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Wildfires and beech forests of Southern Alps during the summer 2003 climate anomaly: fire effects and post-fire management

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Abstract

In the Southern Alps the summer heat wave in 2003 was associated with unusually large wildfires in beech (*Fagus sylvatica* L.) forests. Post-fire management in beech stands has been poorly investigated. In this study we assess the impact of salvage logging on a beech forest affected by different fire intensities during the wildfires of August 2003 in the Alps of NW Italy. In high fire severity patches mortality was complete and beech failed to resprout or to regenerate from seeds. In low severity patches beech mortality was delayed, allowing abundant seed dissemination associated with drought-induced masts in 2004 and 2006. Salvage logging was done in 2007 and the assessment of the vegetation structure took place in 2010 on 33 plots. Post-fire stand development is influenced by fire severity and the timing and intensity of logging. Silvicultural guidelines are provided for post-fire management.

Keywords: *Fagus sylvatica*, Southern Alps, Summer 2003, post-fire management

1. Introduction

European beech (*Fagus sylvatica* L.) is widely distributed in Europe (Buiteveld et al. 2007) and is of particular importance in Alpine regions providing multiple services such as general and direct protection (Brang et al. 2006), timber production (Nocentini 2009), and recreational values (Höchtl et al. 2005). Beech is a fire sensitive species (Herranz et al. 1996, Tinner et al. 2000, Valsecchi et al. 2008, Conedera et al. 2010, van Gils et al. 2010). Therefore, increased fire frequencies in response to forecast climatic change (IPCC 2007) may endanger and compromise stand functionality in the *Fagus* mountain-belt forests of the Alps (Delarze et al. 1992, Hofmann et al. 1998, Zumbrunnen et al. 2009).

Post-fire management interventions have the potential to enhance forest structures linked to the provision of ecosystem services (Moreira et al. 2009). Such positive outcomes require that forest managers make complex decisions regarding the necessity for post-fire rehabilitation measures and the silvicultural prescriptions to adopt (Barbati et al. 2009). In several Alpine regions there is strong political pressure for active management interventions as soon as possible after a wildfire (Providoli et al. 2002, Beghin et al. 2010). Salvage harvesting of burned trees is often suggested to optimize timber value and to reduce the risk of insect infestation, hazardous fuel accumulation and damages to soil and vegetation by the shift of logs. Nevertheless, salvage logging is controversial and its ecological implications are a major concern (Lyndenmayer et al. 2008). Furthermore, forest managers must account for financial restrictions, characteristics of harvesting firms, and consider issues such as biodiversity, climate change and the recreational value of forests (Moreira et al. 2009).

Though relevant scientific knowledge is available for coniferous species in Alpine areas (Beghin et al. 2010, Moser et al. 2010), few studies have addressed the effect of post-fire interventions in broad-leaved forests of the Alps (Providoli et al. 2002). In particular this subject have been poorly investigated in beech stands. Several fire ecology studies suggest that reforestation after fire in beech has to rely mainly on recruitment from seeds because post-fire resprouting in *Fagus* is not common (Herranz et al. 1996, Conedera et al. 2010, Maringer 2010). This is thought to be particularly true for beech in transition from coppice to high stands (Ciancio et al. 2006), which characterize the majority of broad-leaved forests in the alpine area (Piussi and Farrell 2000). Post-fire sources of beech seeds are canopy seeds of surviving trees and green forest islands within and at the edges of the burnt beech patch (Conedera et al. 2010, van Gils et al. 2010). Growing conditions during the early phase of seedling establishment is crucial for regeneration success as beech saplings have limited tolerance of high irradiance (Minotta and Pinzaiuti 1996, Madsen and Larsen 1997, Tognetti et al. 1998). The potential for creating favourable growing conditions for beech seedling with post-fire silvicultural interventions is therefore of interest to forest managers.

This paper aims to contribute to the development of ecologically-based decision criteria for post-fire management in beech forests. We analyzed the effect of passive and active post-fire management interventions in *Fagus sylvatica* L. stands in the Susa Valley, Piemonte Region, Northwest (NW) Italy. The following main questions are addressed: 1) What are the ecological dynamics in the absence vs. presence of post-fire management? 2) Which approach, passive or active management, is the most effective for successful regeneration of *Fagus sylvatica* following a mixed severity wildfire? 3) What are appropriate silvicultural prescriptions for immediate post-fire management?

