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Survival of planted African wild olive seedlings in northern Ethiopian exclosures depends on planting season and shrub cover

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Vegetation such as shrubs and grass tussocks is usually considered to present a competitive barrier for seedlings planted in reforestation programs. However, shrubs also have the ability to facilitate the establishment of seedlings of woody species under their canopy, especially in ecosystems under high abiotic stress. In 2003, an experiment was set up in exclosures in northern Ethiopia to test the use of shrubs as nurse plants for reforestation. Seedlings of African wild olive *Olea europaea* ssp. *cuspidata* were planted in three microhabitats: (1) bare soil between shrubs, (2) under individuals of the dominant thorn shrub *Acacia etbaica*, and (3) under individuals of *Euclea racemosa*, a fruit-bearing evergreen shrub which supports the majority of naturally established olive seedlings. Experimental seedlings were planted during the short spring rains (March–April) and long summer rains (June–September). The present study reports early seedling survival, i.e. until the end of the first winter (February 2004). Olive survival was significantly higher when planted under shrub cover as compared to open areas, especially under *Euclea* canopies, but spring rain enrichment planting showed high mortality in all three microhabitats due to drought stress soon after planting. Reduction of solar radiation by shrub canopies and thus control of soil-water evaporation and seedling transpiration most likely controlled the observed facilitation. We conclude that planting under shrubs during above-average summer rains, as occuring during La Niña episodes, may have important advantages in assisting natural regeneration of dry Afromontane vegetation, and that conserving the pre-existing shrubs at the same time reduces the risk of erosion and keeps levels of indigenous biodiversity high.

Keywords: facilitation, forest restoration, nurse plant, succession, survival analysis

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Introduction

Enrichment planting is considered a practical tool for ecosystem restoration in many degraded areas. In arid and semiarid regions, the integration of tree planting with other management interventions has been used in a range of revegetation models to combat desertification (Puigdefábregas 1998, Holmgren and Scheffer 2001, Pal and Scharma 2001, Ma 2004). Planted trees may complement and accelerate natural regeneration of forest ecosystems (Hardwick et al 1997, Elliot et al 2003, Lemenih et al 2004) and help to restore previous levels of indigenous functional biodiversity (Cusack and Montagnini 2004).

In highly fragmented landscapes with prolonged habitat loss, forest relics will invariably lose forest interior species to local extinction resulting in longer recovery times (Vellend 2003, Verheyen et al 2004). Enriching matrices with forest trees may slow down the loss of species from forest fragments and accelerate succession (Martínez-Garza & Howe 2003). Especially in areas where soil seed banks are depleted or absent and indigenous seed sources scarce, it may be the only means to fully re-establish the diverse and ecologically as well as economically

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valuable natural forest (Aide et al 2000, Yirdaw and Luukkanen 2003).

The success of rehabilitation efforts depends on initial site characteristics, plantation design and management practices (Wunderle 1997). Careful planning of the enrichment operation is therefore as important as post-planting management, in particular in areas poor in biological and financial resources, where failures are not only an economical loss but also discourage local stakeholders. Common techniques used for afforestation consider pre-existing pioneer shrub vegetation as a source of competition for the planted trees, and consequently these shrubs are often cleared before planting (Castro et al 2002 and 2004, Gómez-Aparicio et al 2004). The benefits of such shrubs for tree recruitment do not increase in importance with abiotic stress (Maestre et al 2005), yet many case studies have documented the ability of woody plants to facilitate the establishment of understorey seedlings in environments where plants are exposed to severe stress (e.g. Pugnaire et al 1996, Callaway et al 2002, Castro et al 2002 and 2004, Gómez-Aparicio et al 2004). In such situations, the establishment of new plants is often restricted to the shady places under the canopy of other plants, called nurse plants (Vetaas 1992, Holmgren et al 1997, Flores and Jurado 2003).

