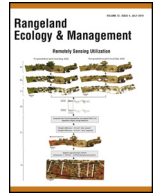


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Prescribed Summer Fire and Seeding Applied to Restore Juniper-Encroached and Exotic Annual Grass-Invaded Sagebrush Steppe[☆]

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ABSTRACT

Western juniper (*Juniperus occidentalis* Hook.) encroachment and exotic annual grass (medusahead [*Taeniatherum caput-medusae* L. Nevski] and cheatgrass [*Bromus tectorum* L.]) invasion of sagebrush (*Artemisia* L.) communities decrease ecosystem services and degrade ecosystem function. Traditionally, these compositional changes were largely confined to separate areas, but more sagebrush communities are now simultaneously being altered by juniper and exotic annual grasses. Few efforts have evaluated attempts to restore these sagebrush communities. The Crooked River National Grassland initiated a project to restore juniper-encroached and annual grass-invaded sagebrush steppe using summer (mid-July) applied prescribed fires and postfire seeding. Treatments were unburned, burned, burned and seeded with a native seed mix, and burned and seeded with an introduced seed mix. Prescribed burning removed all juniper and initially reduced medusahead cover but did not influence cheatgrass cover. Neither the native nor introduced seed mix were successful at increasing large bunchgrass cover, and 6 yr post fire, medusahead cover was greater in burned treatments compared with the unburned treatment. Large bunchgrass cover and biological soil crusts were less in treatments that included burning. Exotic forbs and bulbous bluegrass (*Poa bulbosa* L.), an exotic grass, were greater in burned treatments compared with the unburned treatment. Sagebrush communities that are both juniper encroached and exotic annual grass invaded will need specific management of both juniper and annual grasses. We suggest that additional treatments, such as pre-emergent herbicide control of annuals and possibly multiple seeding events, are necessary to restore these communities. We recommend an adaptive management approach in which additional treatments are applied on the basis of monitoring data.

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Introduction

Woody plant encroachment has substantially altered ecosystem function and decreased ecosystem services on rangelands worldwide over the past 2 centuries (Anadón et al., 2014; Archer et al., 2017). In the Intermountain West, western juniper (*Juniperus occidentalis* Hook.), a fire intolerant tree, has expanded from 0.3 to 3.5 million ha since the late 19th century (Miller et al., 2000, 2005). Juniper encroachment has largely occurred because of elongated fire return intervals caused by fire suppression and historical overgrazing (Miller and Rose, 1999). Juniper encroachment of sagebrush (*Artemisia* L.) communities degrades habitat for sagebrush-obligate wildlife, decreases forage production, reduces snow retention, increases evapotranspiration loss, alters timing of water availability, and increases erosion and runoff risk (Miller et al., 2000; Pierson et al., 2007; Kormos et al., 2017).

Control of encroaching juniper is a priority for the conservation of sagebrush ecosystems. Prescribed burning is often applied to control juniper because it is more effective and also generally less expensive than mechanical treatments (Miller et al., 2005; Boyd et al., 2017). Juniper encroachment was primarily a problem in cool, wet sagebrush communities but has expanded into hot, dry sagebrush communities (Davies et al., 2011). Prescribed burning of high-elevation juniper-encroached sagebrush communities generally achieves management goals of controlling juniper, increasing understory vegetation, and decreasing erosion risk (Pierson et al., 2007; Bates et al., 2014). Information, however, is generally lacking on the effects of applying prescribed fire to control juniper encroachment of hot, dry sagebrush communities, particularly when exotic annual grasses are already an issue.

If a plant community is juniper encroached and annual grass invaded, annual grass management is necessary (Davies et al., 2011). Exotic annual grasses may be reduced by burning when seeds are still on plants. Fires before seed shatter can reduce medusahead (*Taeniatherum caput-medusae* L. Nevski), an exotic annual grass, cover, and density when fires are severe enough to cause mortality of seeds in exposed inflorescences (Kyser et al., 2008; Sweet et al., 2008; Davies

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et al., 2013). After exotic annual grass control, perennial vegetation needs to be established to limit annual grass reinvasion. Non-native grasses generally establish more successfully than native grasses in hot, dry sagebrush communities (Davies et al., 2015); however, established native vegetation can limit medusahead reinvasion (Davies and Johnson, 2017). Information on postfire seeding of natives compared with non-native species in juniper-encroached hot, dry sagebrush communities is lacking.