2. Methods

Study area

The summer heat wave in 2003 (Luterbacher et al. 2004) was associated with substantial fire activity in many European regions (European Communities 2004) including the Alps of NW Italy and Southern Switzerland. Historically these regions are characterized by winter fire regimes (Ascoli and Bovio 2010, Conedera et al. 2011). Several large wildfires (> 100 ha) in the Alps had already affected beech forests in June and July 2003, but the last week of August two large forest fires spread simultaneously at two different sites of the Piemonte Region, NW Italy, burning altogether 1,551 ha of forests, of which 781 ha were dominated by beech (Data source: Regione Piemonte). Comparable fire events in *Fagus* forests have never been observed during summer in this Alpine area.

The present research regards one of these beech wildfires situated in the Susa Valley, 40 km West of Torino (Figure 1) in the municipalities of Bussoleno and Chianocco (7°9'1,534"E - 45°9'44,01"N). The mean annual precipitation and temperature of the area are 805 mm and 11.5 °C respectively. The pre-fire forest stands consisted of downy oak (*Quercus pubescens* Wild) in the lower montane zone (600-1,000 m a.s.l.), and beech mixed with larch (*Larix decidua* Mill.) and sporadic Scots pines (*Pinus sylvestris* L.) in the upper montane zone (1,000-1,700 m a.s.l.) (Camerano et al. 2004); pastures patches were included within the forest matrix. These forest stands play an important role for the general and direct protection of the Susa Valley (Regione Autonoma Valle d'Aosta - Regione Piemonte, 2006). The fire event was a slope-wind driven wildfire which burned 480 ha, as GPS-surveyed in September 2003 by the Corpo Forestale dello Stato (Forest Service), and started the 27 of

August at the wildland-urban interface at the bottom of the valley and developed for three days along an altitudinal gradient of 1,200 m ranging from 600 m to 1,800 m a.s.l. Photo interpretation of post-fire crown mortality within the beech burnt area (258.7 ha) was done using an orthorectified aerial photograph that date July 2004. Immediate post-fire mortality of individuals occurred on 88.1 ha, while 170.5 ha showed delayed mortality, probably due to local differences in fire intensity (Conedera et al. 2010). Most of the low fire severity areas were situated within the municipality of Chianocco which in 2004 approved a post-fire management plan on its properties. Cutting prescriptions were for winter salvage logging of all dead and highly damaged trees which were tagged in 2004. The intervention area (29.3 ha) was subdivided in blocks which were assigned to private citizens, to the Forest Management Consortium of the Susa Valley and to a private firm. The harvesting operations started in 2005 and lasted up to 2010 according to the cutting area (e.g. easiness of access; harvesting firm).

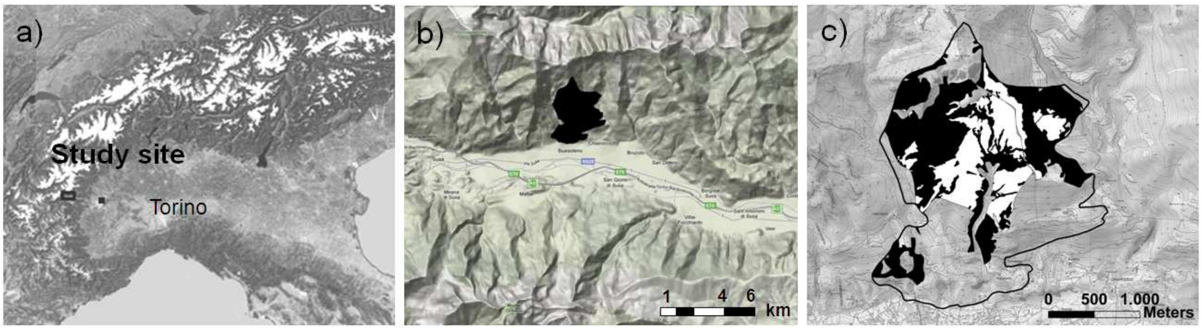

Figure 1 — (a) Location of the study site in the Alps of NW Italy; (b) Locations of the 480 ha burn in the Susa Valley, Piemonte; (c) High (white) and low (black) fire severity areas within the beech burnt stands.

