EDITOR'S CHOICE FROM RANGELAND ECOLOGY & MANAGEMENT

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Synthesis of weed-suppressive bacteria studies in rangelands of the western USA

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In fiction lore, a single shot with a silver bullet can extinguish a werewolf. Killing a single cheatgrass plant is simple too, but for large plant invasions, there are no silver bullets. Occasionally, it is helpful to remind ourselves of knowledge learned in the past and that silver bullets for most invasive species, including cheatgrass, are extremely rare. In fact, in natural systems, evolution tends to ''weed out'' those plant populations that are completely controlled by a single factor or individual selection pressure.

Biological invasions are complex, in part, because within plant communities, plants species have evolved hundreds of mechanisms, processes, and strategies to adapt and capture resources in a changing environment. This complexity ensures that no one factor, or disturbance event controls any individual species and guards against mass extinctions. Plants continuously vie for resources across landscapes over time as weather and disturbance regimes change. To be successful, the entire population must acquire enough resources to complete its annual life cycle. Some species are successful when resources are abundant, while others are when resources are scarce. The ability of plants to acquire resources is partially dependent upon their neighbors, and often, their neighbors are the same species that require the same resources. The struggle to survive is intense, and the fight is fierce.

As primary producers, plants develop negative and positive relationships with various animals. Some animals are completely dependent on plants to provide energy and nutrients for their survival. It is clear that most plant-animal interactions result in ecological benefits to both the plant and animal. For example, out-crossing plants produce nectar to attract honeybees to which pollen sticks to their legs, abdomen, and thorax and the honeybees carry that pollen to other plants for fertilization. Nectar is produced at a cost to the plant but is an investment in reproduction and recruitment. In natural systems, cooperative relationships are more common than deleterious interactions where an animal consumes too much of the plant population that mass die-offs occur. Typically, population dynamics oscillate in a cyclical pattern.

The Editor's Choice for *Rangeland Ecology & Management* Volume 73 Issue 6 is a reminder that controlling invasive plant populations is complicated because plants rarely are controlled by a single ecological factor, especially when animals are used to control the plants on which they depend. One tool for controlling invasive plant populations is augmentative biological control, which is simply the release of large numbers of insectary reared natural enemies with the goal of ''augmenting'' natural enemy populations or ''inundating'' pest populations with natural enemies. The idea is to create epidemic levels of plant pests that suppress the population below some economic threshold. This Editor's Choice for *Rangeland Ecology & Management* includes a series of papers published as a Special Issue on Weed Suppressive Bacteria (WSB) organized by Dr. Matt Germino from USGS. This Special Issue includes six manuscripts and five studies from multiple authors working on this topic.

Rarely do we have enough compiled research to make a solid scientific conclusion. However, all combined, these studies provide a robust test of WSB in terms of high control and replication across many environmental and experimental contexts as well as different WSB application techniques. Moreover, each of these studies was independently conceived and conducted, eliminating the possibility that one or more investigators or factors could influence the results. None of the five studies found that WSB affected exotic annual grasses overall, and the only deviations were moderate reductions in target invasive annual grasses

with WSB (MB906) observed in a single study, and at only two of three sites in one of the three years.. These positive MB906 effects constitute only 22 plots (in 6 polygons occupying about 10 ha) of the 214 total plots and nearly 3150 ha treated with WSB in all five studies combined. Furthermore, there were no WSB effects on non-target plant abundances in the two studies that included assessments of non-target species, whether the non-target species were naturally occurring or were seeded as a co-treatment with WSB application.

In comparison to the null effects of WSB, the studies which included evaluation of herbicides reported strong reductions of exotic annuals by the herbicides. Lazarus et al. (2020) showed that mixing WSB with imazapic, which has been done across many hectares, appears to have reduced the effectiveness of the herbicide with no observed benefit of the WSB. Thus, not only was the management investment into WSB not beneficial, the investment detracted from the otherwise reliable short-term return on investment of herbicide.

These studies are very interesting and confirm what ecologists have been moving toward over the past few decades. Controlling invasive species, such as cheatgrass, is very complicated because they evolved with multiple mechanisms, processes, and strategies to ensure their survival. In the future, effective invasive plant management will require understanding the natural drivers of invasion and carefully selecting a suite of management strategies that amends those drivers to favor trajectories toward desired vegetation. One thing is clear: there are no silver bullets.

Please read this series of excellent papers in *Rangeland Ecology & Management* Volume 73, Issue 6.

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