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Restoration of dry Afromontane forest using pioneer shrubs as nurse plants for *Olea europaea* ssp. *cuspidata*

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Abstract

Shrubs are often considered competitive barriers for seedlings planted in reforestation programs, although they can facilitate tree recruitment, especially in ecosystems under high abiotic stress. An alternative reforestation technique using pioneer shrubs as nurse plants for *Olea europaea* ssp. *cuspidata* was tested in exclosures in northern Ethiopia. Seedlings were planted in three different microhabitats and their survival was monitored. The microhabitats were bare soil patches

1 between shrubs, patches under the dominant shrub *Acacia etbaica*, and
2 patches under *Euclea racemosa*, an evergreen shrub which supports the
3 majority of naturally established *Olea* recruits. The ability of shrubs to
4 offer protection against browsing goats was tested experimentally.
5 Controlled shading was used to determine whether solar irradiation
6 causes seedling mortality in environments without water stress. Data
7 was analyzed using Kaplan-Meier survival analysis, Kruskal-Wallis
8 ANOVA and one-way ANOVA.

9 *Olea* survival was significantly higher and shoot damage by goats lower
10 when planted under shrub cover compared to bare soil patches,
11 particularly under *Euclea* canopies, although high shade levels reduced
12 seedling performance. Reduction of solar radiation by shrub canopies
13 and thus control of soil-water evaporation and seedling transpiration
14 most likely controlled the observed facilitation.

15 Planting under shrubs may increase seedling survival and assist
16 regeneration of dry Afromontane vegetation. Preserving pioneers also
17 reduces soil erosion and conserves biodiversity. Excluding livestock is
18 essential for *Olea* woodland restoration and allows persistent but
19 morphologically modified *Olea* shrubs to develop vigorous regrowth.

20 Facilitative processes are guiding principles for assisted forest
21 restoration but above-average rains may be critical to restore higher
22 biomass levels in semiarid areas.

23

- 1 **Key words:** dry forest restoration, facilitation, rainfall, seedling
- 2 **establishment, semiarid ecosystems**

1 **Introduction**

2 In northern Ethiopia, changing land use and land cover triggered by a long
3 history of cultivation and heavy livestock pressure are proximate causes for
4 severe dryland degradation and desertification (Zeleeke & Hurni 2001; Asefa et
5 al. 2003; Lemenih et al. 2005). In the northernmost regional state Tigray,
6 where almost all accessible land is cultivated or used as grazing land, soil and
7 water conservation practices and a set-aside policy have been implemented
8 to reverse the land degradation process (Nyssen et al. 2004; Hengsdijk et al.
9 2005). Land rehabilitation efforts in exclosures, where removal of remnant
10 vegetation and access by livestock are no longer permitted, aim at restoring
11 the natural Afromontane forest vegetation (Aerts et al. 2004; Mengistu et al.
12 2005).

13 Most Afromontane forest trees lack persistent soil seed reserves
14 (Teketay & Granström 1997; Tekle & Bekele 2000; Wassie & Teketay 2006)
15 and usually disappear from the soil seed bank if forest clearing is followed by
16 grazing or cultivation (Teketay 1997). Natural regeneration of trees in
17 exclosures is therefore restricted to vegetative resprouting or recolonization
18 from nearby forest patches (see also Turner & Corlett 1996; Duncan &
19 Duncan 2000). But since tree stumps are usually completely removed from
20 arable land (Teketay 1997) and most Afromontane tree species exhibit
21 restricted long-distance seed dispersal (Teketay & Granström 1997),
22 exclosures face serious limits to natural forest regeneration, especially in a
23 landscape where forest relics acting as seed sources are small, fragmented
24 and highly isolated (Aerts et al. 2006*b*). In such cases, the integration of tree

1 planting with other management interventions is considered a practical tool for
2 ecosystem restoration (Puigdefábregas 1998; Holmgren & Scheffer 2001).
3 Planted trees may help to restore previous levels of indigenous functional
4 biodiversity (Cusack & Montagnini 2004) and thus complement and accelerate
5 natural regeneration of forest ecosystems, for example by improving the
6 habitat for seed dispersing birds (Hardwick et al. 1997; Martínez-Garza &
7 Howe 2003; Lemenih et al. 2004). Especially in areas where soil seed banks
8 are depleted and indigenous seed sources scarce, tree planting may be the
9 only means to fully reestablish the diverse natural forest (Aide et al. 2000;
10 Yirdaw & Luukkanen 2003).

