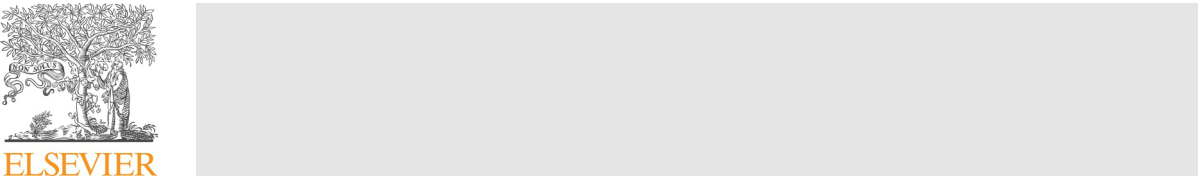
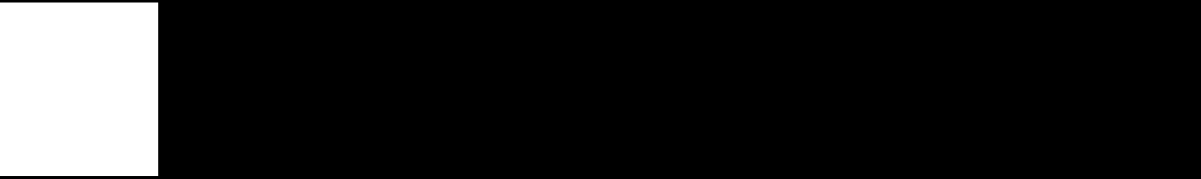
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Feral horses are associated with a decline in a rare semi-arid grassland plant T



Peter Lesica

*Division of Biological Sciences, University of Montana, Missoula, MT, 59812, USA*

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ABSTRACT

*Physaria lesicii* (Rollins) O'Kane & Al-Shehbaz is a globally rare plant known from only three populations in thePryor Mountain Wild Horse Range in Montana, USA, an area subjected to grazing by feral horses for at least 100 years. The purpose of this study was to determine effects of trampling by feral horses on this rare plant. I measured density of *P. lesicii* plants in 33 paired on- and off-trail sample plots at the one of three known po-pulations in a semi-arid habitat where horse trailing was prevalent. I also determined the strength of the as-sociation between the presence of presumed nurse plants and *P. lesicii* at two different populations. Density of *P.* *lesicii* plants was approximately four times as great in grassland than on adjacent trails. There was a significantassociation between the presence of potential nurse plants (canopy cover) and *P. lesicii* density only at the lower, presumably more stressful site. These results indicate that feral horse trampling has resulted in a significant decline in the number of *P. lesicii* plants where horses are most abundant and suggest that loss of nurse plants may partly explain this decline.

**1. Introduction**

Free-roaming feral horses (*Equus caballus*) have been shown to cause a number of adverse environmental effects in arid and semi-arid wes-tern North American landscapes (Davies and Boyd, 2019; [Eldridge](#page3) et al., 2020). Horse trampling removes vegetation, which reduces plant cover and litter, thereby increasing erosion and changing competitive balances (Cole and Spildie, 1998; Ostermann-Kelm et al., 2009; [Davies](#page3) et al., 2014). In addition, horse trampling can cause increased soil compaction with a concomitant reduction in water penetration ([Weaver](#page3) and Dale, 1978; Whinam and Comfort, 1996; DeLuca et al., 1998; Phillips and Newsome, 2002; Beever and Herrick, 2006; [Ostermann](#page3)-Kelm et al., 2009; Davies and Boyd, 2019). Although these habitat and ecosystem effects are well-documented, studies of the effects of feral horses on individual plant species are rare (but see Beever and Herrick, [2006](#page3)).

The Pryor Mountain Wild Horse Range (PMWHR) was established in 1968 on the south side of the Pryor Mountains in south-central Montana and adjacent Wyoming and encompasses 18,000 ha (BLM, 2009). It is managed primarily by the Bureau of Land Management (BLM). The PMWHR supports a number of endemic plant species, most of which occur in arid low elevations and semi-arid middle elevations of the PMWHR. The area has been designated as an Important Plant Area (Montana Native Plant Society, 2019) due to the large number of rare plants present. One of these rare plants, *Physaria lesicii* (Pryor Mountain bladderpod), is a narrow endemic found in only three mid-elevation



*E-mail address:* [lesica.peter@gmail.com](mailto:lesica.peter@gmail.com).

areas of the PMWHR (Lesica, 1995). *Physaria lesicii* is listed as a species of concern by the Montana Natural Heritage Program and a sensitive species by the Bureau of Land Management. The effects of feral horse grazing and trampling on *P. lesicii* have not been previously docu-mented.

