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Rocky Mountain Research Station

Grassland, Shrubland, and Desert Ecosystems Program

GSD Update

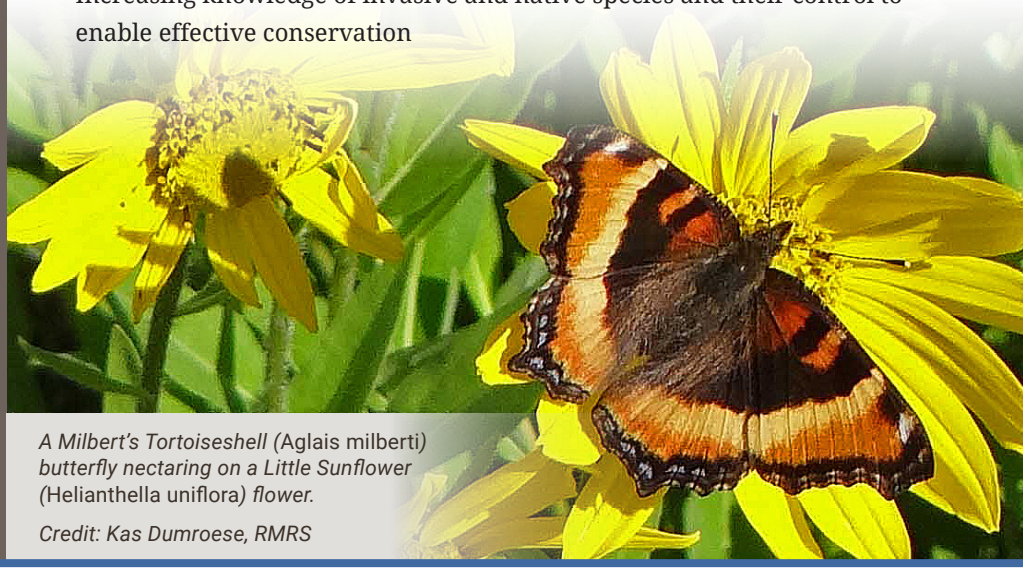
June 2017

IN THIS ISSUE

Year in Review: Spotlight on 2016 Research by the Grassland, Shrubland and Desert Ecosystems Science Program

In this issue of the GSD Update, we take a look back at selected studies of the Grassland, Shrubland and Desert Ecosystems Science Program (GSD) that depict its strengths and focus areas. Significant results of recent research and science delivery by GSD scientists are highlighted. We feature program research that lines up with the strategic priorities of the USDA Forest Service and the Rocky Mountain Research Station (RMRS). In particular, we spotlight accomplishments in GSD research and technology that address:

- Knowledge discovery, restoration and management of sagebrush
- Influences of fire, grazing, flooding and climate in grasslands and other western ecosystems
- Improving seed technology and methodology to ensure successful establishment of native plants
- Increasing knowledge of invasive and native species and their control to enable effective conservation



A Milbert's Tortoiseshell (Aglais milberti) *butterfly nectaring on a Little Sunflower* (Helianthella uniflora) *flower.*

Credit: Kas Dumroese, RMRS

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Bumble bees and other pollinators are crucial to our nation's economy, food security, and ecosystem health.

Credit: R. Kasten Dumroese, RMRS

Restoring forbs benefits sagebrush-dependent species

Kas Dumroese

Land managers are dealing with an increasing number of imperiled species; often mandates focus on each crisis species independently. A myopic approach may develop (e.g., allocating resources and setting conservation and restoration priorities one issue at a time) that can lead to inefficient use of land management resources, or, worse, pit one suite of species against another. Is there a way to take a more holistic approach to maximize the effectiveness of wildlife conservation?

For many important reasons, few species of wildflowers (forbs) have been included in sagebrush traditional restoration efforts in the western United States. With increasing attention placed on the conservation of sage-grouse, native pollinators, and monarch butterflies, we examined the potential benefits of using a high-diversity of native forbs in restoration work to support these fauna. Our science synthesis found that these fauna require a high-diversity of forbs that ensures, for example, a progression of different flower types is available throughout the breeding season for pollinators and monarchs, and provides a wide-range of host plants for the large number of arthropods required for successful development of sage-grouse broods. Although land managers have thousands of forb species to choose from in the sagebrush biome, 12 genera of forbs appear to provide the necessary benefit to sage-grouse, pollinators, and the monarch alike. Thus, focusing research efforts into producing seeds and plants of these genera and using them in restoration work would simultaneously support conservation and restoration of these fauna. Further, outplanting forb seedlings in high-density islands may be a way to accelerate the pace of restoration, reduce the amount of seeds required, and provide critical linkage among remaining high-quality sagebrush habitat.

Key Findings:

- Restoration efforts that focus on conserving multiple species may make more efficient use of resources than projects that focus narrowly on a single species.
- Sage-grouse, pollinators, and monarch butterflies all benefit from restoration activities that promote a high-diversity of native forbs.
- Current restoration activities may lack sufficient forb diversity to support these fauna.
- Twelve genera of native forbs are widely used by these fauna; focusing on them could simultaneously support these fauna.

Featured Publications:

Dumroese, R.K Luna, T.; Pinto, J.R.; Landis, T.D. 2016. Forbs: Foundation for restoration of monarch butterflies, other pollinators, and greater sage-grouse in the western US. Natural Areas Journal. 36(4): 499-511.

Dumroese, K.; Pinto, J.R.; Finch, D.M. 2016. Restoring arid western habitats: Native plants maximize wildlife conservation effectiveness. The Wildlife Professional. 10(4): 40-43.

Dumroese, K.; Luna, T.; Richardson, B.A.; Kilkenny, F.; Runyon, J.B. 2015. Conserving and restoring habitat for Greater Sage-Grouse and other sagebrush-obligate wildlife: The crucial link of forbs and sagebrush diversity. Native Plants Journal. 16(3): 276-299.

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"By counting the number of rings or years between injuries, an estimate of fire frequency can be calculated that corresponds to the point on the landscape where this tree was growing"

–Stan Kitchen

Fire Forensics: Deciphering the past using tree rings

Stanley Kitchen and Emily Heyerdahl

Proper management of naturally forested landscapes requires an understanding of the temporal and spatial patterns in which key disturbance processes are manifest and their effects on species composition and structure. Linked fire and forest histories constructed from tree-ring evidence provide valuable information about drivers of fire occurrence and about the variability and interactions of fire regimes and vegetation on heterogeneous landscapes.