Experimental and sampling design

The study area was divided in 3 blocks according to fire severity and post-fire management. A total of 33 circular plots where randomly distributed within blocks (Table 1) and several parameters were collected or computed in areas of different size as reported in Table 2. The age of saplings, shoots and seedlings was measured by tree ring counting of 10 individuals per species randomly selected in each plot. The ground cover variables were measured by visual estimation of percent cover within each quadrant of the plot by two observers and then averaged. The canopy cover of the vegetation was measured at 3 m above the soil level by the mean of a Gap Light Analyzer (GLA), which is a Windows-based software application designed to import, display, and analyze digital hemispherical (fisheye) canopy photographs to compute canopy openness (Frazer et al. 1999). The field work was carried out in summer 2010.

Data analysis

ANOVA and Redundancy Analysis were combined to assess the effect of severity, post-fire management and environmental variables on computed regeneration descriptors (Table 2). Thirty-two out of 33 plots were considered for the investigation after performing an outlier analysis. One-way ANOVA was used to test significant differences ($p < 0.05$) in basal area among blocks (SPSS$_{®}$ version 17.0). Normal distribution and equivalence of variances were also tested. When the expectations for equivalence of variances were not met, Log transformation was carried out. In the case of significant effects, post-hoc comparisons were made using the Tuckey test. Redundancy Analysis (RDA) has been effectively adopted in similar studies (Beghin et al. 2010) and was used to investigate the variability accounted for by the explanatory variables (Block, environmental variables) and their correlation with variation in regeneration descriptors (20 variables x 32 plots). The statistical significance of RDA was tested by the Monte Carlo permutation method based on 1,000 runs with randomized data. RDA was performed with XL-STAST (Addinsoft®).

Table 1 – *Description of the experiment design .*

Block	Fire Severity	Description	N. plots
B-1	High	Burnt areas where beech showed an immediate and complete post-fire mortality and no management interventions have been carried out.	9
B-2	Low	Burnt areas where beech showed a delayed post-fire mortality and no management interventions have been carried out.	9
B-3	Low	Burnt areas where beech showed a delayed post-fire mortality and salvage logging was carried out in 2006-2007.	15

Table 2 – *Variables collected and regeneration descriptors computed for each sampling point.*

Variable Type	Variable name and unit	Sampling area/plot
Pre-fire trees	Species; diameter at 1.3 m (cm); height (m); dead-live.	706 m^2
Regeneration	Species; saplings-shoots (height > 30 cm); seedlings (height < 30 cm) root-collar diameter (cm); height (m); age (years).	50 m^2 (saplings); 12.5 m^2 (seedlings)
Ground cover	Bare soil (%); herbs (%); shrubs (%); coarse woody debris (%).	50 m^2
Tree cover	Vegetation cover measured with the GLA at an height of 3 m above the soil level (canopy cover provided by surviving trees).	-
Environmental parameters	Site coordinates; elevation (m a.s.l.); aspects (°N); slope (°).	-
Regeneration descriptors	Pre- and post-fire species density (n ha^{-1}); basal area (m^2 ha^{-1}) measured at 1.3 m for pre-fire trees and at the root collar for the regeneration; tree cover (LAI measured at 3 m with the GLA).	-

3. Results

Post-fire tree regeneration was abundant in all blocks with the predominance of seedlings in block B-1 and saplings in blocks B-2 and B-3 (Table 3). The mean density of regeneration (saplings + shoots + seedlings) ranged between 5,940 individuals ha^{-1} (B-1) to 257,708 individuals ha^{-1} (B-3). In blocks B-2 and B-3, beech regenerated mainly by seed; in contrast, no saplings were found in block B-1. The mortality rate of beech regeneration was very low (< 1%), but 25.1% of individuals had apparent heat damage. Damage due to coarse woody debris (CWD) friction, insects and wildlife was observed on 2.5%, 1.3% and 0.1% of the beech regeneration, respectively. The most abundant pioneer species were goat willow (*Salix caprea* L.), silver birch (*Betula pendula* Roth), European aspen (*Populus tremula* L.) maple (*Acer opulifolium* Chaix.), and Laburnum (*Laburnum alpinum* Bercht. et Presl). Pioneer species regenerated mainly by seed in B-1 and B-2, while in B-3 more than 50% of individuals had an agamic origin (Table 3).

