Individual Summaries of Published Scientific Literature related to the Interactions among Grazing, Fire, and Invasive Plants in the Sagebrush Steppe Ecosystem

Prepared by: Strand, E.K., B.H. Brockett, B.J. Goehring, S. Hatch, A.L. Kuchy, A.A. Stebleton, and K.L. Launchbaugh. 2007.

Introduction to Summaries

A team of research professionals including graduate students in fire ecology, grazing management, rangeland ecology, and invasive species biology, supervised by faculty members of rangeland ecology and management and invasive species biology reviewed over 100 publications relating to the interaction between fire, grazing and invasive species in the sagebrush steppe. Literature was located via key word searches in the many library search engines available to students and faculty at the University of Idaho, for example the Web of Science, AGRICOLA, EBSCO, and BioOne. The team met weekly to coordinate research assignments, report and discuss research results, and evaluate progress to answer research questions. Research papers relevant to the project purpose and objectives were summarized according to guidelines specified by Kreuger and Kelly (2000) and were classified into five categories of literature:

I. Experimental research
II. Documented case-study
III. Scientific synthesis
IV. Professional resource knowledge
V. Model-based research

Experimental research articles represent the most credible source of information as such research is grounded in a carefully planned experimental design and evaluated using sound statistical methods. Documented case studies are characterized by local to regional observations that may be repeated through time. Results from a documented case study can sometimes be extrapolated to apply in other areas, but may also be site specific. Scientific synthesis papers are a result of a literature review centering on a specific topic that has been synthesized by an scientist of professional with expertise in that particular topic. Professional research knowledge papers are written by experts in the field, however, statements and assumptions are not necessarily backed up by scientific research but are rather a synthesis of many years of professional experience. Articles describing conceptual, mathematical, spatial, or biophysical models were categorized as Model-based research. In summary, the student team summarized approximately 90 articles relating to the interaction between fire, grazing and invasive species in the sagebrush steppe ecosystems. The summaries are all divided into four sections: Introduction, Summary, Relevant findings, and Summary interpretation. The introduction provides an overview of the article, the summary reviews research methods and study region, the relevant findings section is a condensed version of the most important results found in the article, particularly those results that directly relates to fire-grazing-invasive species interactions in sagebrush steppe. The summary interpretations section in the summary is a brief synthesis of the article provided by the student reviewer.

Krueger, W.C. and C.E. Kelly 2000. Describing and categorizing natural resources literature. Rangelands. 22:37-39.

Citations for Literature Review:

Allen-Diaz, B. and J.W. Bartolome, 1998. Sagebrush-grass vegetation dynamics: comparing classical and state-transition models. *Ecological Applications* 8:795-904.

Literature category: Model-based research
Specific topic: Management toolbox
Reviewed by: Bruce H. Brockett and Eva Strand

Introduction

The paper presents an evaluation of state-and-transition (ST) successional modeling, versus a classical linear succession paradigm, and its derivative the range condition (RC) approach (e.g. excellent, good, poor etc.). At the time of writing ST models had not been used to rigorously test hypotheses about the structure of rangeland communities, or regarding non-equilibrium dynamics. Secondary succession has long been studied in the sagebrush-grass type with traditional linear Clemensian succession regarded as a good fit. In this paper a less subjective ST model is developed to compare its predictive power to classical succession model and its derivative the range condition model.

Summary

Plant cover data were derived from a monitoring program of the Vale Rangeland Rehabilitation program in southeastern Oregon. TWINSPAN was then used to classify the data into groups for the ST model.

Relevant findings

The classical succesional model had five states: (I) annual species dominant, perennials absent, (II) Sagebrush (*Artemisia tridentata)* dominant, perennial grasses absent, (III) Sagebrush (*A. tridentata)* and/or cheatgrass/Sandberg bluegrass (*Bromus tectorum*/*Poa secunda)* dominant, bluebunch wheatgrass (*Pseudoregnia spicata)* absent, (IV) Sagebrush dominant, bluebunch wheatgrass present; (V) *bluebunch wheatgrass* cover greater than sagebrush cover. Using a RC approach, these states were classified as excellent, good, fair or poor. The ST model included 6 states, with eight transitions between states. Transitions were combinations of: do nothing, or related to time and weather over a 10-yr period, or no change in management activities (e.g. plowing and seeding) over a 10-yr period, or spraying. The analysis showed that if an area is plowed and then seeded post-fire then a threshold is crossed, with new states appearing, which appeared to be stable over time. The response of the system to cheatgrass was the most unpredictable of the transitions.