In northern Ethiopia, changing land use and land cover triggered by a long history of cultivation and heavy livestock grazing pressure are proximate causes for severe dryland degradation and desertification (Zeleke and Hurni 2001, Asefa et al 2003, Lemenih et al 2005). In the northernmost regional state Tigray, where almost all available land is under cultivation or used as grazing land, this tendency is slowed down by a set-aside policy (Aerts et al 2004, Nyssen et al 2004, Mengistu et al 2005). Land rehabilitation efforts in exclosures, where removal of remnant vegetation and free grazing are no longer permitted, aim at restoring the natural pre-disturbance Afromontane forest vegetation. In these set-aside areas, natural regeneration of African wild olive *Olea europaea* subsp. *cuspidata* (Wall. ex G. Don) Cif., an important shade-tolerant, fleshy-fruited component of dry Afromontane forest (Friis 1992), is restricted to microhabitats under the pioneer shrub Bush guarri *Euclea racemosa* subsp. *schimperi* (A. DC.) White, and to a lesser extent under the dominant thorn shrub *Acacia etbaica* Schweinf. (Aerts et al 2005). But because seedling densities are fairly low (< 5 seedlings·ha^{-1}), enrichment planting of nursery-raised olive seedlings may be advantageous to assist regeneration in the exclosures. The prevailing reforestation technique used in the region is based on regularly spaced planting designs, where seedlings are planted in the interspaces between pre-existing shrubs, or shrubs are cut prior to planting. As a result of drought, ungulate herbivory (even in the exclosures) and poor planting practices, these operations generally suffer serious plant losses, often resulting in 100% mortality before the arrival of new rains (R. Aerts, 2002–2004, pers. obs.).

In 2003, an experiment was set up in Central Tigray (northern Ethiopia) to test an alternative technique of reforestation using African wild olive. The objective of the study was to analyze the effect of planting season and the effect of shrubs on early survival of olive seedlings, more specific during the first, dry winter, which is often the most critical period for the establishment of planted seedlings (Castro et al 2004). We hypothesized that shrubs enhance the patch suitability for *Olea* seedlings planted during both the short spring rains and the long summer rains, under the assumption that seedlings of a secondary climax tree have a low tolerance to water stress but a strong competitive response to shading.

Materials and methods

Study Area

Two study sites, Sesemat and Mheni (13°37' N, 39°21' E), were located 1,800–1,900 m above sea level in the Geba river catchment of Central Tigray, northern Ethiopia, on slopes over calcareous rocks and lacustrine silified Mesozoic Antalo limestone layers 20 km NW of the regional capital Mekelle, and are set-aside areas since 1996. A third site, Bubu Hills (13°30' N, 39°29'E, 2150 m), was located at the foot of a dolerite cliff at the edge of Mekelle town next to a peri-urban eucalypt plantation. The vegetation in both protected areas and in Bubu Hills was characterized by a discontinuous cover of shrubs and small regenerating trees in a matrix of herbaceous species and bare soil and can thus be defined as semiarid degraded savanna (Vetaas 1992, De Villiers et al 2001). The climate is related to the mountainous facies of the Sudanese zone with hot and dry winters (October–January) and two rainy seasons: a short and moderate (erratic) spring rain (*belg*) in (February)–March–April–(May–June) (Camberlin and Philippon 2002) and a long and heavy summer rain (*kremt*) in July–September (Segele and Lamb 2005). Mean annual precipitation is 625 ± 155 mm (spring rain 125 ± 11 mm; summer rain 466 ± 22 mm; means ± SE for the years 1960–2003; Meze-Hausken 2004) and mean annual temperature 18°C. Total spring and summer rains for 2003 were 149.3 and 357.3 mm (Mekelle Quiha station, National Meteorological Services Agency). In this area, dry Afromontane forest relics and Afromontane savanna woodland are communities dominated by *Olea europaea*, *Acacia etbaica* and *Combretum collinum* Fresen (R. Aerts, 2002, pers. obs.).