The purpose of this study was to evaluate effects of a summer burn and postfire seeding in juniper-encroached and annual grass – invaded sagebrush communities. We accomplished this using a project setup on the Crooked River National Grasslands (CRNG). We hypothesized that 1) prescribed burning would initially decrease exotic annual grasses, but, without seeding perennials, exotic annual grasses would increase over time; 2) seeding perennials after fire would increase perennial vegetation cover and limit exotic annual grasses; and 3) a seed mix containing non-natives would be more successful than only seeding natives at increasing perennial vegetation cover and limiting exotic annual grasses.

Methods

Study Area

This study was conducted in juniper-encroached and annual grass – invaded sagebrush steppe at the CRNG (44.48°N, 121.1°W) in Oregon. Before treatment, juniper and annual grass cover averaged 3% and 44%, respectively. Large perennial bunchgrass, Sandberg bluegrass, and sagebrush cover were 5.7%, 8.6%, and 4.4% before treatments, respectively. Study sites were approximately 1 000 m above sea level and slopes were 5 – 10%. Soils were 25 – 40% clay in the A-horizon and classified as silty clay loam. Average (15-yr) precipitation was 205 mm, and precipitation was above average in 2011, slightly above average in 2012, but below average in the spring of 2013. Cattle were excluded from the study area in 2009.

Experimental Design and Measurements

In 2011, the CRNG conducted prescribed burns across 600 ha to control encroaching juniper and within this project established a study to evaluate restoring juniper-encroached and annual grass – invaded sagebrush steppe. The study design was a randomized complete block with seven blocks and four treatments: unburned (UB), burned (B), burned and seeded with native species (B-NS), and burned and seeded with introduced species (B-IS). Treatments were applied to 3.6 × 27.4 m plots. Prescribed burns were applied as head-fires on 27 July, 2011 and

burned across the entire plot, resulting in 100% mortality of juniper and sagebrush in treatment plots. During burns ambient air temperatures ranged from 22°C to 28°C and relative humidity was between 21% and 26%. In December 2011, seeding treatments were applied by hand-broadcasting followed by raking to improve seed-soil contact. The native and introduced seed mixes were planted at 14.7 PLS kg·ha⁻¹ (Table 1). Sherman big bluegrass (a variety of Sandberg bluegrass [*Poa secunda* J. Presl]) and Lewis flax (*Linum lewisii* Pursh), native species, were included in the introduced mix, but the seed mix was considered introduced because it was 82% non-native species by PLS weight. Seeds were acquired from a local seed dealer, and native seeds were from locally adapted seed sources.

Foliar cover was measured in June of 2011, 2013, 2015, and 2017. Cover was visually estimated inside of four 0.61 × 0.61 m quadrats per treatment replicate. The quadrats were positioned at 3.7, 11.3, 14.9, and 18 m along a 27.4-m transect positioned in the center of each treatment replicate. Visual guides of known cover were used to improve vegetation cover estimates.

Statistical Analysis

Treatment effects were estimated using repeated measures analyses of variance (ANOVAs) with “years” as the repeated factor in PROC MIXED SAS v. 9.4 (SAS Institute Inc., Cary, NC). Treatment was considered a fixed variable, and random variables were block and block-by-treatment interactions. Covariance structure for each repeated measures ANOVA was selected using Akaike’s Information Criterion (Littell et al., 1996). Data were square root transformed when assumptions of ANOVA were not met. Figures and text report nontransformed (i.e., original) data. Treatment means were separated using the LSMEANS method in SAS ($P \leq 0.05$) and reported with standard errors in the text and figures. Herbaceous vegetation was analyzed in the following groups: medusahead, cheatgrass, bulbous bluegrass (*Poa bulbosa* L.), exotic forbs, large perennial bunchgrasses, Sandberg bluegrass, and native forbs. Sandberg bluegrass was analyzed separate from the other perennial bunchgrasses because it is smaller in stature and phenologically develops earlier.

