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THE IMPORTANCE OF EARLY SUCCESSIONAL SHRUBS FOR RECRUITMENT OF AFRICAN WILD OLIVE (*OLEA EUROPAEA* SUBSP. *CUSPIDATA*) IN CENTRAL TIGRAY, ETHIOPIA

R. AERTS[1,3], I. VAN DER BORGHT[1,3], E. NOVEMBER[2,3], MINTESINOT BEHAILU[3], M. HERMY[1] & B. MUYS[1,*]

[1]Laboratory for Forest, Nature and Landscape Research, Katholieke Universiteit Leuven, Vital Decosterstraat 102, B-3000 Leuven, Belgium
[2]Laboratory for Soil and Water, Katholieke Universiteit Leuven, Vital Decosterstraat 102, B-3000 Leuven, Belgium
[3]Land Resources Management and Environmental Protection Department, Mekelle University, P.O.Box 231, Mekelle, Ethiopia
*Corresponding author: bart.muys@agr.kuleuven.ac.be

Abstract

Recruitment of a late successional tree species, African wild olive (*Olea europaea* subsp. *cuspidata*; Oleaceae), was examined in protected and grazed areas in the Geba river catchment of central Tigray, northern Ethiopia, using T-square plotless sampling. The following hypothesis was tested: recruitment of *O. europaea* is higher under certain early colonizing shrubs compared to within gaps and under other shrubs. Both in grazing land and protected areas, recruits were exclusively found under shrubs, predominantly under *Euclea schimperi*, although *Acacia etbaica* was dominant by far in all sampled land uses. Structural traits of shrubs explain this disparity. However, early results of further research suggest that *E. schimperi* shrubs probably act as preferential perching sites for frugivorous birds and that dispersal of *Olea* propagules is directed to dense *E. schimperi* shrubs with a high number of stems at ground level. The application of appropriate protection of early successional shrubs combined with simple silvicultural measures can therefore significantly enhance natural regeneration of indigenous woodlands in the region without having to rely on expensive plantation activities.

Key words: facilitation, *Olea*, recruitment, shrubs, succession

Résumé

Importance des arbustes pionniers pour le recrutement de l'olivier sauvage africain (*Olea europaea* subsp. *cuspidata*) dans le Central Tigray, Ethiopie. L'olivier sauvage africain (*Olea europaea* subsp. *cuspidata*; Oleaceae), qui apparaît tardivement dans la succession, a été examiné dans des zones protégées et pâturées du bassin de la rivière Geba dans le Central Tigray au nord de l'Ethiopie, sur base d'un échantillon T-square plotless. L'hypothèse suivante a été testée: le recrutement de *O. europaea* est plus important sous certains arbustes colonisateurs précoces que dans des clairières et sous

d'autres arbustes. Tant en zone pâturée que dans des régions protégées, les recrûs ont été exclusivement trouvés sous des arbustes, principalement sous *Euclea schimperi*, alors que *Acacia etbaica* était de loin l'arbuste dominant dans tous les placeaux échantillonnés. Les différences de structure des arbustes expliquent cette disparité. Néanmoins, les premiers résultats des recherches suggèrent que *E. schimperi* agit préférentiellement comme perchoir pour les oiseaux frugivores et que la dispersion des diaspores de *Olea* est dirigée vers les peuplements denses de *E. schimperi*. Une protection appropriée des arbustes pionniers combinée à des mesures sylvicoles simples pourrait par conséquent accroître la régénération naturelle des forêts claires indigènes sans avoir à recourir à de coûteuses plantations.

1 Introduction

The ability of rehabilitation areas to recruit and sustain new life forms is a true measure of their contribution to biodiversity and forest resource conservation (Tucker & Murphy, 1997). In Africa, relatively few studies have evaluated the effect of early colonizing shrubs on woody seedling establishment. Shrubs might facilitate, tolerate or inhibit different stages of tree establishment in abandoned pastures or croplands (Holl, 2002). Moreover, little is known about the specific consequences of avian seed-disperser activity and their interaction with perch and non-perch sites for plant demography (Rey & Alcántara, 2000).