Wildfire is a keystone process affecting the composition, structure, and health of western North American forests. An understanding of factors that controlled the frequency and severity of wildfire in historic times may be useful in restoring resiliency to these forests. In a recent study, tree-ring evidence was used to reconstruct multi-century histories of fire frequency and seasonality for 10 eastern Great Basin sites. These histories were then compared to regional reconstructions of climate variability.

Across the region, fires were most common during dry years that were preceded by one or more years of above average precipitation. Fires were least common after extended periods of drought, suggesting that fires were historically fuel limited. These fire probabilities were related to the occurrence of multi-year climate cycles known to vary with variability in Pacific Ocean surface temperatures (El Niño Southern Oscillation and Pacific Decadal Oscillation). Evidence revealed that fires were most common in the early and later part of the fire season. In this region, lightning-caused fires are most common in the mid-season, inferring the importance of Native American ignitions to past fire regimes.

In a separate study, fire and tree recruitment histories were reconstructed for two small watersheds. Fire frequency varied more than 10-fold within each watershed and was closely related to elevation and steepness. Most fires were small, but large fires accounted for a majority of the area burned.

The timing of recruitment pulses varied within sites suggesting that fire severity was mixed across space and through time creating an ever-shifting mosaic of vegetation patches intermixed with stands of long-lived, fire resilient trees.

Key Findings:

- Historically, climate was an important synchronizer of fire in the Great Basin Region where fire was most common when multi-year climatic cycles were transitioning from wet to dry phases and least common when transitioning from dry to wet phases.

Individual fire scars are easy to identify on the exposed surface of this recently cut log. Fingers point to the location of three injuries. Credit: Stanley Kitchen, RMRS.

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Experimental prescribed burn in Chihuahuan Desert grassland at the Sevilleta National Wildlife Refuge, New Mexico. March 2017.

Credit: Dave Hawksworth, RMRS

- Fire seasonality and frequency patterns demonstrate that Native American ignitions played a significant role in maintaining a high frequency, low severity fire regime in the region.
- Historically, fire frequency was under strong topographic control and fire severity was mixed and variable through time and space creating a dynamic mosaic of variable-aged, fire-initiated vegetation patches mixed with long-lived, fire-resilient trees.
- A major change in fire regimes and forest composition began in the 1800s causing shifts in composition and structure at the stand scale and homogenization at the landscape scale, suggesting the need for active management strategies to restore historic vegetative conditions.

Featured Publications:

Kitchen, S.G. 2016. Climate and human influences on historical fire regimes (AD 1400-1900) in the eastern Great Basin (USA). The Holocene 26:397–407.

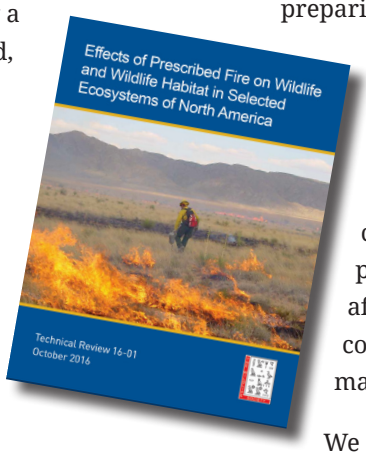
Kitchen, S.G. 2012. Historical fire regime and forest variability on two eastern Great Basin fire-sheds (USA). Forest Ecology and Management. 285:53-66.

Heyerdahl, E.K.; Brown, P.M.; Kitchen, S.G.; Weber, M.H. 2011. Multicentury fire and forest histories at 19 sites in Utah and eastern Nevada. Gen. Tech. Rep. RMRS-GTR-261WWW. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 192 p.

Effects of prescribed fire on wildlife and wildlife habitat

Paulette Ford and William Block

Some objectives for prescribed fire include reducing fuel loads and fuel continuity, returning fire to an ecosystem, enhancing wildlife habitats, improving forage, preparing seedbeds, improving watershed conditions, enhancing nutrient cycling, controlling exotic weeds, and enhancing resilience from climate change. Regardless of the particular objective, fire affects ecosystem structure, composition, and function in many ways.



We used a regional approach, focusing on selected vegetation types for our review. Included were southeastern pine and mixed pine-oak forests, eastern coastal marshes, Midwestern jack pine forests, sagebrush ecosystems of the interior West, mixed-severity forests of the northern Rocky Mountains, subalpine and montane forests of the Canadian Rockies, southwestern ponderosa pine forests, desert grasslands, and shortgrass steppe ecosystems. We structured each regional account by reviewing historical and current uses of fire, and then discussed fire effects on wildlife and the challenges of using prescribed fire in each system.

Prescribed fire affects wildlife in various ways. Population responses by species can be positive, negative, or neutral, short-term or long-term, and they often vary across spatial scales. Whereas prescribed fire can create or maintain habitats for some species, it

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can also remove or alter conditions in ways that render it unsuitable for other species. Furthermore, a species may benefit from fire in one situation but not another. Given the variations in fire and in species responses, the only real generalization one can make is that exceptions occur.

Key Findings:

- Benefits of prescribed fire far outweigh negative effects.
- The science of prescribed fire continues to provide better information and options for resource managers to incorporate into management plans.
- Prescribed fire should be applied within a structured adaptive management framework, which requires developing and implementing monitoring systems to evaluate the efficacy of specific fire prescriptions.
- Prescribed fire is an important resource management tool that can be effective at maintaining or enhancing habitats for many species of wildlife.

RMRS scientists and university collaborators collect buds from the Buffalo Gap National Grassland for a growth chamber experiment.

Credit: Jaqueline Ott, RMRS

Featured Publication:

Block, W.M.; Conner, L.M.; Brewer, P.A.; Ford, P.A.; Haufler, J.; Litt, A.; Masters, R.E.; Mitchell, L.R.; Park, J. 2016. Effects of prescribed fire on wildlife and wildlife habitat in selected ecosystems of North America. Technical Review 16-01. Bethesda, MD: The Wildlife Society. 69 p.

Climate and grazing alter invasive and native perennial grasses

Jacqueline Ott and Jack Butler

The robust vegetative reproductive capacity of smooth brome under a range of environmental conditions is a key mechanism enabling the expansion of smooth brome into western wheatgrass-dominated mixed-grass prairie in North America. Mixed-grass prairie dominated by western wheatgrass experiencing repeated defoliation may require longer recovery times and be more susceptible to smooth brome invasion due to the negative impact of grazing on western wheatgrass bud outgrowth.