11 Several authors recognize that seedling planting is needed to
12 accelerate dry forest regeneration in exclosures in Ethiopia (Tekle & Bekele
13 2000; Yirdaw & Luukkanen 2003; Mengistu et al. 2005). The prevailing
14 reforestation technique used by the regional government and local NGO's is
15 based on regularly-spaced planting designs, where seedlings are planted in
16 bare soil patches between shrubs, or shrubs are cut prior to planting since
17 pre-existing pioneer shrub vegetation is considered a source of competition
18 for the planted trees. Seedlings are planted in deep holes (0.3–0.4 m in
19 diameter), which are supposed to act as micro-basins concentrating runoff
20 water around individual seedlings. Unfortunately, insufficient backfill packing
21 usually causes soil puddling and root exposure. As a result of these poor
22 planting practices, high ambient temperatures and solar irradiation, drought
23 and livestock herbivory (even in the exclosures), these operations generally
24 suffer serious plant losses. A 100%-mortality before the arrival of new rains is

1 not uncommon (R. Aerts 2002–2004, personal observations). Since failures
2 are not only an economical loss but also discourage local stakeholders, who
3 have sacrificed a significant proportion of their crop and grazing lands to be
4 reforested (Hengsdijk et al. 2005), alternative reforestation techniques tailored
5 to dry Afromontane forest are obviously called for.

6 Despite the harsh environmental conditions, natural regeneration of
7 forest trees does occur in exclosures and grazed areas, albeit at low
8 densities. Naturally established seedlings of *Olea europaea* ssp. *cuspidata*
9 (Wall. ex G. Don) Cif. (African wild olive), an important fleshy-fruited
10 component of dry Afromontane forest (Friis 1992), are restricted to the shady
11 places under the canopy of pioneer shrubs: primarily under the fruit-bearing
12 evergreen shrub *Euclea racemosa* ssp. *schimperi* (A. DC.) White (Bush
13 guarri), and to a lesser extent under the dominant thorn shrub *Acacia etbaica*
14 Schweinf. (Fabaceae) (Aerts et al. 2006a). Although the benefits of shrubs for
15 tree recruitment do not always increase in importance with abiotic stress
16 (Maestre et al. 2005), several case studies have documented the ability of
17 early-successional vegetation to facilitate the establishment and survival of
18 understorey seedlings in water-stressed environments; for example, shrubs
19 facilitate the establishment of *Quercus douglasii* Hook (Blue oak) and *Q.*
20 *lobata* Née (Valley oak) in California (Callaway 1992) and of *Pinus nigra*
21 Arnold (Black pine), *P. sylvestris* L. (Scots pine), *Quercus pyrenaica* Willd
22 (Melojo oak) and other tree species in Spain (Castro et al. 2002, 2004;
23 Gómez-Aparicio et al. 2004; Castro et al. 2006). Early establishment of dry
24 forest species is thus favored under nurse shrubs, who cause reduction of

1 dormancy (Franco-Pizaña et al. 1996), increase fertility or soil moisture (e.g.
2 Pugnaire et al. 1996; Moro et al. 1997; Whitford et al. 1997; Verdú & García-
3 Fayos 2003) or offer protection against high irradiance, temperature,
4 predation or browsing (e.g. Valiente-Banuet & Ezcurra 1991; Vetaas 1992;
5 García & Obeso 2003).

6 These facilitative processes in dry forests can be used as guiding
7 principles for assisted forest restoration (Vieira & Scariot 2006). For naturally
8 established seedlings, the facilitative effects may operate during the dispersal,
9 germination and/or seedling stage. To test whether these effects apply for
10 planted seedlings as well, specific studies in the field are necessary.
11 Therefore we set up an experiment in central Tigray (northern Ethiopia) in
12 2003 to test an alternative reforestation technique using *O. europaea*
13 seedlings and pre-existing pioneer shrubs. The main objective of the study
14 was to analyze the effect of pioneer shrub cover on early survival of planted
15 *Olea* seedlings, more specifically during the first, dry winter, which is often the
16 most critical period for the establishment of seedlings in semiarid
17 environments (Castro et al. 2004). We hypothesized that i) the combined
18 effect of shade and moisture conservation under pioneer shrub cover
19 enhances survival of planted seedlings compared to seedlings planted in bare
20 soil patches; ii) shrub cover protects seedlings from livestock herbivory; and
21 iii) shade promotes seedling growth.