Most research on the ability of trees and shrubs to promote recruitment of woody plants by attracting seed dispersers has been conducted in the temperate zones of the northern hemisphere, in the neotropics and in southeast Asia and tropical Australia (see McDonnell & Stiles, 1983; Guevara *et al.,* 1986; McClanahan & Wolfe, 1987; Guevara & Laborde, 1993; Parrotta, 1993; Debussche & Isenmann, 1994; Vieira *et al.,* 1994; Kollman & Pirl, 1995; Nepstad *et al.,* 1996; Tucker & Murphy, 1997; Holl, 1998; Ferguson & Drake, 1999; Toh *et al.,* 1999; Alcántara *et al.,* 2000; Galindo-Gonzalez *et al.,* 2000; Slocum & Horvitz, 2000; Holl, 2002), but Africa, and the Ethiopian highlands in particular, have received little or no attention so far (but see Duncan & Chapman, 1999).

It has been observed that seed rain of animal-dispersed trees was higher below shrub patches (Holl, 2002), scattered, isolated trees and saplings (Debussche & Isenmann, 1994; Duncan & Chapman, 1999; Toh *et al.,* 1999; Slocum & Horvitz, 2000), logs and fern patches (Slocum, 2000) and artificial perches (McClanahan & Wolfe, 1987; Holl, 1998) than below grass or in open pasture. On the other hand, predation of animal-dispersed seeds was found to be significantly higher below shrub patches compared with grass but then again, seedling survival was found to be higher under shrubs (Holl, 2002). The identity of trees or shrubs and whether or not they offer a fruit reward appears to matter less than their structure and suitability as a bird perch. The characteristics that make some trees or other structures better recruitment foci than others, however, are poorly understood (Slocum & Horvitz, 2000).

In Tigray, the northernmost, highly degraded region of Ethiopia, regrowth of woody vegetation in areas recently closed off to cattle (protected areas or grazing exclosures) is often striking. The recovery process of the vegetation usually starts with the increase in number and cover of grassy species. After some years shrubs and small trees develop and depress the grass component. These shrubs and trees are considered as a key element in forest rehabilitation since it has been shown that grasses present a competitive barrier against the establishment of woody species (Aide *et al.,* 1995). Moreover, grasses tend to attract cattle that may trample and consume recruits

(Slocum, 2000), even in protected areas where grazing is officially prohibited. The woody regrowth in Tigray, however, is often composed of early successional species, mainly from the genera *Acacia*, *Carissa*, *Dodonaea*, *Euclea*, *Maytenus* and *Rhus*. These shrubs are well known in the area for their valuable fuel wood, but not at all for their ability to promote natural forest regeneration.

In many tropical regions seed dispersal by animals is the predominant form of distribution of propagules and has the potential to facilitate recolonisation of native vegetation on degraded sites (Wunderle, 1997). Therefore, one approach to forest rehabilitation could be the plantation or protection of already established indigenous tree or shrub species that attract seed dispersing animals such as birds, which are still abundant in the Tigray highlands, and thus promote the dispersal of seeds from remnant forest patches into the forest rehabilitation areas. This paper discusses the importance of species and structure of early successional indigenous shrubs for recruitment of African wild olive (*Olea europaea* subsp. *cuspidata* (Wall. ex G.Don) Cif., *Oleaceae*) in protected and non-protected areas.

2 Materials and methods

Site description

The study was conducted in 250 ha of grazing land and protected area on south-west and north-east oriented slopes adjacent to the Dagaber Mheni and the Giorgis Sesemat church forests in central Tigray, northern Ethiopia (13°37'N, 39°21'E 1980 m elevation). The site is located in the east of the Doga-Tembien district and has an annual rainfall between 550 and 600 mm.

Strips and larger areas of degraded natural vegetation between the various cropland patches are grazed and consist predominantly of grasses and the early successional shrubs typical of the area. In the protected area where logging and grazing is forbidden, larger saplings of *O. europaea* are sporadically present, but were not sufficiently mature to fruit during the study. The forest remnants around the churches of Mheni and Sesemat are respectively mixed *Acacia-Olea* (21 ha) and *Combretum-Olea* (12 ha) associations and serve as seed sources for the area under study.

Data collection

The following hypothesis was tested: recruitment of *O. europaea* is higher under certain early colonizing shrubs compared to within gaps and under other shrubs. Despite the expected higher seed predation and competition under these natural structures, some shrubs are believed to create microhabitats that enhance seedling survival by decreasing the risk of desiccation and predation by livestock and wild animals.