Seedling recruitment of perennial grasses is rare as most tillers (grass stems) are recruited from vegetative belowground buds. Successful tiller recruitment and establishment of native perennial grasses via the bud bank will be necessary for mixed-grass prairie to be resilient to climate change, plant invasions and grazing.

Research Objectives:

1. Compare how spring temperature altered bud outgrowth of native western wheatgrass (*Pascopyrum smithii*) and introduced smooth brome (*Bromus inermis*).

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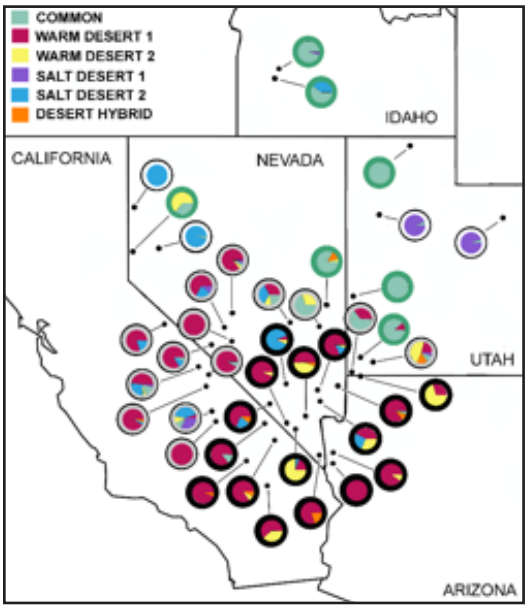

Distribution of six cheatgrass clades across the Mojave - Great Basin transition zone. Note that members of the Warm Desert 1 clade (red) dominate Mojave Desert and many warm desert transition populations (black and gray outer rings) but are absent further north in the Great Basin.

From Meyer et al. 2016.

2. Compare how watering frequency altered bud outgrowth of these two species.

3. Evaluate how clipping interacts with spring temperature or watering frequency to affect western wheatgrass bud outgrowth.

Key Findings:

- Smooth brome had more buds per tiller and initiated a greater proportion of these buds than western wheatgrass under all temperature and moisture conditions.
- Western wheatgrass bud development was reduced at 24°C. Intermittent watering did not significantly impact bud outgrowth of either species.
- Clipping increased western wheatgrass bud mortality and reduced its bud development for the two-week period of the study.

Featured Publications:

Ott, J.P.; Butler, J.L.; Rong, Y.; Xu, L. 2017 Greater bud outgrowth of *Bromus inermis* than *Pascopyrum smithii* under multiple environmental conditions. Journal of Plant Ecology. 10(3): 518–527.

Ott, J.P.; Hartnett, D.C. 2015. Bud bank dynamics and clonal growth strategy in the rhizomatous grass, *Pascopyrum smithii*. Plant Ecology. 216: 395-405.

Ott, J.P.; Hartnett, D.C., 2015. Bud-bank and tiller dynamics of co-occurring C3 caespitose grasses in mixed grass prairie. American Journal of Botany. 102: 1462-1471.

Cheatgrass succeeds through ecotypic variation

Susan Meyer

Bromus tectorum, an inbreeding annual grass, is a dominant invader in sagebrush steppe habitat in North America. It is also common in warm and salt deserts, displaying a larger environmental tolerance than most native species. We tested the hypothesis that a suite of habitat-specific *B. tectorum* lineages dominates warm desert habitats. We sampled 30 B. tectorum Mojave Desert and desert fringe populations and genotyped 10–26 individuals per population using 69 single nucleotide polymorphic (SNP) markers. We compared these populations to 11 Great Basin steppe and salt desert populations. Populations from warm desert habitats were dominated by members of two haplogroups (87 % of individuals) that were distinct from haplogroups common in Great Basin habitats. We conducted common garden studies comparing adaptive traits and field performance among haplogroups typically found in different habitats.

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Sharlene Sing standing to the right of a hybrid toadflax patch in the Beaverhead-Deerlodge National Forest.

Credit: Sarah Ward, Colorado State University

In contrast to the haplogroup abundant in sagebrush steppe, warm desert haplogroups generally lacked a vernalization requirement for flowering. The most widespread warm desert haplogroup (Warm Desert 1) also had larger seeds and a higher root:shoot ratio than other haplogroups. In the field, performance of warm desert haplogroups was dramatically lower than the sagebrush steppe haplogroup at one steppe site, but one warm desert haplogroup performed as well as the steppe haplogroup under drought conditions at the other site.

Key Findings:

- Our results suggest that *B. tectorum* succeeds in widely disparate environments through ecotypic variation displayed by distinct lineages of plants.
- Accounting for this ecotypic variation is essential in modeling its future distribution in response to climate change.

Featured Publication:

Meyer, S.E.; Leger, E.A.; Eldon, D.R.; Coleman, C.E. 2016. Strong genetic differentiation in the invasive annual grass Bromus tectorum across the Mojave–Great Basin ecological transition zone. Biological Invasions. 18: 1611-1628.

Looks aren't everything: cytoplasmic markers detect cryptic hybridization in 'normal-looking' weeds

Sharlene Sing

Two closely related invasive *Linaria* species, Dalmatian toadflax and yellow toadflax, have successfully invaded a broad range of ecosystems throughout most of continental North America. The management challenge imposed by the landscape scale of many toadflax infestations, particularly in the West, is further complicated by hybridization between these two weeds. Herbicide and biological control treatments for invasive *Linaria* are highly species-specific, necessitating the development of a molecular diagnostic tool that can accurately confirm when cryptic hybridization has spontaneously occurred in the field, particularly in plants conforming to typical species appearance.