Horse trampling may also indirectly affect *P. lesicii* by damaging neighboring plants. Plant facilitation is a well-investigated phenom-enon, especially in arid and semi-arid environments, where shade or nutrient accruement beneath the canopy provided by nurse plants benefits establishment (Callaway, 2007). Members of the genus *Phy-saria* have been shown to benefit from nurse plant facilitation ([Greenlee](#page3)and Callaway, 1996; Fowler et al., 2011; Victor, 2015). Grazing and trampling that reduces neighboring plant canopy may hinder facilita-tion. It is not known whether *P. lesicii* benefits from nurse-plant facil-itation.

The purpose of this study was to determine potential effects of feral horses on *P. lesicii* and possible mechanisms for these effects. Results of this study will assist managers to determine appropriate feral horse herd sizes, location of water developments and pasture rotations com-patible with maintaining habitat quality for *P. lesicii* and possibly other plant species in the Pryor Mountains.

**2. Materials and methods**

*Physaria lesicii* (Brassicaceae) is a short-lived (≤5 years) perennialwith an unbranched root crown and prostrate to erect stems 5–20 cm

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**Fig. 1.** Sykes Ridge study area: (above) landscape and (below) close up of feralhorse trails through *P. lesicii* habitat.

long. Rhizomes are lacking so that individuals are easily counted. Leaves are basal and cauline. Plants flower and set fruit in June. They occur in stony or shallow, limestone-derived soil at 1830–2300 m ([Lesica, 1995](#page3); [O'Kane, 2010](#page3)).

My study was conducted at the two largest populations on the PMWHR in south-central Montana, ca. 80 km south of Billings, Montana and ten miles north of Lovell, Wyoming, USA. Annual pre-cipitation ranges from 130 mm in the most arid lowlands at ca. 1300 m to over 500 mm at upper elevations at ca. 2550 m (Fahnestock and Detling, 1999). Mean Feral horse numbers averaged 145 between 1971 and 2009 on the 18,000 ha PMWHR (BLM, 2009). Bighorn sheep and mule deer are also present on the PMWHR; however in the summers of 1995 and 2019, I observed only horse dung on the trails at Sykes Ridge.

The Sykes Ridge population occupies ca. 200 ha and occurs on steep (~54% slope) west-facing slopes at 1880–1900 m in elevation. It was estimated to have ca. 10,000 plants in 1995 (Lesica, 1995). Vegetation is dominated by *Juniperus osteosperma*, *Artemisia nova* and *Cercocarpus ledi-folius*. There are numerous approximately parallel trails ca. 2–10 m aparton the west-facing upper slopes of Sykes Ridge (Fig. 1) where *P. lesicii* occurs. Feral horses are believed to be responsible for these trails because horses have occupied the PMWHR for more than 100 years, while live-stock grazing was discontinued in 1968 (Fahnestock and Detling, 1999). In addition, feral horses are known to repeatedly use the same trails causing high degrees of trampling impact (Beever, 2003). The Mystery Cave site is composed of several subpopulations on narrow ridge tops and occupies a total of ca. 60 ha with a total of ca. 5000 plants (Lesica, 1995). The two subpopulations I sampled are at ca. 2300 m in elevation. Vegetation is dominated by *Agropyron spicatum* and low-growing cushion plants amongst Douglas-fir forests on adjacent slopes. Horse dung and trails were

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minimal at the Mystery Cave site.

In June 2019 I placed 33 0.5 m2 (1.0 m × 0.5 m) sample plots distributed along six transects at Sykes Ridge. With one exception transects were 50–200 m apart where both horse trails and *P. lesicii* were present. Sample plots were placed at 2-m intervals along transect lines. Transects were placed parallel to and within 1 m above the edge of the trails. At each interval a sample plot was placed above the transect line in untrampled vegetation and a paired plot was placed on the trail directly below the off-trail plot. Paired plots were always within 1.5 m of each other. I counted all of the *P. lesicii* plants in each off-trail and on-trail sample plot. At the Mystery Cave population where there were no horse trails, I placed 13 0.5 m2 sample plots along two transects.

In order to assess the importance of nurse plant facilitation, I di-vided each off-trail sample plot at both sites into 20 0.025 m2 (16 × 16 cm) sections and counted the number of sections dominated by bare ground (i.e., not overshadowed by canopy of shrubs or her-baceous plants). Each *P. lesicii* plant occurring under a shrub or within 1 cm of the base of an herbaceous plant was scored as associated with a nurse plant.