Recruitment of *O. europaea* was assessed in a four-month period (August – November 2002). Eight transects were randomly laid out over four different land use types (degraded grazing land [Gde], bushy grazing land [Gbu], spare grazing land, where grazing is allowed only after all other grazing resources are depleted [Gsp] and protected area, where cutting and grazing is prohibited [Fpa]). At equal intervals (50 m), modified T-square plotless sampling was applied to determine recent *Olea* recruitment densities. At each transect point, the distances from the transect point to the nearest recruit (sample point O), and from that sample to the nearest neighbour recruit (sample point N), were measured. Plotless sampling is typically applied to record sessile organisms that are so sparsely distributed that conventional sample plots are unsuitable (Sutherland, 1996). The technique combines the nearest-individual

method with the nearest-neighbour method to limit under- and overestimation of densities in the case of regular or clustered distributions. In total, 44 transect points were sampled. Additionally, 10×10 m² sample plots were laid out around two randomly selected points in each transect to assess shrub layer species composition independently of presence or absence of *Olea* recruits.

The modification of the T-square method consisted of adding a third sample point S, the shrub nearest to the transect point, to the dataset. For all sample points (S, O and N), 23 shrub and environmental variables were assessed: dominant species of the structure (MainSp), secondary species (OtherSp), shrub height (Hperch), number of stems (Nstem), lower crown height (CHlow), height of largest crown diameter (CHbroa), shrub diameter at ground level (Dbase), mean crown diameter (Dcrown), crown density in lower (CDlow), middle (CDmid) and upper (CDup) part of the shrub, presence of raptor perches (RP), presence of human (DisturH) and animal (DisturC) disturbance, density of surrounding shrubs with spherical (PDb), open (PDo) and thorny (PDs) structure and density of *Aloe* spp. (PDa), shrub height relative to surrounding shrubs (PP), mean soil depth around the perch (Mdepth), presence of soil (Mound) and mulch (Mulch) accumulation, rockiness of the soil (Rock) and slope (Slope).

Statistical analysis

The relation between *Olea* recruit presence, shrub type and land use was analysed by means of categorical regression and one-way analysis of variance. Dominance-diversity curves were constructed and one-way analysis of variance was applied to compare the woody species composition between the different land use types. *Olea* recruit densities were derived from the T-square distance measurements (see Sutherland, 1996). One-way analysis of variance and Tukey's LSD were used to estimate the effect of land use on recruit density. Structural differences between perch types were evaluated by means of principal component analysis (PCA) to determine why some shrubs are better recruitment foci than others. Spearman's rank correlations (r_s) were used to correlate original variables with the principal components. PCA axis interpretation was based on the rotated component matrix (varimax with Kaiser normalisation) and eigenvector scores and was verified by means of Spearman's rank correlation.

3 Results and discussion

***Olea* recruitment**

Within the chosen sampling strategy, not a single *Olea* recruit was found in the open field. The majority of recent *Olea* recruits was found under *Euclea schimperi* (A.DC.) Dandy (Ebenaceae).

Recruit position was estimated by means of two categorical predictor variables: land use type and shrub species. Only shrub species affects the position of olive recruits significantly ($F=9.175$; $P< 0.01$).

These results imply that microhabitat or, in other words, the shrub or perch type defines the spatial distribution of recent *Olea* recruits on a micro-scale irrespective of land use. Multiple comparison of means after one-way analysis of variance showed that *E. schimperi* shrubs support three-quarters of all new *Olea* recruits (77.6%), and that the remaining fraction is found under *Acacia etbaica* Schweinf. (Leguminosae: Mimosoideae) (20.0%) and *Aloe* spp. (2.4%) (Table 1). Mean differences are significant

at the 0.05 level. No *Olea* recruits were detected under the other shrub species in the study area (see list of genera in introduction). Estimated recruit densities were 15.27 ha^{-1} for bushy grazing land, 9.83 ha^{-1} for degraded grazing land, 4.82 ha^{-1} for protected area and 2.28 ha^{-1} for spare grazing land. These low densities justify the use of the plotless sampling method.

TABLE 1. Relative frequencies (%) of shrubs supporting recent *O. europaea* recruits per land use type and means over all land uses, based on T^2 plotless sampling in Mheni and Sesemat, Tigray, Ethiopia.