The initial step in the development of this molecular diagnostic tool involved the extraction of total genomic DNA from individual plants. These were selected from a pool of morphologically unambiguous Dalmatian toadflax or yellow toadflax plants. The trnT-D region was selected for screening for species-specific PCR-RFLP markers after the first five chloroplast DNA (cpDNA) regions evaluated provided insufficient interspecific variation. Separate restriction digests were then performed with the enzymes Alu1, Acc1, and Fok1. The trnT-D region was successfully digested with Alu1, generating restriction fragments that through gel electrophoresis were separated by length. Haplotyping based on species-specific PCR-RFLP markers identified the presence of a single toadflax haplotype,

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either for Dalmatian toadflax or for yellow toadflax, in the pool of morphologically non-ambiguous plants. Molecular analysis of DNA extracted from an additional pool of hybrid toadflax plants, including field-collected and controlled greenhouse crosses, consistently indicated the presence of both species haplotypes. The 748 bp fragment for yellow toadflax vs. the 608 bp fragment for Dalmatian toadflax was found to be the most reliable and distinct PCR-RFLP polymorphism, both to distinguish between the two toadflax haplotypes, and to confirm hybridization. Results of plastid DNA analysis using single nucleotide polymorphisms (SNPs) in the matK and trnL-F chloroplast-barcoding regions were consistent with PCR-RFLP diagnoses.

Key Findings:

- Dalmatian and yellow toadflax co-occur in spite of disparate habitat preferences/tolerances
- Hybridization between these species has been confirmed at multiple sites (MT, CO, WY, ID, WA, BC, AB)
- Species-specific markers were developed based on PCR-RFLP polymorphisms in the trnT-D cpDNA region, and matK and trnL-F SNP barcoding regions
- Asymmetric gene flow was confirmed both in controlled greenhouse crosses and field populations of hybrid toadflax, indicating a higher proportion of plants with maternally inherited yellow toadflax cpDNA
- Species-diagnostic cytoplasmic markers identified the presence of introgressed yellow toadflax genetic material in plants drawn from infestations presumed to be Dalmatian toadflax

Featured Publications:

Boswell, A.; Sing, S.E.; Ward, S.M. 2016. Plastid DNA analysis reveals cryptic hybridization in invasive Dalmatian toadflax (*Linaria dalmatica*) populations. Invasive Plant Science and Management. 9: 112-120.

Sing, S.E.; De Clerck-Floate, R.; Hansen, R.W.; Pearce, H.; Randall, C.B.; Tosevski, I.; Ward, S.M. 2016. Biology and biological control of Dalmatian and yellow toadflax. FHTET-2016-01. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Forest Health Technology Enterprise Team. 141 p.

Boswell, A.. 2013. Development of PCR-RFP and DNA barcoding plastic markers for yellow toadflax and Dalmatian toadflax. Fort Collins, CO: Colorado State University. 87 p. M.S. Thesis. https://www.fs.fed.us/rm/pubs_other/rmrs_2013_boswell_a001.pdf

Turner, M. F.S. 2012. Viability and invasive potential of hybrids between yellow toadflax (*Linaria vulgaris*) and Dalmatian toadflax (*Linaria dalmatica*). Fort Collins, CO: Colorado State University, Department of Soil and Crop Sciences. Ph.D. Dissertation. 142 p.

Ward, S.M.; Fleischmann, C.E.; Turner, M.F.; Sing, S.E. 2009. Hybridization between invasive populations of Dalmatian toadflax (*Linaria dalmatica*) and yellow toadflax (*Linaria vulgaris*). Invasive Plant Science and Management. 2: 369-378.

"Understanding the link between discharge and floodplain structure is critical as natural flow regimes are increasingly threatened by diversions, regulation, and climate change."

– Katelyn Driscoll

Floods create ecological diversity

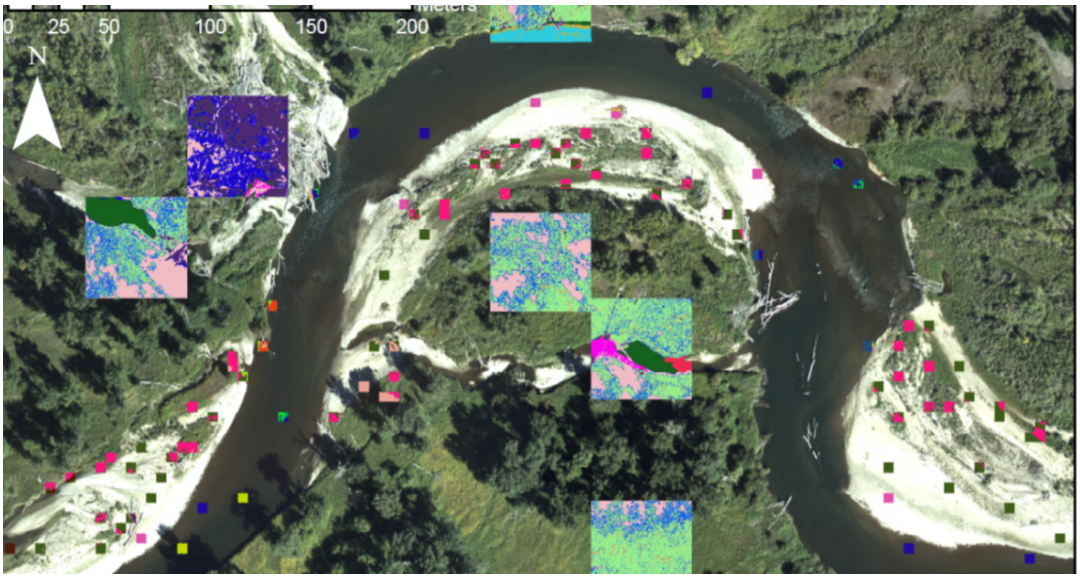
Katelyn Driscoll

The typical way water moves through a floodplain is considered a river's natural flow regime and it includes the size, timing, and duration of flooding events. The normal pattern of a river's discharge is linked to the construction and destruction of its floodplain, which then affects biodiversity, plant and animal life cycles, and ecological integrity. Understanding the link between discharge and floodplain structure is critical as natural flow regimes are increasingly threatened by irrigation, dams, and climate change.

This study used aerial photographs collected at varying discharges throughout a flood to examine how the amount of water moving through a floodplain is related to the abundance and diversity of different habitats. The floodplain was divided into three zones, the main channel, the parafluvial (active channel), and the orthofluvial (seasonally flooded), and researchers tracked changes within each.

The results demonstrated that diverse habitats were created and destroyed throughout the flood, which directly affected habitat heterogeneity at different flows. The three zones evolved and provided different habitat types at each discharge and the complexity of the floodplain as a whole was driven by the parafluvial zone. Furthermore, habitats that occupy a small proportion of the landscape were very important to habitat diversity and therefore ecological integrity. The area of some habitat types, but not all, changed throughout the flood, indicating that discharge was only a partial driver of the abundance of aquatic habitats.