22

23

24

1 **Methods**

2 **Study Species**

3 *Olea europaea* ssp. *cuspidata* (Oleaceae) is a sclerophyllous evergreen tree
4 with a heavy branched and rounded crown. It reaches a height of 5–15 (max.
5 25) m and is widely distributed in Afromontane forests, particularly in drier
6 highland forests in association with *Juniperus procera* Hochst. ex Endl. (East
7 African pencil cedar), forest margins, riverine forests and evergreen montane
8 scrub from 1,250 to 3,000 m above sea level in Sudan, Somalia and
9 southward through East tropical Africa into South Africa (Green 2003). In
10 undisturbed forest, germination results in populations of shade-tolerant and
11 slowly growing seedlings (Teketay & Granström 1997), and both in exclosures
12 and grazing land, natural regeneration has been documented under early-
13 successional shrubs (Aerts et al. 2006a). Once established, the tree is
14 drought resistant, but because of its multiple uses (for example, durable
15 timber, traditional ox-ploughs, firewood and charcoal) both young and mature
16 trees have been over-harvested dramatically in Ethiopia. As a result this
17 valuable tree is now under threat of local extinction (Negash 2003).

18

19 **Site Description**

20 Two study sites, Sesemat and Mheni (lat 13°37'N, long 39°21'E), were
21 located 1,800–1,900 m above sea level in the Geba river catchment of central
22 Tigray, northern Ethiopia, on slopes over calcareous rocks and lacustrine
23 silified Mesozoic Antalo limestone layers 20 km NW of the regional capital
24 Mekelle, and are exclosures since 1996. A third exclosure, Bubu Hills (lat

1 13°30'N, long 39°29'E, 2,150 m above sea level), was located at the foot of a
2 dolerite cliff at the edge of Mekelle town next to a peri-urban eucalypt
3 plantation. The vegetation in the three sites and their surrounding grazing
4 lands was characterized by a discontinuous cover of shrubs and small
5 regenerating trees in a matrix of herbs and bare soil. It can thus be defined
6 as semiarid degraded savanna (Vetaas 1992; De Villiers et al. 2001). The
7 climate is related to the mountainous facies of the Sudanese zone with hot
8 and dry winters (October–January) and two rainy seasons: a short and
9 moderate, highly variable spring rain (*belg*, coefficient of variation 31–55%) in
10 (February)–March–April–(May–June) and a long, heavy and more reliable
11 summer rain (*kremt*, coefficient of variation 19–31%) in (June)–July–August–
12 September (Meze-Hausken 2004). The mean annual precipitation is $625 \pm$
13 155 mm (spring rain 125 ± 11 mm; summer rain 466 ± 22 mm; means $\pm$ SE
14 for the years 1960–2003; Meze-Hausken 2004) and the mean annual
15 temperature is 18°C. Total spring and summer rains for 2003 were 149.3 and
16 357.3 mm (Mekelle Quiha station, National Meteorological Services Agency;
17 Fig. 1). In our study area, dry Afromontane forest relics and Afromontane
18 savanna woodland are communities dominated by *Olea europaea*, *Acacia*
19 *etbaica* and *Combretum collinum* Fresen (Combretaceae) (Aerts et al. 2006b).

21 **Seedling Planting**

22 Seedlings of *Olea europaea* were planted during spring and summer rains in
23 2003 in each of three different microhabitats in three sites and monitored until
24 the end of the main winter drought (February 2004) to test the effect of shrubs

1 on early seedling survival. The microhabitats were: (1) bare soil patch,
2 seedlings planted in areas of bare soil between shrubs; (2) *Euclea*, seedlings
3 planted under the canopy of individuals of *E. racemosa*; and (3) *Acacia*,
4 seedlings planted under the canopy of individuals of *A. etbaica*. Planting
5 points were distributed randomly in two plots of circa 400 m² per site. In each
6 plot, we planted 15 seedlings (five per microhabitat). Spring rain planting was
7 carried out in Mheni and Bubu Hills (60 seedlings: 2 sites × 2 plots × 3
8 microhabitats × 5 seedlings; 17 April–19 May 2003; see Fig. 1); summer rain
9 planting was carried out in Sesemat, Mheni and Bubu Hills (90 seedlings: 3
10 sites × 2 plots × 3 microhabitats × 5 seedlings; 9 July–19 August 2003; see
11 Fig. 1). Planting holes were dug 15–20 cm deep and 20–25 cm wide with a
12 grub hoe. After backfilling and reconstruction of the original mulch (for
13 microhabitats under shrubs) or surface stone cover (for bare soil patches)
14 around the seedling, each seedling received one liter tap water to allow the
15 soil to settle and to alleviate transplantation shock. The seedlings used in the
16 experiment came from the Endayesus tree nursery (Mekelle University,
17 Mekelle, Ethiopia), were grown from seeds collected from local populations of
18 the species (church forests), and were 3–6 months old. The seedlings were
19 grown in small polyethylene tubes (5.25 cm diameter, 15 cm deep) filled with
20 a substrate of local black soil and sieved river sand mixed with organic
21 material; seedlings were planted with the substrate attached to the roots but
22 without the polyethylene tubes. For each planted seedling, we recorded (1)
23 survival, which was sampled approximately every two weeks for six months;
24 and (2) the cause of mortality based on leaf and stem characteristics. To get

1 an idea of long-term seedling survival, seedlings were revisited during the
2 2004 and 2005 spring rains (1 March 2004, 1 May 2004 and 12 March 2005).