Results

Exotic vegetation characteristics were similar among treatments prior to burning ($P > 0.05$). Medusahead cover varied by the treatment × yr interaction (Fig. 1A; $P < 0.001$). Medusahead cover was greater in the unburned treatment compared with burned treatments in 2013 ($P < 0.05$). In 2015, medusahead cover did not vary among treatments, but in 2017, it was less in the unburned treatments compared with burned

Table 1
Native and introduced seed mixes seeded after prescribed fires were applied to control western juniper. Sherman big bluegrass and Lewis flax are natives that were included in the introduced seed mix. Introduced seed mix was 82% non-native species by PLS weight.

Common name	Scientific name	PLS kg·ha ⁻¹
Native mix		
Prairie Junegrass	<i>Koeleria macrantha</i> (Ledeb.) Schult.	5.0
Bluebunch wheatgrass	<i>Pseudoroegneria spicata</i> (Pursh) Á. Löve	1.1
Squirreltail	<i>Elymus elymoides</i> (Raf.) Swezey	5.0
Idaho fescue	<i>Festuca idahoensis</i> Elmer	0.4
Thurber’s needlegrass	<i>Achnatherum thurberianum</i> (Piper) Barkworth	7.0
Lewis flax	<i>Linum lewisii</i> Pursh	0.7
Common name		
Scientific name		
PLS kg·ha⁻¹		
Introduced mix		
Intermediate wheatgrass	<i>Thinopyrum intermedium</i> (Host) Barworth & D.R. Dewey	5.0
Crested wheatgrass	<i>Agropyron cristatum</i> (L.) Gaertn.	3.5
Sheep fescue	<i>Festuca ovina</i> L.	1.8
Russian wildrye	<i>Psathyrostachys juncea</i> (Fisch.) Nevski	1.8
Sherman big bluegrass	<i>Poa secunda</i> J. Presl	1.9
Lewis flax	<i>Linum lewisii</i> Pursh	0.7