Summary findings

This work provides guidelines for how to conceptualize the dynamics within sagebrush steppe vegetation, including transitions into an array of different states, which may occur due to fire and grazing treatments. The flexibility, non-linear properties, reversibility, and sensitivity to management of the ST model emphasize its utility in conceptualizing succession and disturbance dynamics in rangelands.

Anderson, J. E., and R. S. Inouye. 2001. Landscape-Scale Changes in Plant Species Abundance and Biodiversity of a Sagebrush Steppe over 45 Years. *Ecological Monographs* 71:531-556.

Literature category: Experimental research

Specific topic: Management toolbox
Reviewed by: Andréa Kuchy

Introduction

Data for vascular plants sampled in SE Idaho during 45 years was used to (1) assess long-term changes in abundance and distribution of major species and life forms, (2) assess changes in species richness and plot similarity, and (3) test the hypotheses that plant cover and stability of cover are positively associated with species richness and that invasibility is inversely related to native plant cover and richness. This study emphasized richness and cover of native species as a management priority for sagebrush steppe ecosystems.

Summary

A field experiment was conducted using cover, density, and frequency data for 79 permanent plots established in 1950 on the Idaho National Laboratory (INL). The plots were sampled nine times during 45 years. From 1933 through 1957 the area was subject to severe drought, with annual precipitation exceeding the long-term mean only four times. Despite relatively homogeneous conditions of 1950, when the vegetation plots were established, vegetation on the permanent plots at the INL were determined to be non-static over the past 45 years, refuting the prediction of long-term stability under shrub dominance.

Relevant findings

With elevated precipitation after 1957, shrub cover increased from 18% to 25% by 1965, and by 1975 cover of perennial grasses had increased 13-fold, starting at 0.5% cover.

Analyses indicated lags of 2-5 yr in responses of species or functional groups to precipitation.

Richness of shrubs, perennial grasses, and forbs per plot steadily increased from 1950 to 1995. Plots having higher species richness tended to maintain higher levels of cover and to vary less in cover relative to their mean level, indicating links between species richness and function.

Vegetative heterogeneity increased, with mean similarity among plots declining from 72% to 40%.

Summary interpretation

Adequate cover of native species can render these semiarid communities more resistant to invasion. Plots having greater species richness varied less in cover, and presumably in productivity, in relation to their mean level. Plots with higher species richness tended to maintain higher levels of cover.

Bachelet D., J.M. Lenihan, C. Daly, and R.P. Neilson. 2000. Interactions between fire, grazing and climate change at Wind Cave National Park, SD. *Ecological Modeling* 134:229-244.

Literature category: Model-based research
Specific topic: Grazing effects on fire
Reviewed by: Eva Strand

Introduction

The interactions between natural fire regimes, grazing pressure and climate change and effects on biogeographical and biogeochemical characteristics in Wind Cave National Park in South Dakota was simulated using the dynamic vegetation model (DVM). This area is located on the ponderosa pine (*Pinus ponderosa*) / mixed grass prairie ecotone.

Summary

Fire suppression in Wind Cave NP has since Euro-American settlement caused pine to encroach into the mixed prairie. Bison, elk, and deer currently graze in the park. In the early 1900's predators were extirpated resulting in increased populations of grazing animals resulting in overgrazing. In 1930-50 excessively grazed areas were reseeded and the grazing animal population was reduced by introducing hunting permits. For modeling purposes a 1250-ha area of the ecotone landscape was divided into 50 m grid cells. Climate was modeled from 100-year monthly dataset of precipitation, temperature, vapor pressure and wind speed. Future climate was modeled from the HADCM2SUL model, predicting a slight increase in precipitation and an average temperature increase from 7 to 11ºC. Soil texture was estimated based on a digital terrain model. Biogeochemical processes were modeled using a modified version of the CRNTURY model.

Relevant findings

The modeled overgrazing in the early 1900's reduced fuel loads and thereby fire occurrence, promoting conversion from grasslands to shrubby woodlands. An increase in rainfall would allow for a conversion to tree dominance. Even without overgrazing, conversion to woodlands is likely to occur under future climate conditions. Prescribed fire is a means of maintaining grasslands in the area.

Summary interpretation

Grazing is a powerful force that can alter fire regimes and promote conversion from one vegetative state to another, grasslands to shrublands in this case. The removal of biomass during grazing (particularly heavy grazing) reduces fine fuels with a decreased risk for fire occurrence and spread.