3

4 **Controlled Browsing**

5 Domestic goats are the main livestock animals in the area and sometimes
6 illegally or accidentally enter exclosures, eventually causing serious damage
7 to planted tree seedlings. The ability of shrubs to protect *Olea europaea*
8 seedlings against browsing goats was tested using fresh *Olea europaea*
9 shoots in eight controlled browsing experiments in a 30 × 30-m² plot in Mheni.
10 The experiments were carried out during the summer rainy season when
11 green vegetation was readily available and goats could select their preferred
12 food from a variety of woody, herbaceous and grassy vegetation. The shoots
13 had the size and leaf characteristics of normal *Olea* seedlings and could
14 therefore be used as seedling analogues (see Wahungu et al. (2002) for a
15 comparison between shoots and real seedlings in a grazing experiment). For
16 each experiment, three shoots were positioned randomly under each of 10
17 *Euclea* shrubs, 10 *Acacia* shrubs and in 10 bare soil patches. The same
18 shrubs and bare soil patches were used in all replications, but each time, the
19 goats were picked from a different herd to prevent the animals from learning
20 where to find the shoots. In the eight experiments, 4–23 domestic goats were
21 allowed to graze freely in the plot for 10–20 minutes. In each experiment, the
22 number of goats and the grazing time were changed, resulting in a set of
23 browsing pressures ranging between 14.8 and 85.2 goat hours ha⁻¹. These
24 extremes represented, respectively, less than normal browsing and

1 overgrazing, compared to the normal sizes and movement patterns of these
2 herds as observed in the field during our study. Goats were sent into the plot
3 and were kept within plot boundaries by local shepherds who guarded the
4 perimeter. All experiments took place in the morning on different days, before
5 it became too hot for active feeding. Seedling survival was measured as the
6 number of shoots left without damage (0–3) at each patch after the browsing
7 treatment.

8

9 **Controlled Shading**

10 To assess the effect of shading on early seedling performance of *Olea*
11 *europaea* independently from water stress, 50 nursery-raised seedlings were
12 randomly positioned in five blocks with different shade treatment (10
13 seedlings per block). The control treatment was a bare soil patch. The four
14 shading treatments were constructed using cut branches of shrubs to simulate
15 pioneer shrub canopies. The branches were distributed over a mesh-wire
16 frame installed 1 m above the seedling bed and were replaced on a regular
17 basis. The relative illuminance under the treatments was measured using a
18 Gossen Panlux Electronic 2 analogue lux-meter (Gossen Foto- und
19 Lichtmesstechnik GmbH, Nürnberg, Germany) and calculated as follows:
20 $\text{relative illuminance RI} = \frac{\text{illuminance(treatment)}}{\text{illuminance(open field)}}$ (Table
21 3). The open-field light intensity (full insolation at noon) was 99.8 ± 0.7 kLx
22 and corresponded to a relative illuminance $\text{RI} = 1.0$ in the control treatment.
23 To compare the treatments with real pioneer shrub canopies, relative
24 illuminances were measured under *Acacia* ($n = 11$) and *Euclea* ($n = 12$)

shrubs. The relative illuminance under *Acacia* shrubs ranged between 0.31 and 0.67 with a mean of 0.48 ± 0.03 . Under *Euclea* shrubs, the relative illuminance ranged between 0.12 and 0.44 with a mean of 0.26 ± 0.03 . The least dense shading treatment ($RI = 0.61 \pm 0.01$) corresponded to an *Acacia* shrub. The two intermediate treatments ($RI = 0.19 \pm 0.05$ and 0.15 ± 0.01) corresponded to *Euclea* shrubs. The fourth treatment blocked most of the sunlight and may be compared to the light intensity under a very dense forest canopy ($RI = 0.05 \pm 0.01$). Seedlings were kept in their polyethylene containers and were watered daily. Stem diameter, seedling height, number of leaves and number of twigs were measured at the start of the experiment (August 2003), immediately after the summer rains (October 2003) and at the end of the experiment (February 2004).