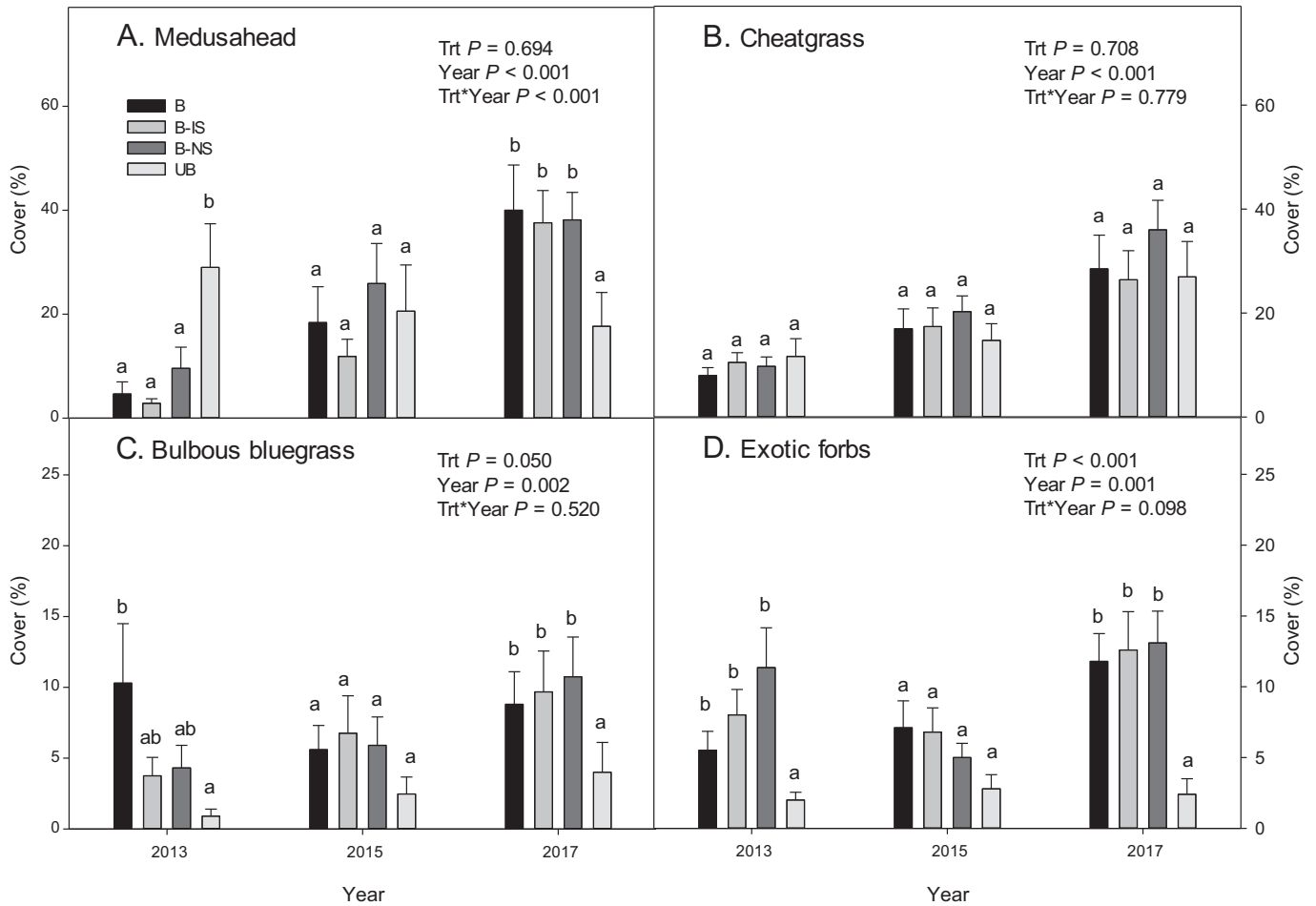


Figure 1. Cover (mean + S.E.) of medusahead, cheatgrass, bulbous bluegrass, and exotic forbs in burned (B), burned and seeded with introduced species (B-IS), burned and seeded with native species (B-NS), and unburned (UB) treatments in juniper-encroached and annual grass – invaded sagebrush steppe. Different lowercase letters indicate a difference ($P \leq 0.05$) among treatments in that year.

treatments ($P < 0.05$). Medusahead cover did not differ among treatments that were burned ($P > 0.05$). Cheatgrass cover was not influenced by treatment or the treatment \times yr interaction (see Fig. 1B; $P = 0.708$ and 0.779 , respectively). Cheatgrass cover increased with time in all treatments ($P < 0.001$). Bulbous bluegrass and exotic forb cover varied by treatment ($P = 0.050$ and < 0.001) and yr ($P = 0.002$ and $= 0.001$), but not by the treatment \times yr interaction (Fig. 1C and D; $P = 0.520$ and 0.098). Bulbous bluegrass cover was less in the unburned treatments compared with treatments that included burning ($P < 0.05$) but did not vary among burned treatments ($P > 0.05$). Exotic forb cover was 3.4–4.1 times greater in treatments that included burning compared with the unburned treatment ($P < 0.05$) but did not differ among burned treatments ($P > 0.05$).

Large bunchgrass, Sandberg bluegrass, native forb, and biological soil crust cover were similar among treatments before burning ($P > 0.05$). Large bunchgrass cover varied by treatment ($P = 0.003$), but not by yr or the treatment \times yr interaction (Fig. 2A; $P = 0.230$ and 0.215 , respectively). Large bunchgrass cover was approximately 1.9–2.3 \times greater in the unburned treatment compared with the other treatments ($P < 0.05$) but did not differ among burned treatments ($P > 0.05$). Sandberg bluegrass cover did not vary by treatment or the treatment \times yr interaction (Fig. 2B; $P = 0.104$ and 0.579 , respectively). Sandberg bluegrass varied by yr ($P < 0.001$), with it generally being greatest in 2013. Native forb cover varied by treatment and yr ($P = 0.026$ and < 0.001 , respectively), but not by the interaction between them (Fig. 2C; $P = 0.186$). Native forb cover was less in the unburned treatment compared with other treatments ($P < 0.05$) but did not vary among burned treatments ($P >$

0.05). Biological soil crust cover varied among treatments and yrs (Fig. 2D; $P = 0.004$ and 0.015 , respectively). Biological soil crust cover was greater in the unburned than burned treatments ($P < 0.05$) but did not vary among burned treatments ($P > 0.05$). Biological soil crust cover was generally less in 2017 than 2015 and 2013.