Baker, W.L. 2006. Fire and restoration of sagebrush ecosystems. *Wildlife Society Bulletin* 34:177-185.

Literature category: Professional resource knowledge
Specific topic: Grazing/ fuels/ fire
Reviewed by: Shannon Hatch

Introduction

The author discussed the role of fire in sagebrush steppe ecosystems prior to EuroAmerican settlement. The author reviewed evidence concerning fire history, fire rotation, and fire patterns in sagebrush ecosystems. Citing inaccurate data correction methods, the author felt that prior estimates of fire return intervals were too low. The author presented evidence that sagebrush (*Artemisia tridentata*) ecosystems have typically experienced long fire rotations. As a result, he argued that sagebrush has not been negatively affected by fire suppression policies implemented in the twentieth century.

Summary

Fire-scar and recovery evidence were used to argue the idea that naturally ignited, historic fires did not occur as frequently as once believed. Past fire rotation estimates did not make accurate mean composite fire interval (mean CFI) corrections, and as a result, sagebrush ecosystems were thought to burn more frequently than current evidence may suggest. The author stated that fire rotations may be a minimum of 325-450 years in low sagebrush (*A. arbuscula*), 100-240 years in Wyoming big sagebrush (*A.t.* ssp. *wyomingensis*), 70-200 years or more in mountain big sagebrush (*A.t.* ssp. *vaseyana*), and 35-100 years in mountain grasslands interspersed with sagebrush. The use of fire as a restoration tool was not advocated in this paper.

Relevant findings

Areas now dominated by cheatgrass (*Bromus tectorum*) are burning at short fire rotations; fire regimes are significantly altered from historical range (condition class 3).

Sagebrush steppe that does not contain significant cheatgrass should be considered within historical range (condition class 1).

Fires should be suppressed in areas prone to cheatgrass invasion. Wyoming big sagebrush (*A.t*. spp. *wyomingensis*) is especially susceptible; prescribed burning is not advocated in these communities.

In mountain big sagebrush (*A.t.* spp. *vaseyana*) communities, improper prescribed burning can have adverse impacts on sage-grouse habitat.

Summary interpretation

Sagebrush ecosystems are more negatively impacted by cheatgrass invasion than by continued fire suppression; therefore fires should be suppressed where cheatgrass dominance is a potential.

Barker, J. R., and C.M. McKell. 1983. Habitat differences between basin and Wyoming big sagebrush in contiguous populations. *Journal of Range Management* 36:450-454.

Literature category: Experimental research
Specific topic: Sagebrush restoration
Reviewed by: Andréa Kuchy

Introduction

Basin and Wyoming big sagebrush plants growing in contiguous populations were studied to identify potential habitat differences in plant water and soil relationships at 3 study sites in Wyoming and Utah. This study evaluated differences in big sagebrush subspecies for management implications.

Summary

This study discussed habitat variation in water and soil relationships between two subspecies of big sagebrush that would partially account for differences in plant stature. At each site, basin big sagebrush plants grew within and next to a drainage, while Wyoming big sagebrush occupied adjacent sites away from drainages. Soil-water potential, leaf-water potential, and leaf-transpiration resistance were measured at each site to compare the various water relations of basin and Wyoming big sagebrush. Five randomly selected plants per population per site were studied. To identify edaphic differences between basin and Wyoming big sagebrush habitats, soils associated with each population were described and classified according to Soil Conservation Service methods. Chemical analyses were performed on collected plant material.

Relevant findings

Seasonal differences in soil-water exist to condition plant development and segregation into separate populations. The difference in soil-water potentials indicates that basin big sagebrush plants grew in a more mesic habitat than did Wyoming big sagebrush.

Wyoming big sagebrush experienced a greater water stress than basin big sagebrush plants.

Soils associated with basin big sagebrush plants have higher organic carbon, nitrogen, cation exchange capacity, potassium, and phosphorus than soils associated with Wyoming big sagebrush plants. These differences may have occurred in response to differences in site productivity sustained by favorable soil water.

Summary interpretation

Site conditions should be considered when selecting big sagebrush subspecies that are most adapted to specific environmental conditions for range improvement projects.

Beck, J.L. and D.L Mitchell. 2000. Influences of livestock grazing on sage grouse habitat. *Wildlife Society Bulletin* 28:993-1002.