Data Analysis

Survival of planted seedlings was analyzed using a time-to-event approach, which measures the time to an event for each individual (Altman & Bland 1998). In this study the critical event is seedling mortality and the data is conventionally called survival data. The characteristic feature of survival data is that at the end of the follow up period, the critical event will probably not have occurred for all seedlings, or seedlings may be lost to follow up during the study. For these seedlings, the survival time is said to be censored (Altman & Bland 1998). Such seedlings are seedlings that were still alive at the end of the follow-up period and seedlings that were alive but destroyed by human disturbance at some point in the follow-up period. Because of the

censuring, we used Kaplan-Meier survival analysis, a model for censored survival data based on estimating conditional probabilities for each time interval in which an event occurs (Bland & Altman 1998). In this particular experiment, Kaplan-Meier survival analysis offers the benefit of including the data recorded for destroyed seedlings in the model; disturbed seedlings are not simply removed from the statistical analysis. Survival to any point in time is calculated as the product of the probabilities for each cumulative time interval (Bland & Altman 1998). Equality of survival distributions for the different microhabitats and sites was tested using the Breslow statistic (BS), which takes the whole follow up period into account to compare the total survival of different groups. In this statistic, time points are weighted by the number of individuals at risk at each time point, which is the main difference with the log-rank test most commonly applied on survival data (Bland & Altman 2004). Differences in mean survival time between the two planting seasons for all microhabitat $\times$ plot combinations were analyzed using the Kolmogorov-Smirnov test.

The effect of shrub cover on the fraction of shoots (simulated seedlings) damaged by browsing goats was tested with one-way ANOVA ($p_{\text{Levene}} = 0.994$ showed equality of variance), using browsing pressure in goat hours ha⁻¹ as a covariate.

Since the original size of the seedlings used in the shading experiment conditioned their subsequent growth, variables measured in October and February were relativized prior to analysis. Seedling height, number of twigs and number of leaves were divided by the initial seedling height, and the stem

diameter by the initial stem diameter. August–October, October–February and August–February relative differences in growth characteristics between shading treatments were analyzed using Kruskal-Wallis one-way ANOVA by ranks.

Pairwise comparisons after Kruskal-Wallis ANOVA were computed manually using the multiple comparison between treatments procedure outlined in Siegel & Castellan (1988). All other analyses were performed using SPSS 12.0 for Windows (SPSS Inc., Chicago, IL).

Results

Seedling Planting

Six months after planting, the overall mortality rate was 89.3 % for the seedlings planted during the spring rains. The highest mortality rates occurred during the first three months, which contained substantial dry periods prior to the onset of the summer rains (Fig. 1). For the seedlings planted during the main summer rains, the overall mortality rate was 54.9% six months after planting, excluding 19 seedlings that were lost due to human disturbance. In contrast to spring rain planting, almost no mortality occurred during the first three months. Four months after planting, mortality under shrub cover was less than 10%, while already 30% of all seedlings in the bare soil patches had died. Since seedlings dried out without any visible damage, drought was considered the main cause of mortality in both planting seasons.

The microhabitat had a significant effect on seedling survival in both planting seasons (Table 1). The contrast between *Euclea* and bare soil

1 patches was significant in either season, while the contrast between *Acacia*
2 and bare soil patches was only significant in the summer planting season.
3 Within-plot data analysis showed that the differences of mean survival times
4 between microhabitats and the levels of significance for these differences
5 were highly variable and plot-dependent (Fig. 1), but the patterns of variation
6 among microhabitats were similar for most plots in both seasons, with the
7 longest survival times under *Euclea*, generally followed by *Acacia*. Mortality
8 was higher and occurred sooner in the bare soil patches. Mean survival times
9 for all microhabitat × plot combinations were significantly higher in the
10 summer planting season than in the spring planting season ($Z = 2.619$, $p <$
11 0.001).

12

13 **Controlled Browsing**

14 Browsing pressure had a significant effect on shoot or simulated seedling
15 survival (Table 2): with increasing browsing pressure, more *Olea europaea*
16 shoots were detected and damaged or eaten by goats (Fig. 2). There was
17 also a significant effect of microhabitat on shoot survival (Table 2). At low
18 browsing pressures, shoots under both *Euclea* and *Acacia* shrubs were less
19 likely to be eaten or damaged than shoots in bare soil patches. On the
20 contrary, nearly all shoots were detected and eaten in both bare soil patches
21 and under shrubs at high browsing pressures. This illustrates the limited
22 ability of shrubs to protect seedlings against browsing livestock. Between
23 these two extremes, *Euclea* shrubs offered better protection than both *Acacia*
24 shrubs and bare soil patches.

1

2 **Controlled Shading**

3 All *Olea* seedlings survived until the end of the experiment, except one
4 seedling under the highest shade level, which wilted after visible rodent
5 damage. Differences in growth characteristics between shading treatments
6 were more pronounced during the rainy season (Table 3). Seedlings exposed
7 to strong shade performed relatively poor compared to seedlings subjected to
8 weaker shading treatments. In general, high values for relative stem diameter
9 growth, relative height growth and net-accumulation of leaves per cm were
10 found during the summer rains under the mildest shading treatment, which
11 corresponded to the shade under an *Acacia* shrub. The poorest results were
12 found under the strongest shading treatment (Table 3). With the exception of
13 net leave accumulation, growth characteristics did not differ significantly
14 among treatments during the dry October–February period. On the whole,
15 mild shading resulted in better seedling performance than heavy shading and
16 no shading at all (Table 3).