Experimental Design

Seedlings of *Olea europaea* were planted during spring and summer rains in 2003 in different microhabitats (treatments) in three sites and monitored until the end of the main winter drought (February 2004) to test the effect of shrubs and planting season on early seedling survival. The microhabitats were: (1) Open, seedlings planted in areas of bare soil between shrubs; (2) *Euclea*, seedlings planted under the canopy of individuals of *E. racemosa*; and (3) *Acacia*, seedlings planted under the canopy of individuals of *A. etbaica*. Planting points were distributed randomly among shrubs and interspaces between shrubs in two areas (plots) of circa 400 m² per site. In each plot, we planted 15 seedlings (five per treatment). Spring rain planting was carried out in Mheni and Bubu Hills (60 seedlings: 2 sites × 2 plots × 3 microhabitats × 5 seedlings; 17 April–19 May 2003); summer rain planting was carried out in Sesemat, Mheni and Bubu Hills (90 seedlings: 3 sites × 2 plots × 3 microhabitats × 5 seedlings; 9 July–19 August 2003). Planting holes were dug 30 cm deep and 30 cm wide with a grub hoe. After reconstruction of the original mulch (shrub treatments) or surface stone cover (open treatment) around the seedling root collar, each seedling received one litre tap water to alleviate transplantation shock and to allow the soil to settle. The olive seedlings used in the experiment came from the Endayesus tree nursery (Mekelle University, Mekelle, Ethiopia), were grown from seeds collected from local populations of the species (church forests), and were between 3 and 6 months old. The seedlings were grown in small polyethylene tubes (5.25 cm in diameter, 15 cm in depth) filled with a substrate of local black soil and sieved river sand mixed with organic material. For each planted olive, we recorded (1) survival, which was sampled approximately every two weeks for six months (when monitoring intervals are longer, survival probabilities may be positively biased); and (2) the cause of mortality based on leaf and stem characteristics (predation or desiccation).

Data Analysis

Seedling survival was analyzed using a time to event approach, which measures the time to an event for each individual (Altman and Bland 1998). In this study a critical event is seedling mortality. Because of the occurrence of censored cases, these 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, 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. Survival to any point in time is then calculated as the product of these probabilities for each cumulative time interval (Bland and Altman 1998). Equality of survival distributions for the different microhabitats and sites was tested using the Breslow statistic. Differences in mean survival time between planting seasons for all microhabitat × plot combinations were analyzed using the Kolmogorov-Smirnov test. Analyses were preformed using SPSS 11.0 for Windows (SPSS Inc., Chicago, IL).

Results and discussion

Results

Six months after planting, the overall mortality rate was 89.3 % for the seedlings planted during the spring rains (Fig. 1a). The highest mortality rates occurred during the first three months (Fig. 1a), which contained substantial dry periods prior to the onset of the summer rains. For the seedlings planted during the main summer rains, the overall mortality rate was 54.9% six months after planting, not counting 19 seedlings that were lost due to human disturbance. In contrast to spring rain planting, almost no mortality occurred during the first three months (Fig. 1b). Four months after planting, mortality under shrub cover was still fairly low, while already 30% of all seedlings in the bare interspaces had died. Since seedlings dried out without any visible damage to leaves or stems, 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 open patches was significant in either season, while the contrast between *Acacia* and open interspaces was only significant in the summer planting season. Within-plot data analysis showed that the differences of mean survival times between microhabitats and the levels of significance for these differences are highly variable and plot-dependent (Table 2), but the patterns of variation among microhabitats were similar for most plots in both seasons, with the longest survival times under *Euclea*, generally followed by *Acacia*. Mortality was higher and occurred sooner in the open interspaces. Mean survival times for all microhabitat × plot combinations were significantly higher in the summer planting season than in the spring planting season ($Z = 2.619$, $P < 0.001$).