Literature category: Scientific synthesis
Specific topic: Grazing/ fuels/ fire
Reviewed by: Shannon Hatch

Introduction

The authors provided a synthesis of the literature related to the impacts of grazing upon sagebrush (*Artemisia tridentata*) steppe ecosystems; sage-grouse habitat was emphasized.

Summary

Through an examination of pertinent literature, the authors examined how livestock grazing potentially alters sage grouse habitat. Indirect livestock effects were also examined.

Relevant findings

Sagebrush density was found, in one study, to increase as the production and viability of herbaceous species was reduced by sheep grazing. In a contradictory report, however, sagebrush increases were not associated with grazing. Conflicting findings were also found with regards to the effects of grazing on herbaceous composition. The removal of grazing was not linked to an increase in the herbaceous productivity of one site; however, the removal of grazing from a site in a similar study resulted in the increase of basal cover of perennial grasses.

The authors cited the importance of considering grazing history, season of usage, and community composition when analyzing the effects of grazing upon an ecosystem.

Summary interpretation

Conflicting evidence exists regarding intensive grazing and its role in the increase of sagebrush density. Many factors should be taken into account when attempting to determine impacts.

Blackmore, M. and P.M. Vitousek. 2000. Cattle grazing, forest loss, and fuel loading in a dry forest ecosystem at Pu'u Wa'aWa'a Ranch, Hawai'i. *Biotropica* 32:625-632.

Literature category: Documented case study
Specific topic: Grazing effect on fuels
Reviewed by: Shannon Hatch

Introduction

The authors evaluated and quantified the dual roles of grazing in seasonally dry forests in Hawai'i. While livestock contributed to declines in forest cover, grazing also reduced fuel loads and the subsequent risk of catastrophic fire in remnant forest stands.

Summary

Study sites, located on the island of Hawai'i, were established in grazed and ungrazed areas; elevation ranged from 900 and 1300 m. Fuels were primarily comprised of introduced grasses, kikuyu grass (*Pennisetum clandestinum*) and fountain grass (*Pennisetum setaceum*). Changes in forest cover were first determined from digitized aerial photographs taken from 1954 to 1994. Field data were then collected to determine the effect of grazing on mass per unit area, live/dead fuel ratio, surface/volume ratio, height, percent cover, water content and specific heat. Grass composition was subsequently determined. Field data were used to construct fuel models, through the use of BEHAVE, for each site.

Relevant findings

Grazing reduced the mass of kikuyu from a mean of 770 to 229 g/m^2.

Results from BEHAVE modeling indicated that grazed grasses had a much lower fire potential than ungrazed grasses.

Grazed kikuyu cannot support rapidly spreading, intense fires despite wind and drought conditions.

Although grazing contributes to forest loss, it also helps to reduce forest loss from destructive fires due to grass biomass removal.

As grazing thins out the forest, it also exposes more fuels to wind, thereby increasing fire spread potential. Even as grazing leads to a decline in forest health, it is now an essential link in the control of fire risk.

Summary interpretation

While this study was conducted in Hawaii, important parallels may be drawn from the authors' findings. Although livestock may have detrimental effects in sagebrush steppe ecosystems, grazing may help to reduce fuel loading and the subsequent risk of fire. Cheatgrass (*Bromus tectorum*) infestation and spread may be ameliorated as a result.

Blesky, A.J. and D.M. Blumenthal. 1997. Effects of livestock grazing on stand dynamics and soils in upland forests of the Interior West. *Conservation Biology* 11:315-327.

Literature category: Scientific synthesis
Specific topic: Grazing/ fuels/ fire/historic role
Reviewed by: Shannon Hatch

Introduction

The authors provided a synthesis of the literature pertaining to the contribution of livestock in the decline of forest health in the Interior West. In addition to fire suppression and the selective logging of more fire-tolerant trees, livestock were implicated as playing a large role in changing forest dynamics.

Summary

In addition to providing historical background on grazing in the West, numerous case studies were provided that examined the role of grazing and its effects on forest structure and function. Case studies from rangelands in Washington State, forested land in the Bitterroot Mountains of Idaho, ponderosa pine (*Pinus ponderosa*) forests in Utah, and ponderosa pine forests on the Arizona-New Mexico border were examined. Studies examined often involved the comparison of grazed and non-grazed sites. In several of the case studies, fire had been absent from both grazed and non-grazed sites; the presence or absence of grazing was determined to be the decisive variable affecting vegetation change.

Relevant findings

The introduction of livestock to the Southwest began in the 1700s; the Northwest introduction began in the mid-1800s. Heavy stocking was seen on nearly all grass and sedge supporting areas, including ponderosa pine and mixed-conifer forests, by the early 1800s in the Southwest and the late 1800s in the Northwest.