	Shrub species				
Land use[1]	No shrub	Aloe	Acacia	Euclea	Other shrubs
Gde	0.0	4.6	31.8	63.6	0.0
Gbu	0.0	5.0	15.0	80.0	0.0
Gsp	0.0	0.0	0.0	100	0.0
Fpa	0.0	0.0	33.3	66.7	0.0
All	0.0	2.4	20.0	77.6	0.0

[1]Land use types: **Gde**: degraded grazing land; **Gbu**: bushy grazing land; **Gsp**: spare grazing land; **Fpa**: protected area

The overall ratio of *Euclea* to *Acacia* shrubs supporting recent *Olea* recruits reaches more than three to one (3.25). Within individual land use types, the *Euclea/Acacia* ratio with new *Olea* recruits is 2.17 for degraded grazing land and 2.00 for protected area. In the bushy grazing land, this ratio rises to 4.00 (Table 2). For the spare grazing land this ratio could not be calculated since *Olea* recruits were exclusively detected under *Euclea*. If *Olea* recruits are randomly distributed over the shrub or perch pool, overall *Euclea* and *Acacia* shrub densities should have proportions similar to the above-mentioned 3.25 to 1 ratio. Alternatively, if *Olea* recruitment preferentially occurs under *Euclea* perches, the overall *Euclea/Acacia* ratio of the shrub pool should be less than the observed 3.25 to 1 fraction. In that case, recruits are not randomly distributed, and not dominance, but attractiveness or suitability of shrubs will cause *Euclea* to be a preferential recruitment focus.

Dominance-diversity curves of all land use types (Figure 1) follow geometric series (*sensu* Gray, 1987) indicating strong dominance of one or few species. Pairwise comparison of shrub densities ($\alpha = 0.05$) confirms that *A. etbaica* shrubs are more numerous and dominate all land uses. Overall relative density of *A. etbaica* amounts to 45% as compared to 11% for *E. schimperi*. The general *Euclea/Acacia* ratio is 0.24 or almost 1 to 4 (Table 2).

These findings support the alternative hypothesis that *Olea* recruits are not randomly positioned under the available shrubs, but preferentially under the less dominant *E. schimperi* shrubs. The shrub ratio *Euclea* to *Acacia* harbouring *Olea* recruits divided by the overall *Euclea/Acacia* availability is proposed as a measure for the relative attractiveness of *Euclea* compared to *Acacia* for *Olea* recruitment. A value of 1 would indicate that *Olea* recruits are proportionally located over the available perches. Higher values indicate a preference for *Euclea*; values lower than 1 a preference for *Acacia*. The relative attractiveness of *Euclea* versus *Acacia* ranges from 14.8 in bushy grazing land to

TABLE 2. *Euclea/Acacia* ratios in different land use types and relative attractiveness of *Euclea* versus *Acacia* for *Olea* recruitment in Mheni and Sesemat, Tigray, Ethiopia.

		Land use				
		Gde	Gbu	Gsp	Fpa	Overall
Euclea/Acacia ratio	overall	0.10	0.27	0.45	0.13	0.24
	with *Olea*[1]	2.17	4.00	∞	2.00	3.25
		(n = 19)	(n = 20)	(n = 13)	(n = 15)	(n = 67)
Relative attractiveness		21.7	14.8	∞	15.4	13.5

[1] with *Olea* recruits under the shrubs

21.7 in degraded grazing land. The mean relative attractiveness of *Euclea* is 13.5 (Table 2). Contrary to the findings of e.g. Slocum & Horvitz (2000), the identity of the shrubs therefore appears to determine *Olea* recruitment.

Spearman's rank correlation (r_s) showed a high degree of autocorrelation among the shrub variables, which can be explained by the many mutual interactions between the various size parameters of the shrubs (size relationships). Figure 2 shows the ordination of the sampled shrubs along the first two principal axes of the PCA; the first two principal components explain 41% of the initial variance in the dataset. The selected variables have the highest eigenvector scores (factor loading) and are significantly correlated to the principal axes at the 0.01 level.

The first (horizontal) axis represents a set of intercorrelated variables that distinguishes shrubs based on their number of stems, diameter at ground level, crown density, thorns and mulch characteristics under the perch. It clearly separates *Euclea* type shrubs (positive side) from *Acacia* types (negative side) (32% of the total variance). The second (vertical) axis can be interpreted as the shrub height component. Small shrubs that are lower than the surrounding vegetation are found on the negative side of the axis. Larger shrubs are found in the mid-range and tree-forms (high shrubs with crowns starting relatively high above ground level) at the upper positive side of the axis. This immediately explains the empty upper-right-hand side of the ordination diagram: multi-stemmed *Euclea* shrubs with a large diameter at ground level are restricted to the mid-range. *Euclea* shrubs that are developing to a tree form will lose some of the multi-stemmed character and become less broad at ground level – this implies a shift to the left over the first axis, which can also clearly be seen in Figure 2.

