

Attribute	Management	
	Open	Protected
Density *J. procera*	1272 ± 170	947 ± 252
Density *O. europaea*	67 ± 22	87 ± 19
Density all species	1853 ± 75	1499 ± 264
Basal area of all species	21.10	19.40
Species richness	9.00	14.00
Shannon Wiener Diversity Index (H′)	1.08	1.42
Simpson's Index of Diversity (D)	0.56	0.63

FIGURE 2 Diameter (Dbh) class distribution of (A) *J. procera* and (B) *O. europaea* L. subsp *cuspidata* in the protected and open sites. Diameter classes (cm): 1 = < 2; 2 = 2–6.9; 3 = 7–11.9; 4 = 12–16.9; 5 = 17–21.9; 6 = 22–26.9; 7 = 27–31.9; 8 = 32–36.9; 9 = 37–41.9; 10 = > 42.



The spatial distribution of *J. procera* and *O. europaea* seedling densities at the open and protected sites is depicted in the kriged maps (Figure 3), which indicate that forest protection has a different effect on the species abundance of the 2 species.

Discussion

Our results show higher species diversity and seedling abundance at the protected than the open site, suggesting that protection of the forest contributes positively to Dessea forest restoration in northern Ethiopia. Similar findings have been reported for other protected areas located in relatively mesic environments in northern Ethiopia (eg Mengistu et al 2005b; Yayneshet et al 2009). Although *J. procera* and *O. europaea* are the dominant species (ie the target species in this study) in Dessea forest, they responded differently in terms of regeneration to the restoration intervention (Figure 3). We found significantly higher seedling abundance of *O. europaea* at the protected site than at the open one. However, there was no evidence of any direct effects of exclosure on the abundance of *J. procera*, calling for further investigation on other influencing factors.

The structural composition analysis for *J. procera* (Figure 2) indicates that this species is less represented in the lower-diameter classes, in which higher regeneration and recruitment are needed for a viable population of the species. Although *J. procera* is the most dominant species in the overstory and has higher availability of seeds in the study area, seedling abundance in both protected and open sites was very low. This is also in agreement with the findings of Wassie et al (2009a), who found lower regeneration of *J. procera* in church forests in other parts of northern Ethiopia. Although not statistically significant, we found higher regeneration of *J. procera* at