While researchers concluded there was a relationship between discharge and floodplain complexity, the association is influenced by location on the landscape. The study underscores the importance of natural flow patterns and how the timing, size, and frequency of flooding impacts complexity.



Example of habitat classification scheme, with main channel, parafluvial, and orthofluvial plots. Each color describes a different habitat cover type. From K. Driscoll's Master's Thesis.

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Key Findings:

- Observed a relationship between discharge and floodplain complexity through a flood pulse.
- Diverse habitats were created and destroyed throughout the snowmelt event, directly affecting habitat heterogeneity at different flows.
- Maximized complexity during intermediate discharges is manifested in the parafluvial zone
- Understanding the link between discharge and floodplain structure is critical as natural flow regimes are increasingly threatened by diversions, regulation, and climate change.

Collecting sagebrush volatiles (odors) in a common garden near Ephraim, Utah.

Credit: Justin Runyon, RMRS

Featured Publication:

Driscoll, K.P. 2015. Use of airborne digital imagery to examine floodplain complexity at varying discharges. Thesis, University of Montana, Missoula, MT.

Driscoll, K.P.; Hauer, F.R. (In Press). Discharge effects complexity and habitat variation of a gravel-bed river floodplain. Freshwater Science.

Using volatiles to identify sagebrush species and subspecies

Justin Runyon and Bryce Richardson

Big sagebrush (*Artemisia tridentata*) is the dominant plant species across much of the Western U.S. and provide critical habitat and food for many endemic species, including the threatened greater sage-grouse. Sagebrush habitat is imperiled due to disturbances, increased wildfire frequency, and exotic annual grasses. Sagebrush habitat restoration is needed, but success rate of restoration efforts is low, sometimes because the right sagebrush subspecies is not used in the right place. Sagebrush subspecies are difficult or impossible to identify and reliable methods of identification are needed.

We collected and analyzed volatile organic compounds (VOCs) emitted from five species and subspecies of sagebrush (*Artemisia*, subgenus *Tridentatae*) growing in two common gardens in Idaho and Utah using gas chromatograph and mass spectrometry. We show that the bouquet of VOCs emitted by plants can discriminate closely related species and subspecies of Artemisia, which are difficult to identify using molecular markers or morphology.

Of the 74 total VOCs emitted, only 15 were needed to segregate sagebrush species and subspecies using the random forest classification algorithm with 96% accuracy. All but one of these 15 VOCs showed qualitative differences among taxa. Five VOCs could be used to identify environment (common garden and month), which do not overlap with the 15 VOCs that segregated taxa.

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Winter mortality of big sagebrush not adapted to colder areas of the species distribution.

Credit: Bryce Richardson, RMRS

It appears that changes in VOCs either lead the way or follow closely behind speciation in this group. This suggests that VOCs could allow identification of sagebrushes for restoration, helping match the proper plant with the proper habitat.

Key Findings:

- Sagebrushes are famous for their abundant and complex volatile bouquets.
- We found that the composition of sagebrush volatile bouquets differ reliably among closely related species and subspecies.
- Only 15 volatile compounds were needed to confidently identify plants, suggesting that plant odor could be used to identify sagebrushes for restoration.

Featured Publications:

Jaeger, D.M.; Runyon, J.B.; Richardson, B.A. 2016. Signals of speciation: Volatile organic compounds resolve closely related sagebrush taxa, suggesting their importance in evolution. New Phytologist. 211: 1391-1401.

Dumroese, K.; Luna, T.; Richardson, B.A.; Kilkenny, F.; Runyon, J.B. 2015. Conserving and restoring habitat for Greater Sage-Grouse and other sagebrush-obligate wildlife: The crucial link of forbs and sagebrush diversity. Native Plants Journal. 16(3): 276-299.

Influence of climate and seed weight for restoring sagebrush ecosystems

Bryce Richardson

Sagebrush communities are the cornerstones of arid ecosystems in the West, mitigating soil erosion, fostering plant and animal biodiversity, storing carbon, and providing cover and forage for wildlife, such as the greater sage-grouse. However, these ecosystems are being compromised by increased fire frequency and climate change, coupled with encroachment of invasive plants. Subsequently, post-fire restoration has become a fundamental component for maintaining ecosystem function and resiliency in these communities. Knowledge of how plants are adapted to their environments is fundamental to ecological restoration and mitigating impacts from climate change.

This research focuses on ecological genetics of big sagebrush (*Artemisia tridentate*), which is under threat principally from wildfire and exotic weed encroachment. Conserving and restoring big sagebrush is critical for the recovery of sage-grouse (*Centrocercus urophasianus*) and other sagebrush-dependent wildlife species. Our goal is to provide management tools to promote successful restoration by: 1) predicting the geographic areas where contemporary and future climates are suitable for this species, 2) developing empirical seed transfer zones, and 3) developing subspecies diagnostic tests to improve seed purity.

Key Findings:

- Climate change is projected to have a large impact on sagebrush ecosystems. Projections show that approximately one-third of the climatic niche of Wyoming sagebrush will be lost by 2050.

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- Populations of big sagebrush are adapted to local climates, specifically cold temperatures. Movement of seed should be restricted to prevent maladaptation.
- Seed weight can be used to differentiate co-occurring subspecies of big sagebrush. Weighing can be used as a seed certification step for evaluating subspecies composition of seed intended for restoration.

Featured Publications:

Richardson, B.A.; Ortiz, H.G.; Carlson, S.L.; Jaeger, D.M.; Shaw, N.L. 2015. Genetic and environmental effects on seed weight in subspecies of big sagebrush: Applications for restoration. Ecosphere. 6(10): 1-13.

Still, S.M.; Richardson, B.A. 2015. Projections of contemporary and future climate niche for Wyoming big sagebrush (*Artemisia tridentata* subsp. *wyomingensis*): A guide for restoration. Natural Areas Journal. 35: 30-43.

Richardson, B.A.; Page, J.T.; Bajgain, P.; Sanderson, S.; Udall, J.A. 2012. Deep sequencing of amplicons reveals widespread intraspecific hybridization and multiple origins of polyploidy in big sagebrush (*Artemisia tridentata,* Asteraceae). American Journal of Botany. 99(12): 1962-1975.