Shrubs of the *Euclea* type are more suitable for *Olea* recruitment. Both in the small and mid-ranged types, *Olea* recruitment is present, whereas for the *Acacia* type, *Olea* recruitment is restricted to the mid-range. If shrub characteristics shift to the negative side of the second PCA axis (lower shrubs with crown starting near to ground level), *Acacia* type shrubs lose their suitability for *Olea* recruitment compared to *Euclea* types. This suggests that some characteristics of the latter type can compensate for the less suitable characteristics of small shrubs. Although both mid-range size shrubs of the *Acacia* and *Euclea* type seem suitable, higher densities of recruits on the positive side of

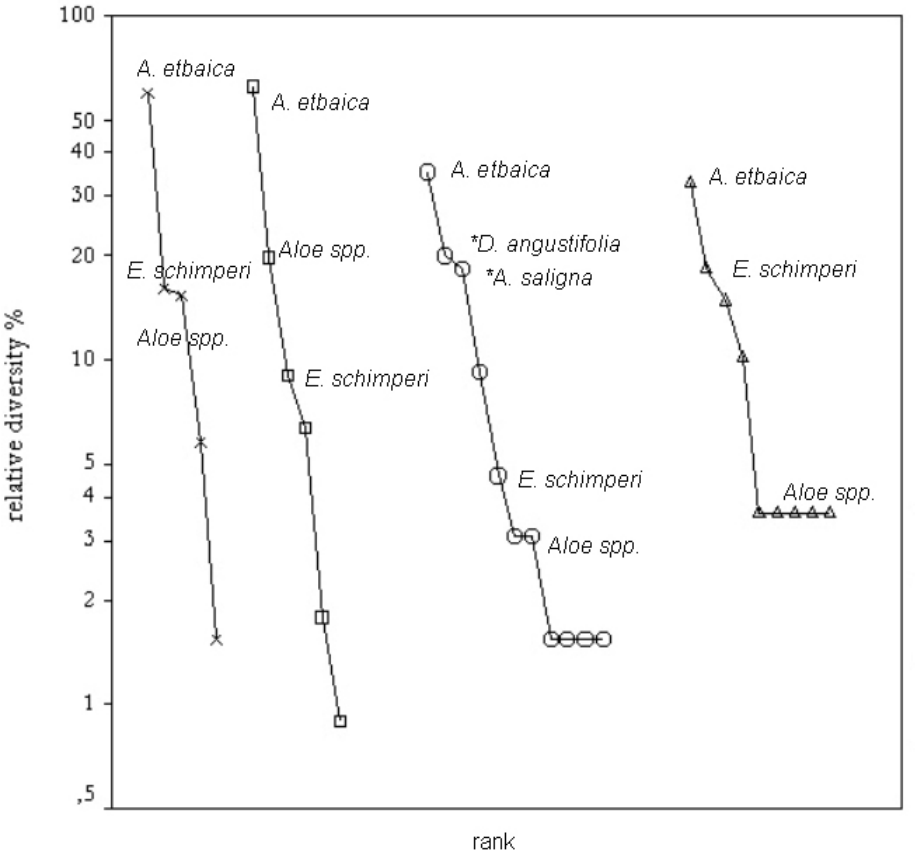


FIG. 1. Dominance-diversity curves for bushy grazing land (×), degraded grazing land (□), protected area (○) and spare grazing land (Δ). Asterisks (*) indicate shrubs planted in enrichment programs.

the first PCA axis suggest that here also, the characteristics of the *Euclea* type facilitate natural regeneration of *Olea*.

The accumulation of soil and organic matter under most of the *E. schimperi* shrubs could create favorable circumstances for olive germination and growth. Moreover, *E. schimperi* shrubs could offer more adequate seedling protection through numerous branches at ground level. However, early results of further research indicate that secondary dispersal, post-dispersal predation and seedling predation rates do not differ significantly between *Euclea* and *Acacia* shrubs (Aerts, unpublished data) and can therefore not explain the relative attractiveness of *Euclea* for *Olea* recruitment. Additionally, *E. schimperi* is a fleshy-fruited species, potentially offering a fruit reward to avian seed dispersers unlike the *Acacia*. This suggests that dispersal of *Olea* propagules is directed to dense Euclea shrubs with a high number of stems at ground level and as a consequence *Olea* recruitment is subject to passive facilitation by *Euclea*.