17

18 **Discussion**

19 The results of the three experiments showed that the survival of
20 planted *Olea* seedlings was positively related to shrub cover. Our results
21 support the central hypothesis that the combined effect of shade and moisture
22 conservation under pioneer shrub cover enhances survival of planted
23 seedlings compared to seedlings planted in bare soil patches. Shrub cover

1 protected seedlings from livestock herbivory and shade promoted seedling
2 growth, but both only to a certain extent.

3 The shading experiment illustrated that if water is not a limiting
4 resource, shade will be: seedlings exposed to strong shade performed poorer
5 than the ones under weaker shading treatments. On the other hand it showed
6 that in the absence of water stress, seedlings can survive in bare soil patches.
7 High solar irradiation or high temperatures do not cause mortality in seedlings
8 planted in bare soil patches directly, but indirectly through water stress.
9 Nurse plants may thus have a facilitative effect related to the shade they
10 provide by reducing the solar radiation, soil temperature and evaporation and
11 thus improving the water status of the seedlings (see also Valiente-Banuet &
12 Ezcurra 1991; Vetaas 1992; Holmgren et al. 1997; Castro et al. 2002, 2004).

13 The summer rain seedling planting experiment illustrated that *Olea*
14 seedlings can also survive in bare soil patches between shrubs, but only
15 during and shortly after the rains, when drought stress is presumably rather
16 limited. For seedlings planted during the spring rains, drought stress probably
17 occurs soon after planting, resulting in short survival times and high mortality
18 irrespective of the microhabitat in which they were placed. Seedlings planted
19 during the summer rains seem to have a higher resistance against first
20 drought. This may be attributed to a more extensively developed root system
21 of the seedling, but equally to a higher soil moisture reserve after the long
22 rains. Probably, seedlings benefit more from extended rainy seasons than
23 from high rainfall intensities. Notwithstanding this initial durability, seedlings
24 planted under shrub cover have a distinctively higher probability to survive

1 winter drought than seedlings planted in bare soil patches between the
2 existing pioneer shrubs. Almost two years after planting (12 March 2005),
3 three of the four seedlings that were still alive were planted under *Euclea*, and
4 the other one was planted under *Acacia*.

5 Herbivore damage was high in bare soil patches, but also under shrub
6 cover. Browsing behavior of goats means that they must be controlled, along
7 with other livestock, in areas where young trees have been planted or forests
8 are regenerating naturally (Peacock 1996). Once established (probably when
9 it has formed sufficient above- and below-ground biomass), *Olea* can resist
10 high browsing pressure by increasing shoot and leaf density, decreasing leaf
11 size and transforming shoots to spines (and thus adopting a
12 nanophanerophytic/chamaephytic life form), which has also been documented
13 in Mediterranean maquis by Massei and Hartley (2000). But since goats
14 actively feed on *Olea* (for wild goats see Sfougaris et al. 1996), we may
15 expect that successive browsing events will eliminate the majority of *Olea*
16 seedlings. Total exclusion of goats from set-aside areas is therefore essential
17 to permit *Olea* woodland restoration. Since goats naturally prefer to eat at a
18 height 20–120 cm above the ground (Peacock 1996), this exclusion must be
19 sustained well beyond the sapling stage. Suppressed *Olea* shrubs released
20 from browsing pressure form new vigorous shoots rapidly and can be
21 transformed to strong saplings by plain back-cutting (removing all shrubby
22 biomass and secondary shoots in favour of one or two leading shoots; R.
23 Aerts, unpublished data), which is an additional advantage of excluding
24 livestock.