I used Fisher's exact test to determine if there was a significant as-sociation between the proportion of *P. lesicii* plants associated with nurse plants and the mean proportion of the bare ground plot sections across all of the sample plots at each study site. A significantly higher proportion of *P. lesicii* plants associated with canopy cover of potential nurse plants would indicate a positive association between *P. lesicii* plants and nurse plants. I compared the number of plants present in on-trail and above-trail sample plots at the Sykes Ridge site using a paired-sample *t*-test.

**3. Results**

Plant cover was ≤10% for on-trail sample plots at Sykes Ridge, and density of *P. lesicii* plants was approximately four times greater in the untrampled grassland than on the adjacent trails. There were 138 *P.* *lesicii* plants in off-trail and 31 plants in the paired on-trail sample plots(paired-sample t = 5.6, P < 0.001). This suggests that the number of plants was reduced by 78% on feral horse trails.

At the Mystery Cave site, bare ground occupied a mean of 10 sample plot sections (50%), and 55% (32 of the 58) of *P. lesicii* plants were associated with nurse plants (Fisher exact test, P = 0.31), suggesting that there was no association between *P. lesicii* presence and nurse plants. Mean plants canopy cover in off-trail sample plots at Sykes Ridge was 45%; however, 70% (97 of 138) *P. lesicii* plants occurred with nurse plants (P = 0.04), indicating a positive association between the occurrence of *P. lesicii* and nurse plants at this site. Mean number of *P.* *lesicii* plants at Sykes Ridge was 2.5/m2in bare ground of the un-trampled grassland and 1.9 plants/m2 on the trails (paired sample t = 1.07, P = 0.29).

**4. Discussion**

Results of this study suggest that the trails on the steep slopes of Sykes Ridge have degraded the habitat for the largest known population of *P. lesicii*. Aerial and on-the-ground photographs (Fig. 1) indicate that ca. 25% of the habitat may have been trampled into trails with 78% reduction in *P. lesicii* plants, suggesting that the trailing caused a 19% loss (25% x 0.78) of *P. lesicii* plants across the largest of the three known populations.

Results of this study indicate that there is a significant positive re-lationship between the presence of *P. lesicii* and potential nurse plants in the Sykes Ridge population. The relatively small number of *P. lesicii* plants in the trail habitat may be due in part to the reduced presence of vegetation able to act as nurse plants since the density of *P. lesicii* plants on trails was similar to that of bare soil off of the trails. Another possible explanation for the lack of plants on trails in arid environments is soil

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compaction and the associated runoff of moisture and loss of safe sites for germination (Ostermann-Kelm et al., 2009; Davies and Boyd, 2019 and references therein). However, this hypothesis needs to be tested.

Although there was a positive relationship between the presence of *P. lesicii* and potential nurse plants in the Sykes Ridge population, thiswas not the case for the Mystery Cave population. The Mystery Cave site is approximately 450 m higher than the Sykes Ridge site and on nearly level terrain compared to the steep, southwest-facing slope at Sykes Ridge. Thus the Sykes Ridge site is expected to be more stressful due to greater evapotranspiration (Weaver and Dale, 1978), and facil-itation might be more likely to occur (Greenlee and Callaway, 1996; Callaway, 2007). Seventy percent of the *P. lesicii* plants at Sykes Ridge occurred under potential nurse plants even though bare ground covered an average of 55% of the sample plots. These results are similar in magnitude to those observed by Greenlee and Callaway (1996) for *Physaria carinata* in a similar habitat in western Montana.

My study suggests that the presence of free-ranging, feral horses can have a negative impact on even unpalatable plants as a result of trailing and trampling and perhaps grazing of nurse plants. These effects will be most apparent in water-stressed environments where nurse plants are most important. In arid and semi-arid environments supporting feral horses, it would be advisable to limit the number of horses and refrain from locating water developments and mineral placements in the vi-cinity of rare plants such as *Physaria lesicii*.

**CRediT authorship contribution statement**

**Peter Lesica:** Conceptualization, Methodology, Validation, Formalanalysis, Investigation, Data curation, Writing - original draft, Writing - review & editing, Visualization, Resources, Funding acquisition, Supervision, Software, Project administration.

**Declaration of competing interest**

The author declares the following financial interests/personal re-lationships which may be considered as potential competing interests: The author received financial support from the Montana Wilderness Association (MWA) for this study. MWA would like to see improved management of wild horses in the Pryor Mountains because part of the Pryor Mountains Wild Horse Range is also a wilderness study area.

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