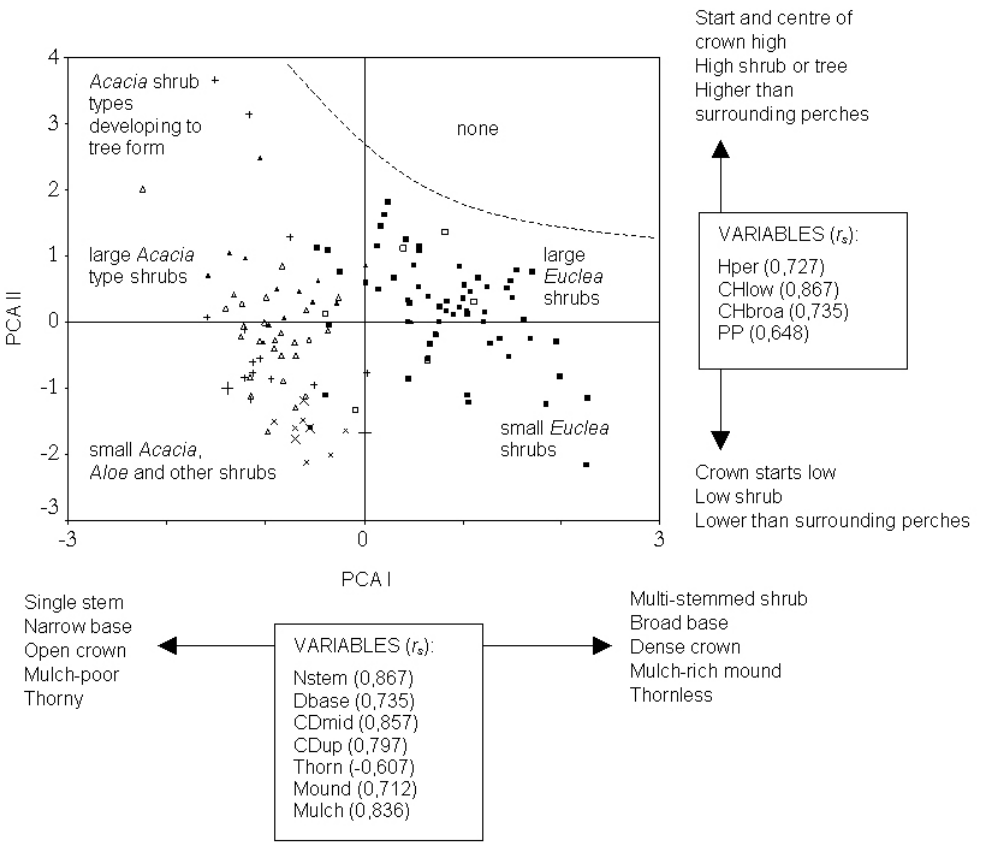


FIG. 2. Ordination of shrubs in central Tigray, Ethiopia, based on PCA. Perches are labelled with main species and presence or absence of *Olea europaea* recruit: *Euclea schimperi* with (■) and without (□) recruit; *Acacia etbaica* with (▲) and without (△) recruit; *Aloe* sp. with (×) and without (×) recruit; other species (+) without recruit.

4 Conclusions

Dependence on animals for seed transport means that the plants are susceptible to dispersal failure when their seed vectors become rare or extinct (Willson, 1992). Small-fruited, vertebrate dispersed species such as *O. europaea* tend to have many dispersal agents, and the loss of one vector species may have minor consequences for plant population biology (Willson, 1992). However, if remnant forest stands continue to be decimated, many dispersers will be lost and potentially severe consequences for tree species survival are to be expected. Natural regeneration strategies should provide adequate protective measures for both source (e.g. church forests) and target areas (e.g. protected areas) as well as for the seed disperser population (in the case of *Olea*, frugivorous birds).

In the study area in central Tigray, *E. schimperi* shrubs are the most favorable microsites for *O. europaea* regeneration. *E. schimperi* shrubs are natural structures that probably act as preferential perching sites for frugivorous birds. Although further research is needed to identify the critical steps in the entire succession process, primary dispersal directed to *E. schimperi* seems to dominate in the study area.

Even small changes in shrub structure can alter the suitability of the microsite for olive recruitment. All this suggests that the application of appropriate protection of early successional shrubs combined with simple silvicultural measures (e.g. pruning and back-cutting to develop dense shrubs with a high number of stems at ground level and direct sowing of regurgitated or defecated seeds under *Euclea* shrubs) can significantly enhance natural regeneration of indigenous woodlands in the region without having to rely on expensive plantation activities.

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