Table 3 – *Post-fire mean (±SE) density of saplings, shoots and seedlings by block and species*

Species		All			Fagus			Pioneer species		
	Type	Seedlings	Shoots	Saplings	Seedlings	Shoots	Saplings	Seedlings	Shoots	Saplings
Blocks	B-1 n. 9	6,480 (± 1,387)	2,205 (± 1,484)	14,028 (± 2,600)	0	0	0	3,759 (± 951)	2,205 (± 1,484)	11,250 (± 2,357)
	B-2 n. 8	77,140 (± 8,551)	3,569 (± 1,728)	23,001 (± 5,341)	19,639 (± 5,099)	0	7,961 (± 2,647)	55,024 (± 8,515)	3,569 (± 1,728)	8,138 (± 2,987)
	B-3 n. 15	102,931 (±10,930)	25,396 (±4,629)	15,947 (± 3,093)	74,781 (±10,061)	1,698 (±831)	6,982 (± 1,896)	21,402 (±3,519)	23,320 (±4,135)	3,491 (± 1,432)

The basal area (measured at the root collar) of the regeneration (saplings + shoots), including all species, ranged between 0.2 and 22.2 $m^2\ ha^{-1}$ and varied significantly among blocks ($F_{2,29}$=14.95, $p < 0.001$); the Tuckey post-hoc test identified significant differences between B-1 and B-3 (Figure 2). Significant differences ($F_{1,21}$=6.56, $p < 0.018$) in basal area of beech were also found between B-2 and B-3, excluding from the analysis block B-1 where no beech individuals were observed.

The influence of blocks and environmental parameters on regeneration descriptors, ground and tree cover was analyzed through Redundancy Analysis (Figure 3). The RDA was highly significant ($p < 0.001$). A clear separation of blocks emerged from the ordination graph. The overall basal area of regeneration, and both basal area of beech and larch, and of pioneer species such as goat willow and silver birch, were positively associated to B-3. Laburnum was positively associated to B-2 and to elevation. Aspen and other species (e.g. downy oak, Scots pine) were positively correlated to B-1 and to aspect and slope. A positive correlation was also found between the basal area of maple aspect and B-1. According to the ground and tree cover variables, bare soil poorly correlated to B-1 and B-3, while CWD, shrubs, and to a minor extent herbs were positively associated to B-1, and to increasing aspect and slope. LAI measured at 3 m and the basal area of individuals predating the fire were positively correlated to B-2.

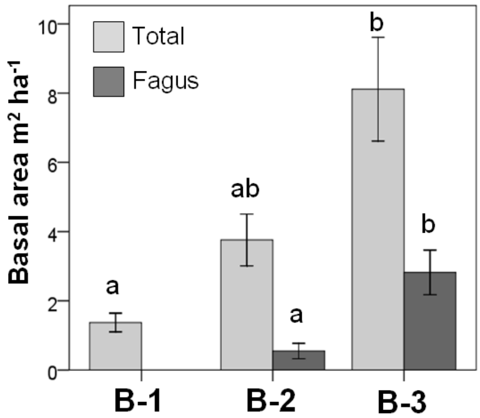

Figure 2 — Variation in mean (±SE) root collar basal area of saplings+shoots of overall species (light grey) and beech (dark grey) by blocks. Significant differences are evidenced by different letters.

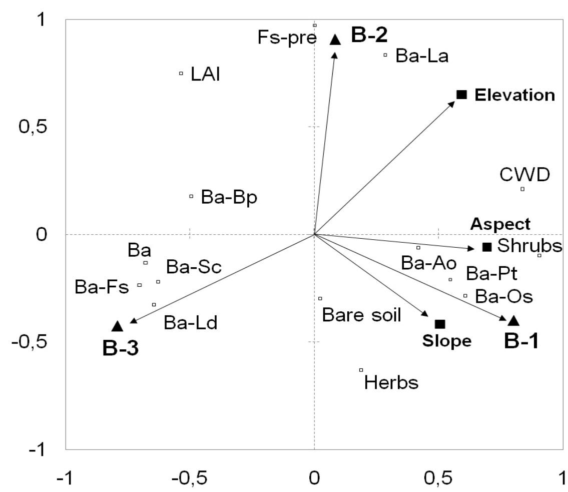

Figure 3 — Redundancy Analysis (RDA 32 plots) of regeneration descriptors (Ba=total basal area; Ba-Ao=basal area *A. opulifolium*; Bp=*B. pendula*; Fs=*F. sylvatica*; La=*L. alpinum*; Ld=*L. decidua*; Os=*other sp.*; Pt=*P. tremula*; Sc=*S. caprea*) and ground cover (Shrubs, Herbs, CWD, Bare soil) in relation to blocks (triangles) and environmental parameters (squares).