Heavy grazing contributed to a decline in the biomass and health of grasses and sedges; the competitive advantage of the herbaceous layer was subsequently lost and tree seedlings became more readily established as a result. Fire frequency was reduced due to a loss of fine fuels.

The effects of livestock grazing were exacerbated by fire exclusion policies that were implemented in the early part of the twentieth century. However, case studies comparing grazed versus non-grazed areas found that livestock grazing alone could contribute significantly to increased tree densities. For example, on the grazed Horse Pasture Plateau (HPP) in Utah, the mature-to-young tree ratio was 1:598. On nearby ungrazed mesas, the ration was 1:0.8. Neither the grazed or ungrazed areas had been burned.

Livestock grazing can also reduce biomass availability; litter production is thereby decreased. Grazed areas may have higher proportions of bare ground. Loss of litter can be attributed to higher overland flow, decreased water infiltration, loss of soil nutrients and organic material, and loss of protective properties (i.e. protection from freezing and protection from the erosive force of raindrops). In a ponderosa pine/bunchgrass ecosystem, litter biomass was reduced 40% to 60% by moderate and heavy livestock grazing, respectively.

Livestock can also affect soil compaction and infiltration, which are critical for plant productivity and vegetative cover. Negative feedback loops can be perpetuated as water-stress and tree morality are associated with an increased fire incidence. Soil disturbance has also been linked to an increase in invasive plants.

Summary interpretation

Through vegetation alteration, livestock can significantly affect fire regimes. Initially, livestock can reduce fire frequency through the consumption and disturbance of the herbaceous layer. As the herbaceous component looses its competitive advantage, tree seedlings can become more readily established. Fire intensity and/or severity may subsequently increase as the result of fuel accumulation. Changes in litter and soil composition, which result in decreased water storage and availability, may exacerbate fire conditions.

Brown J.K. 1982. Fuel and Fire Behavior Prediction in Big Sagebrush, United States Department of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station, Research Paper INT-290, Ogden, UT.

Literature category: Model-based research
Specific topic: Fire effects on sagebrush steppe
Reviewed by: Eva Strand

Introduction

The effect of fuel composition in sagebrush steppe (*Artemisia tridentata* ssp. *vaseyana* and *wyomingensis*) on fire behavior was assessed using Rothermel's mathematical model for fire spread and intensity. Measurements of individual sagebrush plants and cover of sagebrush, herbaceous plants, and litter were taken in the field to assess the fuel properties and loads.

Summary

Modeling of fire behavior (fireline intensity, flame length and rate of spread) using Rothermel's equation requires a number of input variables: fuel loading of different size classes of vegetation, proportion live and dead fuel of different size classes, moisture content by size class. Sagebrush height, crown area, bulk density, and cover were measured. Two phenological scenarios were modeled in the FIREMOD computer program; 1) early summer (57% of the herbaceous vegetation live) and 2) fall (1/3 of the sagebrush foliage cured, all herbaceous vegetation cured). Litter and herbaceous vegetation beneath sagebrush plants were considered part of the sagebrush for modeling purposes. The herbaceous fuel loading spatial distribution were modeled in three ways; 1) equal amounts beneath and between sagebrush plants, 2) twice as much beneath as between sagebrush plants, and 3) three times as much beneath as between sagebrush.

In the interpretation of results, rate of fire spread, was computed as an average of spread rates for sagebrush and grass, each weighted by their percent cover.

Relevant findings

For large sagebrush plants the influence of litter on fire behavior was marginal. For small sagebrush plants however, the litter influenced fire behavior.

Varying the distribution of herbaceous fuels beneath and between sagebrush plants had little influence on the fire behavior in this model.

The fire rates of spread were approximately 2-3 times higher in the fall scenario compared to the early spring scenario.

At low sagebrush cover the fire spread rate is almost entirely governed by the spread rate of grass. Sagebrush cover affects the rate of spread and at 30-40 % sagebrush cover the spread rate is noticeably increased.

The fire spread rate increases with sagebrush plant height and cover.

Current fire models cannot deal adequately with discontinuous fuel beds and results predicted at low winds and fuel loadings are particularly misleading. Fire is here predicted to spread in the model world while it may not in the real world.

For grass, herbaceous loadings as low as 267-446 kg/ha (300-500 lb/acre) and winds of 6-8 km/h (4-5 miles/h) are needed for the fire to spread depending on the fuel distribution.