Discussion

Summer burning to control western juniper initially reduced medusahead cover. This likely occurred because medusahead seeds remained in the inflorescences at this time and were susceptible to fire mortality. Most medusahead seeds disperse off parent plants by mid-August (Davies, 2008). Similarly to our study, a summer (mid-July) wildfire substantially reduced medusahead cover and density (Davies et al., 2013). In our study, however, 6 yr after burning, medusahead was greater in all burned treatments compared with the unburned treatment. Postfire seeding did not affect medusahead cover as seedlings were unsuccessful (no increase in perennial vegetation cover). Establishment of perennial vegetation after medusahead control is critically important to sustain long-term reductions in medusahead (Davies et al., 2015; Davies and Johnson, 2017).

Burning also increased bulbous bluegrass (an exotic grass) and exotic forbs, but not cheatgrass. The lack of effect on cheatgrass was unexpected as cheatgrass often increases with fire (Chambers et al., 2007). We expect that increases in medusahead and bulbous bluegrass, as well as exotic forbs, preempted resources that would have been available to cheatgrass. The increase in exotics in burned treatments was

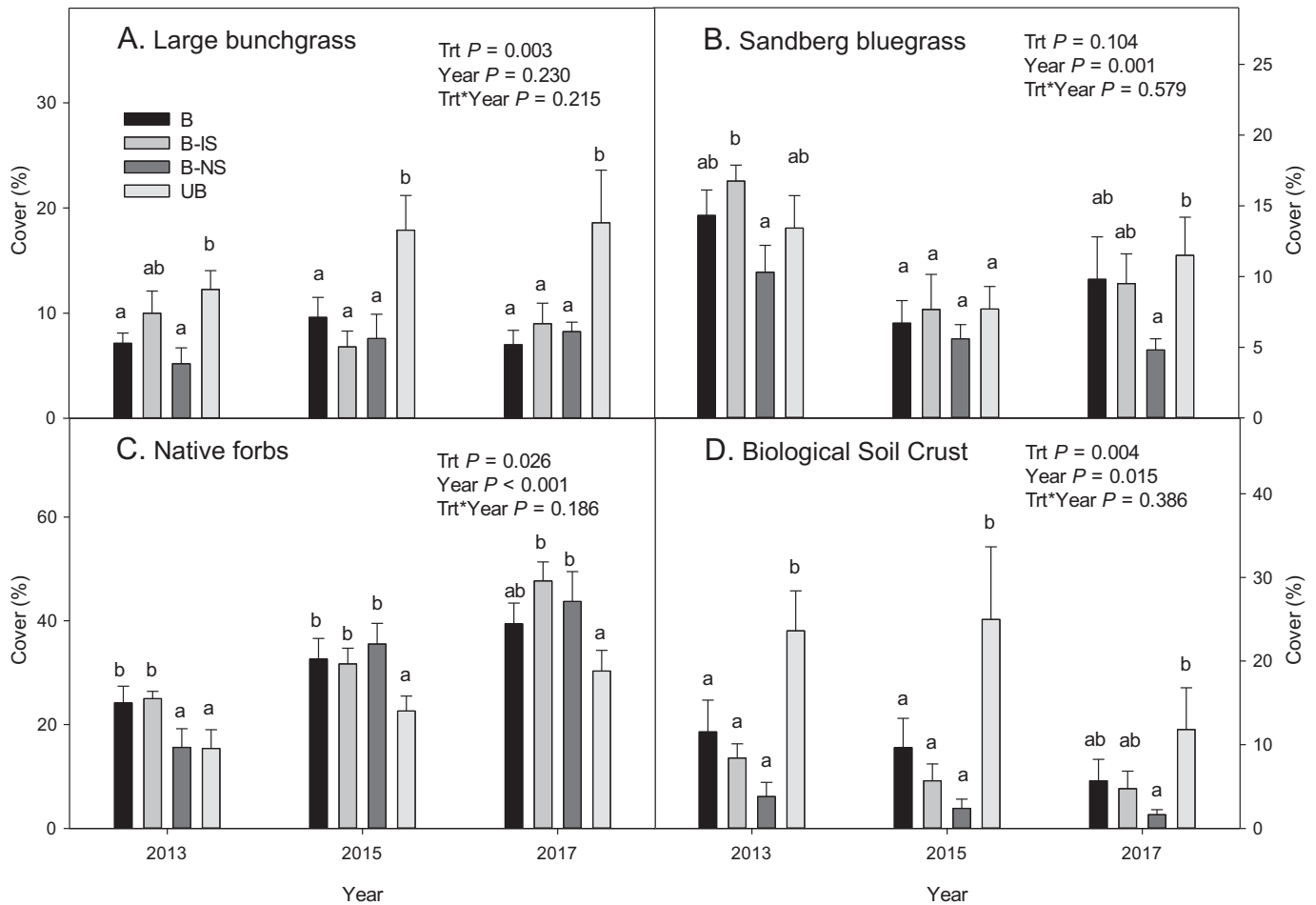


Figure 2. Cover (mean + S.E.) of large bunchgrasses, Sandberg bluegrass, native forbs, and biological soils crust in burned (B), burned and seeded with introduced species (B-IS), burned and seeded with native species (B-NS), and unburned (UB) treatments in juniper-encroached and annual grass – invaded sagebrush steppe. Different lowercase letters indicate a difference ($P \leq 0.05$) among treatments in that year.

likely facilitated by burning decreasing large bunchgrass and biological soil crust cover. Decreases in native perennial vegetation often promotes increases in exotic plants (Chambers et al., 2007; Stanley et al., 2011; Bates et al., 2014). Biological soil crust can limit exotic annual grasses in arid plant communities (Deines et al., 2007). The substantial increase in exotic plants, especially short-lived species, likely indicates a threshold has been crossed that will be difficult to reverse. Furthermore, increases in short-lived exotic grasses increases the likelihood of more frequent wildfires, potentially leading to the development of an exotic grass-fire cycle (D'Antonio and Vitousek, 1992).