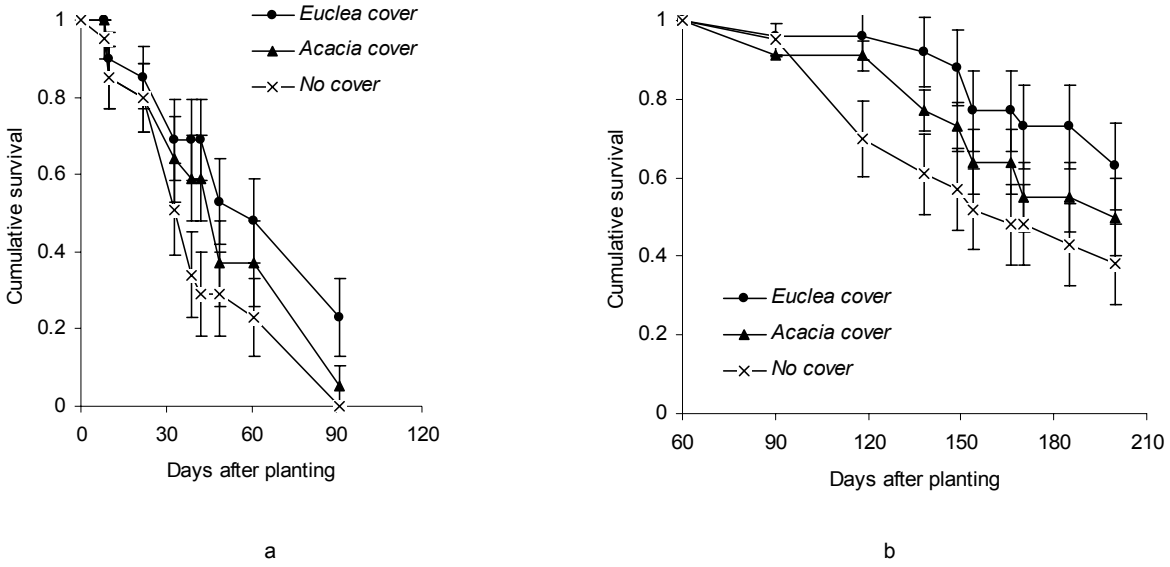

Fig. 1. Cumulative survival of *Olea europaea* seedlings planted under *Euclea* cover, under *Acacia* cover and in open field in exclosures of northern Ethiopia: a. spring rain enrichment planting (n = 60; significance of difference between patch types: P = 0.02); b. summer rain enrichment planting (n = 90; significance of difference between patch types P = 0.01). Values are mean cumulative survival ± SE.

Discussion

African wild olive is a secondary climax species that lacks persistent soil seed reserves and usually forms seedling banks on the forest floor (Teketay and Granström 1997). This may give the impression that olive seedlings are typically unable to establish in open interspaces between shrubs in exclosures, which are barren and where the soil surface temperature can be extremely high (Aerts et al 2004). Our results show that the survival of planted olive seedlings can be promoted under pioneer shrubs compared to open areas. These shrubs may have a facilitative effect related to the shade they provide by reducing solar radiation, soil temperature and evaporation and thus improving the water status of the seedlings (Valiente-Banuet and Ezcurra 1991, Vetaas 1992, Holmgren et al 1997, Castro et al 2002 and 2004). The summer rain enrichment planting experiment illustrated that *Olea* seedlings can also survive in open interspaces between shrubs, but only during and shortly after the rains, when drought stress is presumably rather limited.

For seedlings planted during the spring rains, drought stress occurs soon after planting, resulting in short survival times and high mortality ratios irrespective of the microhabitat in which they were placed. Nevertheless, seedlings under *Euclea* performed slightly better, and almost two years after planting (12 March 2005), the two only seedlings still alive were found under *Euclea*. Seedlings planted during the summer rains have a higher resilience against first drought, which may be attributed to higher soil moisture reserves after the long rains, and/or to a more extensively developed root system of the seedling. This may suggest that seedlings do not require high rainfall intensities but preferably an extended rainy season.