Chaney, L., Richardson, B. A., & Germino, M. J. (2017). Climate drives adaptive genetic responses associated with survival in big sagebrush (*Artemisia tridentata*). Evolutionary Applications, 22, 699–10.

Richardson, B. A., Chaney, L., Shaw, N. L., & Still, S. M. (2016). Will phenotypic plasticity affecting flowering phenology keep pace with climate change? Global Change Biology, 23(6), 2499–2508.

A Science Basis for Conserving and Restoring the Sagebrush Biome

Jeanne Chambers

Land management agencies face the need for effective strategic conservation actions for the conservation and restoration of sagebrush ecosystems. In 2014, the Grasslands, Shrublands and Deserts Program became part of a synergistic interagency collaboration for conservation and restoration of sagebrush ecosystems that began with development of two General Technical Reports published by the Rocky Mountain Research Station on using resilience and resistance concepts to manage threats to sagebrush ecosystems and sage-grouse. This collaboration expanded with development of the U.S. Department of Interior's Integrated Rangeland Fire Management Strategy, and led to publication of RMRS-GTR-360: Science Framework for Conservation and Restoration of the Sagebrush Biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to Long-Term Strategic Conservation Actions.

The Science Framework for Conservation and Restoration of the Sagebrush Biome (Science Framework) provides a strategic, multiscale approach for prioritizing areas for management and determining effective management strategies across the sagebrush biome. A geospatial process is used in which sagebrush ecosystem resilience to disturbance and resistance to nonnative, invasive plant species is linked to information on the habitat requirements of sagebrush obligate species. The predominant ecosystem and land use and development threats are assessed, and a habitat matrix is used to help decision makers evaluate risks

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and determine appropriate management strategies at regional and local scales. The Science Framework provides a new and valuable approach that helps to ensure conservation and restoration actions are implemented where they will have the greatest benefits.

RMRS Research Ecologist Jeanne Chambers is first author and led the team of scientists and managers who developed the Science Framework. The team included individuals from the U.S. Department of Agriculture Forest Service and Natural Resources and Conservation Service, U.S. Department of the Interior USGS, Bureau of Land Management, and Fish and Wildlife Service, the University of Wyoming, the Western Association of Fish and Wildlife Agencies, and individuals from the departments responsible for wildlife in the states of Idaho, Nevada, Montana, Wyoming and Colorado.

Key Findings:

- Widespread concern about conservation of sagebrush ecosystems and sage-grouse creates expectations for natural resource agencies to demonstrate an ability to effectively manage sagebrush habitat and conserve sage-grouse across the 11 western States encompassed by the sagebrush biome.
- The Science Framework provides an approach for maintaining or improving ecosystem services, such as water for consumer and agricultural use, forage for livestock, and hunting and recreational opportunities, that can help sustain local communities over time.

Spring bloom in sagebrush country in the Bodie Hills overlooking Mono Lake near the Nevada-California State line.

Credit: Bob Wick, BLM.

- The Science Framework provides a valuable tool for prioritizing areas for management action using a geospatial approach that overlays resilience and resistance, species habitat information, and predominant threats.
- The Science Framework is divided into four topic areas that can be used by the reader to gain an understanding of:

1. the purpose and structure of the Science Framework

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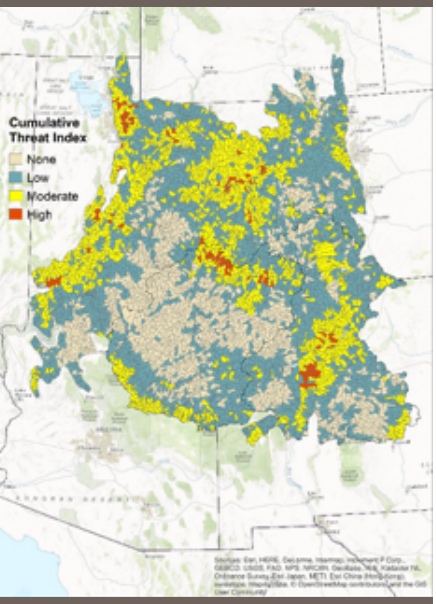

The project is using indicators of exposure, sensitivity and adaptive capacity to create spatially explicit data products for use by resource managers. Here is an example of the cumulative Threats or Exposure map for Sagebrush Habitat within the SRLCC boundary.

Created by Megan Friggens.

2. the biophysical characteristics of sagebrush ecosystems and threats to sagebrush ecosystems and greater sage-grouse

3. the key concepts and approach used in the Science Framework to prioritize areas for management and develop effective management strategies

4. the available information for determining appropriate management treatments.

Featured Publications:

Chambers, J.C.; Beck, J.L.; Bradford, J.B.; Bybee, J.; et al. 2017. Science framework for conservation and restoration of the sagebrush biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions. RMRS-GTR-360. Fort Collins, CO: U.S Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Chambers, J.C.; Maestas, J.D.; Pyke, D.A.; Boyd, C.; Pellant, M.; Wuenschel, A. 2017. Using resilience and resistance concepts to manage persistent threats to sagebrush ecosystems and greater sage-grouse. Rangeland Ecology and Management. 70:149-164.

Chambers, J.C., Beck, J.L., Campbell, S., Carlson, J. et al. 2016. Using resilience and resistance concepts to manage threats to sagebrush ecosystems, Gunnison sage-grouse, and greater sage-grouse in their eastern range: a strategic multi-scale approach. Gen. Tech. Rep. RMRS-GTR-356. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 143 p.

RMRS partners with Southern Rockies Landscape Conservation Cooperative to develop management tools

Megan Friggens

Successful management of natural and cultural resources needs to account for increasing stress due to climate change, wildfire, and anthropogenic disturbance and requires collaborative processes to identify effective strategies at landscape scales. Recognizing this need, the Southern Rockies Landscape Conservation Cooperative (SRLCC) is implementing a landscape conservation design framework to develop data and tools for use during land management planning, with relevance to multiple stakeholder groups. Rocky Mountain Research Station (RMRS) scientists have partnered with the SRLCC to provide expertise and analytical data products to use towards this effort.

RMRS has joined with the SRLCC to develop science and tools that address partner identified needs for management at the landscape scale. As part of this effort, Adaptation Forums were held to deliver and develop relevant science and decision support tools for practitioners based on previous and ongoing SRLCC projects. In addition, the SRLCC solicited feedback from Forum participants on pressing needs and questions related to the management of locally significant resources. Equipped with this information, RMRS is developing vulnerability assessments and associated data products for select conservation targets to assist landscape planning efforts within two geographic focus areas. These products will be the focus of a webinar series during the summer of 2017 and provide the foundation for a second set of Adaptation forums to be held in the fall.