Most understory vegetation responses to burning were undesirable; however, native forb cover increased with burning. Seeding after burning did not influence native forb cover even though Lewis flax was included in seed mixes. Annual forb cover generally increases with burning in hot, dry sagebrush communities, but perennial forb cover usually is not influenced or declines (Davies et al., 2009; Rhodes et al., 2010). Though increases in native forbs may be beneficial to some wildlife species (Collins and Urness, 1983; Gregg et al., 2008), the increases in exotic species likely negates any benefits (Davies and Svejcar, 2008; Davies, 2011).

Management Implications

The shift in the plant community to exotic dominance with burning to control juniper suggests that a different approach is necessary in hot, dry sagebrush communities that are also exotic annual grass invaded. These results are in contrast to cooler and wetter juniper-encroached sagebrush communities where postfire seedings are generally

successful (e.g., Davies et al., 2014, 2019). Including a pre-emergent herbicide application may be necessary in sagebrush communities with substantial exotic annual grass cover to reduce competition to improve establishment and growth of perennial vegetation; however, seeding will have to be delayed (usually 1 yr) until herbicide toxicity has abated (Davies, 2010; Davies et al., 2013). When seeded perennial vegetation fails to establish, reseeding may be necessary to establish a perennial-dominated plant community. Our results highlight the need for post-treatment monitoring and the flexibility to apply additional treatments when management goals are not met. Our study also demonstrates that when an area is both exotic annual grass invaded and juniper encroached, juniper control may increase the exotic annual grass problem. Therefore, in this situation, junipers and annual grasses will both need to be managed to restore ecosystem function and services. An alternative would be site-specific treatments that avoid this situation and focus on areas with a higher probability of success.

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