1 All in all, we must keep in mind that early survival of planted seedlings
2 was limited and long-term survival poor, even for seedlings planted under
3 *Euclea* canopies during the summer rains. Interaction between plants is
4 species-specific and may not only show important between-plot variability, but
5 also between-year variability (Lloret et al. 2005). Many disturbed ecosystems,
6 such as overgrazed savannas, have distinct alternative stable states (for
7 example, barren, herbaceous and woody). These states are separated by
8 critical thresholds. Transitions across state boundaries (for example, from
9 woody to herbaceous) are difficult to reverse because they are usually sudden
10 and not gradual. Certain restoration measures such as herbivory control or
11 seedling planting may be sufficient to induce woodland recovery in a wet year
12 but not in a dry year (Holmgren et al. 2001; Holmgren & Scheffer 2001): the
13 extra rainfall is the critical impulse needed to reverse the transition and
14 restore the stable state with higher biomass level. In the tropics, wet years
15 are often related to above-average rainy seasons caused by the El Niño-
16 Southern Oscillation (ENSO). Rainy conditions during ENSO events have
17 been shown to trigger the regeneration of woody vegetation in many arid and
18 semiarid ecosystems, and may thus be seen as a window of opportunity for
19 dryland restoration (Holmgren & Scheffer 2001). But in the drought-prone
20 northern highlands of Ethiopia, the warm ENSO is associated with below-
21 average summer rainfall over the Ethiopian highlands (Seleshi & Zanke
22 2004), and seedling planting should therefore be avoided during ENSO
23 episodes. Roughly the opposite climatic conditions may be found during the
24 next phase, known as La Niña. Results from our planting trials during the

1 summer rainy season suggest that coupling planting activities with above-
2 average summer rainfall may further improve seedling survival (see Gissila et
3 al. (2004) and Segele & Lamb (2005) for predictability studies of Ethiopian
4 summer rainfall). During the last four decades in our study area (1960–2002),
5 such above-average (at least +25%) summer rainfall events occurred on
6 average every four years (Meze-Hausken 2004:27, Fig. 9).

7

8 **Conclusion**

9 The central conclusion of the present study is that African wild olive seedling
10 survival can be enhanced by pre-existing early-successional shrubs that serve
11 as nurse plants, probably through limiting drought stress. Especially the
12 evergreen pioneer shrub *Euclea racemosa* provides suitable microhabitats for
13 seedling planting. On the other hand, excluding livestock is an essential
14 requirement since shrubs do not protect seedlings efficiently enough against
15 browsing. Even then, ultimate seedling survival is limited to a certain extent.
16 Planting during the spring rains or in bare soil patches between pioneer
17 shrubs must not be promoted due to high seedling mortality, and thus high
18 replacement costs. Planting under shrubs during above-average summer
19 rains, which may occur during La Niña episodes, may have important
20 advantages in assisting regeneration of dry Afromontane vegetation.
21 Moreover, conserving the pre-existing shrubs reduces the risk of soil erosion
22 and keeps levels of indigenous biodiversity high, while excluding livestock
23 allows persistent but morphologically modified *Olea* shrubs to develop
24 vigorous regrowth.

Box 1. Implications for Practice

The following points may interest practitioners aiming to assist restoration of dry Afromontane forest in semiarid degraded mountainous regions of northern Ethiopia, using seedling planting of *Olea europaea* ssp. *cuspidata* (African wild olive) in set-aside areas:

- Total exclusion of domestic goats from set-aside areas during the seedling and sapling stage is essential for olive woodland restoration.
- Persistent olive shrubs released from browsing pressure form new, vigorous shoots rapidly and can be transformed to strong saplings by plain back-cutting of shrubby biomass in favor of one or two vertical leading shoots.
- Do not plant seedlings when drought is expected; therefore, do not plant during the short and unreliable spring rains.
- Plant in the beginning of the long summer rains but wait until soil moisture levels are high enough (one or two weeks after the start of the rains). Take advantage of above-average summer rainy seasons.
- Plant under pre-established pioneer shrubs, not in bare soil patches. Seedlings planted under *Euclea* shrubs have the highest probability to survive the first dry season.
- Avoid planting under very dense canopies, because these shrubs tend to slow down seedling growth.

1

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10

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11

Table 1. Differences in survival for *Olea europaea* seedlings planted in three microhabitats during spring and summer rains in exclosures of northern Ethiopia, obtained from Kaplan-Meier survival analysis.

	Spring rains		Summer rains	
	(n = 60)		(n = 90)	
	BS	p	BS	p
Full model (PLOT × TREATMENT)	7.73	0.02	9.98	0.01
Contrasts in survival time between microhabitats (TREATMENTS adjusted for PLOT)				
<i>Euclea</i> cover <> <i>Acacia</i> cover	2.53	0.11	0.70	0.40
<i>Euclea</i> cover > Bare soil patch	6.31	0.01	7.75	0.01
<i>Acacia</i> cover > Bare soil patch	2.53	0.11	4.80	0.03
BS = Breslow statistic for differences between groups in Kaplan-Meier survival analysis.				

Table 2. One-way ANOVA effect of microhabitat (bare soil patches, *Euclea* shrub cover and *Acacia* shrub cover) on herbivore-induced *Olea europaea* shoot damage (see Fig. 2).