A Joshua tree in Joshua Tree National Natural Landmark in southwestern Utah, USA. The photograph was taken in a northwesterly direction. Notice that most of the seed pods, which follow blooming, either occur on the south side of the plant or tilt toward the south.

Credit: Lynne Scott, BLM.

From these efforts, RMRS, in partnership with the SRLCC, will help develop adaptation strategies that are both feasible and effective for reaching conservation targets of a wide range of partner organizations.

- Natural and cultural resource managers need information and methods to develop effective conservation strategies. RMRS researchers are developing spatial data products and assessment tools that address identified issues and inform development of adaptation strategies for two focal regions: the Four Corners and Upper Rio Grande.
- During the first of two Adaptation Forums convened in Durango, CO and Albuquerque, NM, federal, state and private land managers and scientist met to identify priority management issues and focal areas for vulnerability assessment and adaptation options.
- Two working groups have been established within the SRLCC Conservation Planning Atlas (https://srlcc.databasin.org/) to facilitate data exchange and dissemination. Anyone interested in participating or contributing to these working groups is encouraged to contact Megan Friggens at megan.friggens@fs.fed.us.

The location of flowers and fruits in some species of arid land plants is determined by the position of the sun

Steve Warren

While working in the hyper-arid Atacama Desert, Warren and his Chilean colleague discovered two species of a genus of cactus that produce their floral tissue exclusively on the north side of the plants. Because the Atacama Desert lies south of the Tropic of Capricorn, the southernmost zenith of the sun, the sun is present at various distances to the north all year long. The production of flowers and fruits is energetically expensive, and lateral movement of nutrients is difficult within cacti. Hence, it makes sense that the cacti would limit their reproductive tissue to areas of the plants that maximize exposure to direct sunlight, i.e., the north.

After returning to the United States, Warren hypothesized that some plants of the arid West might also have adopted a similar strategy, but limiting the reproductive tissue to the south, because arid zones here are north of the Tropic of Cancer. Wishing to extend the philosophy to a genus other than cacti, he called biologists at Yucca Tree National Park in southern California and Joshua Tree National Landmark in southwestern Utah to investigate. He was told that such a phenomenon had never been observed. Undaunted, he travelled to Joshua Tree National Landmark to make his own observations. He quickly discovered that his suspicions were correct. Despite the millions of visitors to the National Park and National Landmark to observe Joshua Trees, the phenomenon had never been previously reported.

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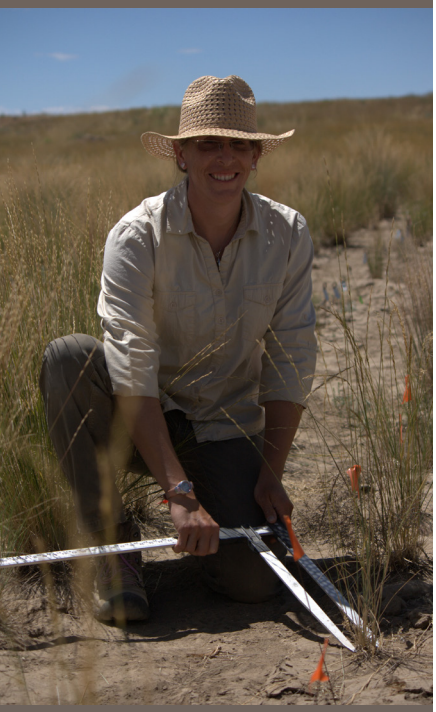

RMRS botanist Jessica Irwin measuring a bluebunch wheatgrass plant at the Richfield Garden Site in Idaho.

Photo by: Francis Kilkenny, RMRS.

Key Findings:

- Flower panicles of the iconic Joshua tree tend to tilt to the south, presumably to maximize exposure to the sun.
- The strategy may also produce a thermal reward for the obligate moth pollinator that emerges shortly after sundown to forage within flower clusters that have been exposed to sunlight all day long.
- For restoration projects that seek to transplant Joshua trees from one site to another, care should be exercised to ensure that the south side of the plant in one site is also oriented to the south at the new site.

Featured Publications:

Warren, S.D.; Aguilera, L.E.; Baggett, L.S.. 2016. Directional orientation of reproductive tissue of *Eulychnia breviflora* (Cactaceae) in the hyperarid Atacama Desert. Revista Chilena de Historia Natural 89:Article 10 (6 pp) DOI 10.1186/s40693-016-0060-z.

Warren, S.D.; Baggett, L.S.; Warren, H. 2016. Directional floral orientation in Joshua trees (*Yucca brevifolia*). Western North American Naturalist 76:374-378. DOI 10.3398/064.076.0313.

The right seed at the right place

Francis Kilkenny

Native plant community restoration is a vital tool for preserving and maintaining diverse ecosystems that support wildlife and provide ecosystem functions essential to healthy human communities. The success of restoration projects depends on using plant materials that are adapted to local environmental and climatic conditions. Seed transfer guidelines and seed zones help land managers in selecting the right seed for the right place.

Researchers at the Rocky Mountain Research Station and the Pacific Northwest Research Station developed seed zones for bluebunch wheatgrass (*Pseudoroegneria spicata*), a keystone bunchgrass species in sage-steppe ecosystems and an important restoration species, using a common garden approach. The researchers are now testing the efficacy of bluebunch seed zones with a large reciprocal transplant study, by planting over 20,000 bluebunch plugs at fifteen sites across four states (Idaho, Nevada, Oregon and Washington) that represent the full range of climates that bluebunch experiences. Sites have been monitored for two years, and will be monitored for a third. Traits related to growth, phenology, physiology, survival, and reproduction are being measured to determine how bluebunch populations are adapted to environmental and climatic conditions across their range. Early results have shown that local populations at a garden site have higher growth and reproduction than populations that are not local to that site. This indicates that the local bluebunch varieties are adapted to specific environmental and climatic conditions. This information will help to increase restoration success.

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Measuring gas exchange on an establishing seedling.

Credit: Kasten Dumroese, RMRS.