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

	Spring rains (n = 60)		Summer rains (n = 90)	
	BS	P	BS	P
Full model (PLOT × TREATMENT)	7.73	0.02*	9.98	0.01**
Contrasts in survival time between patch types (adjusted for PLOT)				
Euclea <> *Acacia*	2.53	0.11^{ns}	0.70	0.40^{ns}
Euclea > *Open*	6.31	0.01**	7.75	0.01**
Acacia > *Open*	2.53	0.11^{ns}	4.80	0.03*

BS = Breslow statistic for differences between groups in Kaplan-Meier survival analysis.
Levels of significance: ns: P > 0.05; *: 0.01 < P ≤ 0.05; **: 0.001 < P ≤ 0.01.

Table 2. Survival time in days after planting (mean + SE) of *Olea europaea* seedlings planted in different microhabitats and seasons in exclosures of northern Ethiopia.

		Cover type					
Plots (planting date) [1]		*Euclea* shrub	*Acacia* shrub	No cover	df	BS [2]	P
Spring rain enrichment planting		n = 20	n = 20	n = 20			
Bubu Hills 1 (17/04/2003)	n = 15	73 (25)	56 (14)	33 (0)	2	2.58	0.28^{ns}
Bubu Hills 2 (17/04/2003)	n = 15	124 (18)	108 (15)	81 (9)	2	3.58	0.18^{ns}
Mheni 1 (10/04/2003)	n = 15	69 (16)^{a}	47 (2)^{ab}	37 (8)^{b}	2	5.83	0.05*
Mheni 2 (19/05/2003)	n = 15	36 (12)	15 (3)	17 (3)	2	0.64	0.73^{ns}
Summer rain enrichment planting		N = 30	N = 30	N = 30			
Sesemat 1 (19/08/2003)	n = 15	154 (5)	154 (7)	136 (9)	2	2.94	0.23^{ns}
Sesemat 2 (19/08/2003)	n = 15	160 (9)^{a}	140 (10)^{ab}	125 (7)^{b}	2	6.33	0.04*
Bubu Hills 1 (10/07/2003)	n = 15	>200 (0) ^{X}	>200 (0) ^{X}	164 (22)	2	3.97	0.14^{ns}
Bubu Hills 2 (10/07/2003)	n = 15	>200 (0) ^{X}	>200 (0) ^{X}	197 (4)	2	0.95	0.62^{ns}
Mheni 1 (09/07/2003)	n = 15	>200 (0) ^{X}	149 (0)	184 (20)	2	3.26	0.20^{ns}
Mheni 2 (09/07/2003)	n = 15	184 (17)	>200 (0) ^{X}	disturbed	2	2.49	0.29^{ns}

[1] Spring: seedlings planted during the short spring rains, between 10/04/2003 and 19/05/2003; Summer: seedlings planted during large summer rains, between 09/07/2003 and 19/08/2003. [2] Breslow statistic for differences between groups (letters) in Kaplan-Meier survival analysis. Levels of significance: ns: P > 0.05; *: 0.01 < P ≤ 0.05. [X] High fraction of censored cases (survival exceeds follow-up period): indicated means are minimal survival times.

Notwithstanding this initial hardiness, seedlings planted under *Euclea* or *Acacia* shrub cover have a distinctively higher probability to survive winter drought than seedlings planted in-between pioneer shrubs. But because *A. etbaica* is a semi-deciduous shrub that partially sheds its bipinnate leaves and has usually less dense canopies than *Euclea* which is evergreen and has larger, leathery leaves, irradiance and consequently evaporation are higher under *Acacia* patches, which may therefore be less suitable.