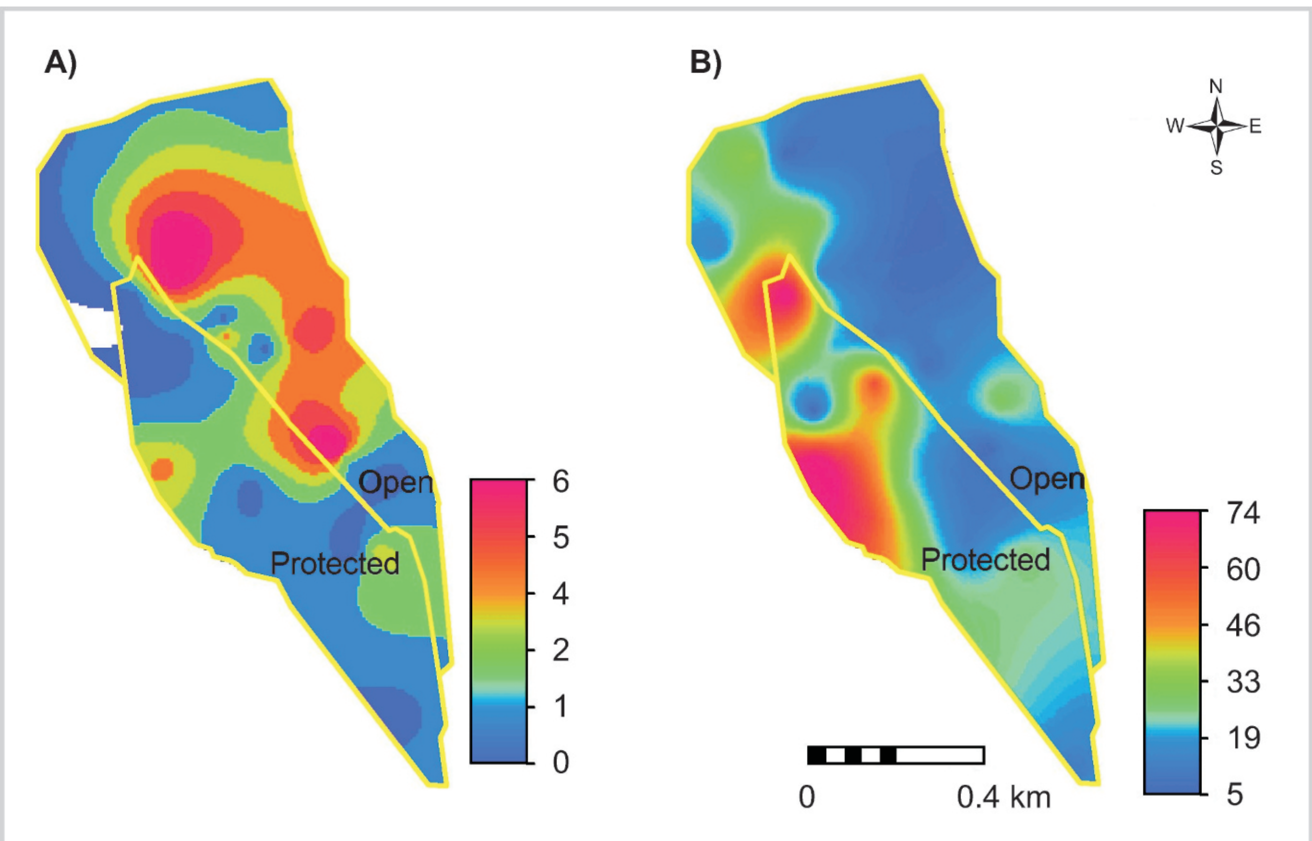
TABLE 3 Seedling density (mean ± SE) of *J. procera* and *O. europaea* under open and protected management systems in Dessea forest, northern Ethiopia.

Species	Management	Seedling density (number of seedlings per ha)	F	P
J. procera	Open	275 ± 156	2.10	0.16
	Protected	156 ± 104		
O. europaea	Open	1450 ± 929	7.29	0.01
	Protected	3113 ± 1852		

the open than at the protected site (Table 3). Our results thus reinforce the findings of Mamo et al (2006), who reported that *J. procera* has poor germination capacity under field conditions, suggesting a need for additional manipulation.

Although some studies have indicated that light may not be a major limiting factor for the germination of *J. procera* (Sharew et al 1997; Wassie et al 2009a), the dense grass and herb cover at the protected site might prevent optimum radiation of the forest floor (Yirdaw and Leinonen 2002; Teketay 2005) and thus influence germination (Cabin et al 2002). The thick, less decomposable litter of *J. procera* (Prescott et al 2000) at the protected site also prevents seeds from contacting the soil. This might slow down the breaking of seed dormancy, which would ultimately hamper germination (Rotundo

FIGURE 3 Kriged maps showing spatial distribution of seedling density of *J. procera* (A) and *O. europaea* (B) at the open and protected sites. Numbers in the legend indicate the number of seedlings per plot (10 m × 10 m).



and Aguiar 2005; Cierjacks et al 2008). The thick litter might also have influenced emergence of newly germinated seedlings (Yirdaw and Leinonen 2002; Teketay 2005).