Key Findings:

- Seed zones were developed for bluebunch wheatgrass to show where different varieties are likely to be successfully planted
- The efficacy of these seed zones is being tested with a large scale reciprocal transplant experiment
- Preliminary data suggests that bluebunch wheatgrass populations are adapted to specific environmental and climatic conditions
- Seed zones are an effective way to predict successful restoration of bluebunch wheatgrass

Featured Publications:

Kilkenny, F.F. 2015. Genecological approaches to predicting the effects of climate change on plant populations. Natural Areas Journal. 35(1):152-164.

St. Clair, J.B.; Kilkenny, F.F.; Johnson, R.C.; Shaw, N.L.; Weaver, G.. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in the northwestern United States. Evolutionary Application. 6(6): 933-948.

Koch, G.; St. Clair, B.; Erickson, V.. 2015. No place like home: using seed zones to improve restoration of native grasses in the West. Science Findings 171. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 6 p.

Understanding seedling physiology, biophysics, and edaphic environments to maximize restoration goals

Jeremy Pinto

Restoration and reforestation using nursery-produced seedlings can be an effective means of increasing successful establishment and rapid growth following outplanting. This, in turn, can accelerate the recovery trajectory of these ecosystems. However, in many ecosystems of the world, seasonal changes as well as changing climate can create dry conditions that are not favorable to seedling establishment. Most critically, dry conditions can create temporal and spatial limitations in soil moisture, which can be difficult for a planted seedlings to access. Recent work has highlighted the importance of maintaining the understanding of how physiology, biophysics, and edaphic environments can be better understood to mitigate dry conditions for successful seedling establishment.

The Target Plant Concept is a holistic approach to native plant restoration and reforestation. It outlines a framework of interrelated ideas that ensure the right plant material is put in the right place at the right

time. Quantifying and mitigating the factors most limiting to seedling establishment is critical. In most cases, soil moisture is the most limiting factor. This research has examined how soil moisture dynamics can change over dry periods and what the subsequent physiological responses of planted seedlings might entail. Our research shows that site preparation, appropriate stocktype selection, and planting timing, can mitigate the changes in soil moisture and increase the establishment likelihood of seedlings. In some cases, this can mean a significant boost in growth, in other cases, it can mean the difference or survival or mortality.

Using a one-size-fits-most approach to accomplishing revegetation projects is becoming increasingly hard to justify. Understanding the synchronicity of these relationships is increasingly important as restoration and reforestation goals are undertaken in highly disturbed ecosystems and in changing climates. These findings and concepts give managers footholds to generate informed decisions and justifications regarding plant materials, site preparation, and timing of planting windows.

Featured publications

Pinto, J.R.; Marshall; J.D., Dumroese; R.K., Davis, A.S., Cobos D.R. 2016. Seedling establishment and physiological responses to temporal and spatial soil moisture changes. New Forests 47:223-241.

Finch, D.M.; Pendleton, R.L., Reeves, M.C.; Ott, J.E.; Kilkenny, F.F.; Butler, J.L.; Ott, J.P.; Pinto, J.R.; Ford, P.L.; Runyon, J.B.; Rumble, M.A., Kitchen, S.G. 2016. Rangeland drought: effects, restoration, and adaptation. In: Vose JM, Clark JS, Luce CH, Patel-Weynand T, editors. Effects of drought on forests and rangelands in the United States: a comprehensive science synthesis. USDA Forest Service, Research & Development. General Technical Report WO-93b. p 155-194.

Dumroese, R.K.; Landis, T.D.; Pinto, J.R., Haase, D., Wilkinson, K.W., Davis, A.S. 2016. Meeting forest restoration challenges: using the Target Plant Concept. Reforesta 1:37-52.

Pinto, J.R.; Davis, A.S., Leary, J.K., Aghai, M.M. 2015. Stocktype and grass suppression accelerate the restoration trajectory of *Acacia koa* in Hawaiian montane ecosystems. New Forests 46:855-867.

Field testing provisional seed zones for basin wildrye

Scott Jensen

In the effort to use genetically appropriate plant materials for restoration projects, provisional seed zones were developed as one method of pairing seed sources to restoration sites.

Provisional zones were developed through grouping similar climate parameters across broad geographic areas without regard to species specific performance or genetic information. As such, they function as a tool for identifying similar climate envelopes which may serve as an acceptable interim surrogate for species specific genecological work in pairing seed sources to restoration sites.

Basin wildrye (*Leymus cinereus*) is a common Great Basin restoration grass for which no species specific seed zones have been developed. In this study we test whether 27 native populations collected from four

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provisional seed zones in the Central Basin and Range (covers parts of Nevada, Utah, Idaho, and California) demonstrate a home court advantage when planted on four test sites, each representing a provisional seed zone. Four basin wildrye cultivars are included. Our metrics include emergence and survival through the first two growing seasons.

This project is ongoing.

New state records for Hieracium spp. in South Dakota

Brian Dickerson

Hieracium spp. (Asteraceae) are noted for their taxonomic complexity, frequent incidence of apomixis and polyploidy, and invasive tendencies. Here we report the Eurasian taxa, *Hieracium caespitosum* Dumort and *Hieracium piloselloides* Vill., as recent additions to the flora of South Dakota. Plants were collected at three locations in the Black Hills during 2014 and 2015 and compared to specimens of *H. caespitosum* and *H. piloselloides* at major herbaria (RM, MO, SDC) for five morphometric traits. We found significant differences (P<0.05) between previously identified specimens of these species for involucre and pappus lengths and stellate leaf hair number; the latter was especially discriminatory in univariate and multivariate analyses and probably the most useful trait for field identification.

Key Findings:

- *Hieracium* specimens from the Black Hills exhibited morphological characteristics of *H. caespitosum* and *H. piloselloides*, suggesting that both species were introduced in the region.
- These data will assist South Dakota land managers in identification of nascent weedy *Hieracium* populations and may also be of interest to biologists studying demographic and genetic factors related to weed establishment.

Featured Publication:

Dickerson, B.E.; Mayer, C.; Ramsey, J.; Mergen, Z.; Gabel, M. 2016. *Hieracium caespitosum* and *Hieracium piloselloides* (Asteraceae) in the Black Hills National Forest: New state records for South Dakota, U.S.A. Journal of the Botanical Research Institute of Texas. 10(2): 541-546.

Hieracium caespitosum, *Pennington County, South Dakota.*

Credit: Brian Dickerson, RMRS.

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