Finally, the age analysis of regeneration (Figure 4) showed that beech established in B-2 since 2005 up to 2008, and most of individuals recruited in 2006 as indicated by the median value in box plots of Figure 4. Conversely, in B-3 the majority of beech individuals established in 2007, concurrent with the cutting; similarly, most of individuals of pioneer species established in 2007 indicating a strong effect of the cutting also on sexual and vegetative regeneration of willow, birch and laburnum.

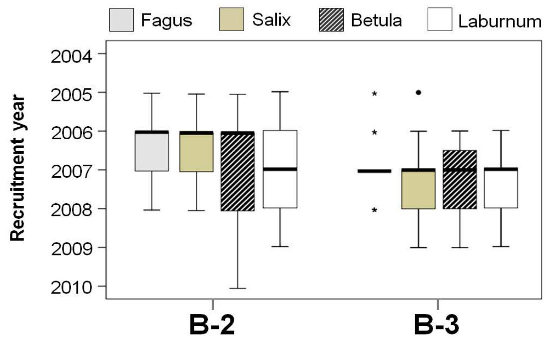

Figure 4 — Recruitment year of saplings + shoots by species and block in case of low severity.

4. Discussion

In B-1 (high severity), beech mortality was immediate and over large areas. Consequently beech failed to either resprout or establish from seed; this is consistent with observations in several previous studies (Conedera et al. 2010, Maringer 2010, van Gils et al. 2010). The RDA revealed a negative correlation among LAI of pre-fire species (beech and larch) and aspect and slope, which were higher in B-1 in comparison with B-2 and B-3. Several studies (e.g. Broncano and Retana 2004) related fire behaviour and effects to topography and reported a positive correlation between increasing severity and increasing slope and exposed aspects. Similarly, in B-1 slope and aspect were associated with high fire intensity and high mortality rates of beech individuals. Subsequently, the absence of surviving tree cover over a large area has effectively eliminated the beech seed source. Moreover, beech stumps did not resprouted, probably as a consequence both of the fire scorch at the root collar and to the week resprouting capability which characterizes beech aged stumps (Conedera et al. 2010). Finally, as the RDA shows, post-fire regeneration in B-1 mainly consists of pioneer species such as *Pinus sylvestris*, *Acer opulifolium*, *Quercus pubescens* and *Populus tremula*. Dominance by these pioneer species and the lack of surviving canopy cover, indicate meso-xeric conditions unfavourable to beech seed germination and seedling establishment (Minotta and Pinzaiuti 1996, Madsen and Larsen 1997).