Our results agree with other studies on rehabilitation of water-stressed environments, where similar facilitative effects of early-successional vegetation on woody species establishment and survival have been reported; for example, for the effect of shrubs on Blue oak *Quercus douglasii* Hook and Valley oak *Q. lobata* Née in California (Callaway 1992) and on Black pine *Pinus nigra* Arnold, Scots pine *P. sylvestris* L. and other tree species in Spain (Castro et al 2002 and 2004, Gómez-Aparicio et al 2004), and for the effect of Alpha grass *Stipa tenacissima* L. on Aleppo pine *Pinus halepensis* Miller (Gasque and García-Fayos 2004) and on Kermes oak *Quercus coccifera* L. and Mastic tree *Pistacia lentiscus* L. (Maestre et al 2001 and 2004) in Spain.

Because of the lack of sufficient soil seed reserves of woody species in exclosures in Ethiopia (Teketay 1997), we concur with several authors who have advocated (but not tested) enrichment planting to accelerate natural regeneration in the set-aside areas (e.g. Argaw et al 1999, Tekle and Bekele 2000, Yirdaw and Luukkanen 2003, Mengistu et al 2005). Yet in disagreement with Mengistu et al (2005), we explicitly advise against the widespread use of invasive exotic species such as Orange wattle *Acacia saligna* (Labill) H. Wendl. (see Van Wijk et al this issue).

All in all, we must keep in mind that early survival of planted seedlings was limited and long-term survival uncertain, even in *Euclea* patches enriched during the summer rains. Almost two years after planting, only four seedlings were still alive, in only one site (Bubu Hills): two under *Euclea* from the spring rain enrichment, and one under *Acacia* plus one under *Euclea* from the summer rain enrichment. Interaction between plants is species-specific and may not only show important between-plot variability, but also between-year variability (Lloret et al 2005). Many disturbed ecosystems, such as overgrazed savannas, have distinct alternative stable states which are separated by critical thresholds and transitions across state boundaries are difficult to reverse. Because these systems usually experience sudden transitions from one state to the other when certain climatic events occur, rather than showing gradual responses to changing conditions, certain restoration measures (for example, herbivory control or enrichment planting) may be sufficient to induce woodland recovery in a wet year but not in a dry year (Holmgren et al 2001, Holmgren and Scheffer 2001). In the drought-prone northern highlands of Ethiopia, forecasts of summer rain may be the ultimate decisive factor to plan enrichment planting operations. Since the warm El Niño-Southern Oscillation (ENSO) is associated with below-average summer rainfall over the Ethiopian highlands (Seleshi and Zanke 2004), enrichment planting should be avoided during ENSO episodes. Roughly the opposite climatic conditions may be found during the next phase, known as La Niña, which may be seen as a window of opportunity for dryland restoration (Holmgren and Scheffer 2001). Summer rainfall over the Ethiopian highlands is positively correlated to the equatorial east Pacific sea level pressure and the southern oscillation index (Seleshi and Zanke 2004), thus high values of these climatological variables may be seen as proxies for good planting years (see Camberlin and Philippon (2002) and Segele and Lamb (2005) for predictability studies on Ethiopian rainfall). During the last four decades in our study area (1960–2002), such above-average (at least +25%) summer rainfall events occurred on average every four years (Meze-Hausken, 2004:27, Fig. 9; Tilahun, in press).

Conclusion

The central conclusion of the present study is that African wild olive seedling survival can be enhanced by pre-existing early-successional shrubs who serve as a nurse plant probably through limiting drought stress. Especially the evergreen pioneer shrub *Euclea racemosa* provides suitable microhabitats for enrichment planting. On the other hand, we must consider the fact that ultimate seedling survival is limited to a certain extent. Planting during the spring rains in any microhabitat, and in open interspaces between shrubs during the summer rains, must not be promoted due to high seedling mortality, and thus high replacement costs. Planting under shrubs during above-average summer rains, which may occur during La Niña episodes, may have important advantages in assisting natural regeneration of dry Afromontante vegetation, and conserving the pre-existing shrubs at the same time reduces the risk of erosion and keeps levels of indigenous biodiversity high.

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