Seed dormancy, which varies depending on the provenance of *J. procera* in Ethiopia (Tigabu et al 2007), might also influence germination. Sharew et al (1997) found that land preparation by raking and burning increased the germination capacity of this species. Hence, the relatively higher abundance of *J. procera* seedlings at the open compared to the protected site indicates that other factors such as absence of shade, less litter, low livestock preference, and the breaking of seed dormancy through livestock pressure and erosion processes may determine regeneration. As reported by Cierjacks et al (2008) for *Polylepis* species in Ecuador, trampling by livestock may have contributed to the better regeneration of *J. procera* in the open than in the protected site.

We found higher seedling abundance of *O. europaea* at the protected site than at the open one (Table 3), indicating that this species is negatively influenced by livestock browsing and other microsite characteristics such as shade. Studies have indicated that the establishment and recruitment of *O. europaea* are better under shaded and protected conditions (Fetene and Feleke 2001; Bekele 2005; Aerts et al 2008). In contrast, Tesfaye et al (2002) found that *O. europaea* was a light-demanding species in the Harena forest in the southeastern highlands of Ethiopia, which is wetter than our study site. This indicates that *O. europaea* requires shade in drier environments, which also supports our findings. Holmgren et al (1997) indicated that shade lessens the water deficit by reducing moisture loss during the dry season and improves seedling establishment in dry areas. In line with this, Aerts et al (2006a) also found successful regeneration of *O. europaea* under *Euclea* shrubs, which create a better moisture regime through thick humus and organic matter accumulation (Descheemaeker et al 2006) in protected sites in northern Ethiopia. Rey et al (2000) also found that regeneration of *O. europaea* is influenced more by abiotic than by biotic factors, and that availability of moisture is the limiting factor. Although trees of this species are more resistant to browsing (Tesfaye et al 2002; Aerts et al 2007), seedlings are more sensitive to herbivory (Tesfaye et al 2002). Thus, protection of *O. europaea* seedlings from herbivory at the protected site contributed to a higher abundance of seedlings than at the open site. Like Aerts et al (2008), we observed a good proportion of coppice shoots of this species in the protected site, which may assist restoration of the degraded dry forest in the study site.

The complete closing of Dessea forest where the density of trees is low might favor the production of pasture (Richter et al 2001; Cabin et al 2002). Such efforts may cause a gradual shift of forestland to wooded grassland. Hence, it is important to plan other intervention measures alongside protection that regulate the extensive cover of the forest habitat by grass and other herbs (Cabin et al 2002). It is well documented that livestock are important agents of regeneration (eg Cierjacks et al 2008). However, in degraded environments where there is overgrazing, the impact of livestock in enhancing regeneration is limited. Instead, livestock contribute negatively (Wassie et al 2009b) in such environments through intensive browsing. In such degraded environments, species such as *O. europaea* are frequently browsed and suppressed to the extent of losing their ecological resilience (Gunderson 2000) in the absence of other feed sources, particularly during the long dry season.

Implications for management

Results of many studies have concluded that there is a strong need to give more priority to conservation of the existing natural forest remnants in northern Ethiopia before they lose their ecological resilience (eg Nyssen et al 2004; Aerts et al 2006b). In this regard, our study revealed that protecting the degraded natural forest contributed positively to the natural regeneration of *O. europaea* in the Dessea forest. The study has, therefore, provided scientific knowledge to support a change from the traditional pattern of exploitation to a targeted management of the species. However, other management options or factors seem to influence the natural regeneration of *J. procera* other than protecting this species from livestock and related disturbances. It may also be worthwhile to consider other management options such as enrichment planting and reducing litter accumulation and dense grass cover, especially in the protected areas, as suggested by Yirdaw and Leinonen (2002), in order to maintain a viable population of *J. procera*.

Based on our findings, we conclude that restorion of the degraded dry Afromontane dry forest in northern Ethiopia through exclosures requires a better understanding of the ecological requirements of the different species involved. Since the objective of forest restoration is to improve the status of key native tree species, experience from the exclosures in other areas should be carefully applied when attempting to restore degraded dry forest remnants in the study area. Our study is based on a 3-year protection period, and thus the results should be interpreted cautiously and extrapolated to other forests with care.

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