Source	MS	df	F	p
Corrected Model	34.35	3	23.28	<0.001
Intercept	342.04	1	231.86	<0.001
Covariate : BROWSING PRESSURE	76.64	1	51.95	<0.001
Treatment : MICROHABITAT	13.20	2	8.95	<0.001
Error	1.48	236		

Table 3. Kruskal-Wallis one-way ANOVA effect of shading treatments on early growth of *Olea europaea* seedlings. Values are means (SE).

Shade level	Shading treatment					KW	p
	No shade	Low	Medium		High		
	(bare soil patch) n = 10	(≈ <i>Acacia</i>) n = 10	(≈ <i>Euclea</i>) n = 10	n = 10	(≈ dense forest) n = 9		
Relative light intensity (TREATMENT)	1.0 (–) ^a	0.61 (0.01) ^a	0.15 (0.01) ^{ab}	0.19 (0.05) ^{ab}	0.05 (0.01) ^b	21.85	<0.001
Rainy season (August–October)							
Relative stem diameter increment	0.30 (0.06) ^{ab}	0.58 (0.07)^a	0.40 (0.05) ^{ab}	0.23 (0.04) ^b	0.23 (0.06) ^b	15.95	0.003
Relative height growth	0.38 (0.08) ^{ab}	0.97 (0.24)^a	0.69 (0.08)^a	0.60 (0.08) ^{ab}	0.25 (0.06) ^b	18.42	0.001
Net leave accumulation per cm	3.35 (0.42) ^b	4.32 (0.37)^{ab}	4.69 (0.55)^{ab}	1.47 (0.19) ^{bc}	1.39 (0.20) ^c	32.69	<0.001
Net twig accumulation per cm	0.33 (0.10)	0.22 (0.14)	0.17 (0.07)	0.00 (0.04)	0.07 (0.06)	8.29	0.081
Dry period (October–February)							
Relative stem diameter increment	0.62 (0.12)	1.13 (0.70)	0.75 (0.08)	0.62 (0.07)	0.51 (0.11)	2.64	0.619
Relative height growth	0.18 (0.09)	0.27 (0.08)	0.37 (0.13)	0.52 (0.15)	0.33 (0.09)	2.68	0.614
Net leave accumulation per cm	0.45 (0.66) ^{ab}	<i>-0.43 (0.43)^a</i>	0.03 (0.31) ^{ab}	1.01 (0.59) ^{ab}	1.71 (0.30)^b	11.57	0.021
Net twig accumulation per cm	-0.02 (0.09)	0.15 (0.18)	0.32 (0.18)	0.17 (0.09)	0.27 (0.07)	5.76	0.218
Overall growth (August–February)							
Relative stem diameter increment	0.92 (0.16)	0.78 (0.12)	1.15 (0.09)	0.85 (0.07)	0.74 (0.11)	7.198	0.126
Relative height growth	0.57 (0.12) ^a	0.78 (0.14) ^a	1.06 (0.14) ^a	1.13 (0.23) ^a	0.59 (0.13) ^a	9.97	0.041
Net leave accumulation per cm	3.80 (0.71) ^{ab}	2.20 (0.78) ^{ab}	4.72 (0.43)^a	2.48 (0.51) ^b	3.10 (0.38) ^{ab}	11.97	0.018
Net twig accumulation per cm	0.30 (0.09)	0.28 (0.07)	0.49 (0.18)	0.17 (0.08)	0.33 (0.07)	5.73	0.220

Stem diameter and height increment are relative to the initial stem diameter and seedling height respectively. Leave and twig accumulation are the increase in number of leaves and twigs per cm, using the initial seedling height as the height reference. Letters indicate significant differences between groups. High performance is indicated in bold, low performance in italics.

Figure 1. Survival of *Olea europaea* seedlings planted under *Euclea* cover, under *Acacia* cover and in bare soil patches in different plots in exclosures in northern Ethiopia. Values are mean survival time in days $\pm$ SE derived from Kaplan-Meier survival analysis. Letters indicate significant differences between groups. D = disturbed experiment. X = survival exceeds monitoring period and the indicated means are the minimal survival time (censored cases). Rainfall data: Mekelle station, National Meteorological Services Agency, Ethiopia.

Figure 2. Fraction of *Olea europaea* shoots (simulated seedlings) left untouched by browsing goats during controlled browsing experiments in Mheni, Ethiopia, in relation to browsing pressure for two types of shrub cover (*Euclea* and *Acacia*) and a control treatment (bare soil patches). Values are estimated marginal means $\pm$ SE. Trend lines are linear regressions. At low browsing pressures, shoots under both *Euclea* and *Acacia* shrubs are less likely to be eaten or damaged than shoots in bare soil patches. At high browsing pressures practically all shoots are detected and eaten irrespective of the microhabitat in which they were placed.

Figures

Fig. 1

Fig. 2