In contrast, beech seedling mean density observed in B-2 is consistent with abundant disseminated seed germinating in the years following the fire. Regeneration densities are comparable to natural regeneration densities observed in several studies a few years after mast under similar canopy densities (Bernetti 1995, Madsen and Larsen 1997). Several factors could have contributed to an abundant seed crop following the fire event. Piovesan and Adams' (2005) studies of masting behaviour in beech indicate that a drought in the early summer is a very strong predictor of masting, and that the predictive power is increased if there has been an uncommonly moist summer the year before the drought. Summer 2002 in the Susa Valley was characterized by 500 mm of rain, 60% of the yearly precipitation, the highest level recorded in the last 20 years (Arpa Piemonte: 1991-2010). In summer 2003 the anomalous heat wave impacted the Southern Alps (Mercalli et al. 2008). Moreover, early summer (May-July) in 2005 showed even lower precipitation levels than early summer 2003. These climatic patterns likely contributed to mast in 2004 and 2006 in the study area; these patterns and associated mast have also been observed at many different sites throughout Europe (Övergaard et al. 2007, Granier et al. 2008, Mund et al. 2010). Another factor which could have induced an abundant seed crop after fire is related to the stimulation of flowering which characterizes many trees species when subjected to stresses of various type (Philipson 1990), and specifically to fire (Bond and van Wilgen 1996). Further, dissemination was facilitated by pre-fire trees which survived to fire. Where local fire intensity is low, or low to moderate, injured beech may remain alive and standing for 5-6 years (Conedera et al. 2010). This detail allows for both seed production and dissemination, as observed in other studies (Maringer 2010). The RDA shows in fact a strong correlation among tree cover (LAI), basal area of surviving beech individuals in B-2. Most beech saplings in B-2 germinated following the mast in 2006, while very few saplings date back to 2004. The mast in 2006 was probably more abundant than the one in 2004 (Övergaard et al. 2007, Mund et al. 2010). Moreover, in 2004 in B-2 light conditions for saplings establishment (Harmer 1995) was likely inadequate, as the majority of pre-fire beech individuals were still alive. As we assessed by interpreting the 2004 aerial photograph, stand canopy density was, on the whole, maintained immediately following the fire. In subsequent years, pre-fire injured individuals started to fall, as verified by examining an aerial photograph from August 2006. This delayed mortality created intermediate conditions of canopy openness, suitable for seed germination and saplings establishment (Minotta and Pinzaiuti 1996, Madsen and Larsen 1997).

Beech seedling recruitment was significantly different, in amount and timing, in B-3 than in B-2. In B-3 the majority of beech saplings recruited in spring 2007, following salvage logging operations carried out the previous winter. Several studies document the beneficial effect of felling and extraction during the dormant season, both before and after seedfall, in order to disturb the soil and incorporate seeds (Gemmel et al. 1995, Harmer 1995). Seeds buried in soil are more likely to survive and germinate than exposed seed. Moreover, there are comments in the literature stating that litter layers that are too deep have an adverse effect on establishment (Harmer 1995); this results from the failure of young saplings to root adequately into the mineral soil before the litter dries in summer. Fire and post-fire salvage logging may provide excellent seed beds, having a reduced litter, and loose friable soil covered with a light covering of humus. In addition, the RDA showed a positive correlation not only between B-3 and beech basal area, but also with larch, willow and birch, and with the overall basal area of the regeneration. This result could be explained by the fact that the salvage logging in 2007 determined a substantial damage to early saplings of beech, larch and of pioneer species: in fact very few individuals which recruited before 2007 were observed in B-3. Nevertheless, the cutting stimulated not only the germination of beech and larch seeds, but also the vegetative regeneration of pioneer species resulting in high basal area. At this point the abundance of pioneer regeneration is appearing to facilitate rather than inhibit the beech regeneration above all in more exposed sites (results not shown). The shading provided by pioneer species is probably protecting beech from heat damage to the stem and some foliage, reducing transpiration, producing humus and providing a favourable environment for photosynthesis and growth, as has been observed in other studies (Helgerson 1990, Tognetti et al. 1998).

5. Conclusions

In order to enhance seed germination and seedling establishment of beech, post-fire management interventions should consider processes of regeneration ecology observed in the present study. For example, post-fire treatments should reflect: 1) timing of masting; 2) cutting could be delayed 1 year to stimulate, with a single intervention, both seed germination of beech and resprouting of pioneer species, above all in areas with less residual canopy cover; 3) excessive delay of post-fire harvesting may have an adverse impact on established beech saplings; 4) due to the delayed and progressive mortality of injured beech individuals, marking of individuals for felling should be at least 2 years post-fire; 5) salvage logging should extract most of the woody debris to reduce hazardous fuels accumulation, but the cutting should leave some fraction of the injured beech trees and canopy cover to serve as general and direct protection, seed sources, and maintain, once they will upset, some flux of woody debris within the system as suggested by several authors (Lyndenmayer et al. 2008, Beghin et al. 2010); 6) the common practice of extending salvage logging over several years, i.e., coinciding with progressive mortality and tree fall, should be avoided; 7) cutting should leave most of the surviving larch and pine trees, as a seed source, because they contribute to stand fire resistance, and in consideration of their important role in direct protection (Regione Autonoma Valle d'Aosta - Regione Piemonte, 2006) on steep Alpine slopes.

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