For herbaceous loadings of < 267 kg/ha (300 lb/acre) and sagebrush cover < 20%, a wind of > 16 km/h (10 miles/h) may be required to spread fire.

Higher windspeeds or fuel loadings are required for fire to spread in bunchgrasses compared to other grasses.

Predicted fire line intensities in grass are 10-100 times lower than when sagebrush is present.

Predicted fireline intensities at 40% sagebrush cover are 8-10 times higher compared to 10% sagebrush cover for tall (120 cm) sagebrush plants. This difference decreases for shorter sagebrush plants.

Doubling the wind speed from 13 to 26 km/h (8 to 16 miles/h) increases the rate of spread ~3 times and the fireline intensity 2.5 times. Predictions below 6 km/h (4 miles/h) wind are not recommended due to inadequacies of the fire model.

Slope effects fire rate of spread and intensity such that at 30% slope the fire behavior increases 2-3 times and at 50% slope the increase is 4-7 times compared to 0% slope.

Comparison of the model results from this study with three field case studies show that predictions of fire rate of spread is good, however prediction of flame length was half of what was observed in the prescribed burns. Modeled fire line intensities were 3-6 times lower than the ones observed.

Summary interpretation

Many factors affect the fire behavior in sagebrush steppe. The most important factors are: sagebrush cover, sagebrush height, herbaceous cover and loadings, fuel moisture, wind speed, and slope. Current fire models do not account for discontinuities in fuel distribution and should be used with caution particularly at low wind speeds and fuel loads. Compared to field studies the predictions presented here underestimate the fuel consumption and thereby the fireline intensity.

Burkhardt J.W. 1996. Herbivory in the Intermountain West. Station Bulletin 58. Moscow, ID: 18p.

Literature category: Scientific synthesis
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

The author provided a synthesis of the literature related to prehistoric and historic herbivory in the Intermountain West of North America. The author challenged the popular theory that rangelands at the time of European settlement were representative of the pristine, stable natural state for the region. Based on fossil records indicating that bison survived the Pleistocene extinctions, the author supported the idea that large herbivores have been an integral part of the ecosystem in the Intermountain West for thousands of years.

Summary

Citing fossil evidence, the author questioned the widely accepted assumption that the Intermountain West evolved without heavy grazing pressure from large herbivores. The author argues that these areas had been subject to extensive human use prior to European settlement and he suggested that human predation may have led to the decline and eventual extinction of several herbivore species. The author suggested that livestock could be used to fill a vacant niche left in the wake of the extinction of the megafauna, however, stocking levels and seasonal grazing practices need to be considered.

Relevant findings

Heavy livestock grazing of annual grasses after European settlement resulted in increases in shrubs and woodland. Grazing patterns and stocking levels essentially resulted in the "fireproofing" of the sagebrush steppe. The author supported the idea that cheatgrass (*Bromus tectorum*) invasion is inevitable, regardless of livestock grazing or stocking rates in lower elevation, more xeric areas. Cheatgrass is more highly adapted than native perennials in areas with mild, wet winter and early hot, dry summers. At higher elevations, however, poor grazing practices often result in cheatgrass invasion.

Summary interpretation

Heavy grazing may result in reduced fire frequencies as more readily ignitable fuels are consumed.

Targeted grazing will have little effect on annual grass conversion at lower elevation sites, while poor grazing practices at higher elevations may result in disturbances that facilitate the invasion of cheatgrass.

Chambers, J.C., B.A. Roundy, R.R. Blank, S.E. Meyer, and A Whittaker. 2007. What makes Great Basin Sagebrush ecosystems invasible by *Bromus tectorum*? *Ecological Monographs* 77:117-145.

Literature category: Experimental research
Specific topic: Grazing effects on cheatgrass
Reviewed by: Andrea Stebleton

Introduction

The purpose of this research was to investigate the invasibility of sagebrush ecosystems over the typical topographic gradient of sagebrush (*Artemisia tridentata)* within the Great Basin. Specific components examined across elevation gradients included differences in environmental conditions and resource availability at the different elevations and the response of cheatgrass (*Bromus tectorum*) to direct and cumulative effects of herbaceous grazing and fire. Study sites were located in Shoshone Mountain Range of Nevada and the East Tintic Range of Utah.

Summary

Invasibility was defined based on the probability of establishment, growth and reproduction for the individual plant within a sampling quadrat. Individual study plots 3.0m in diameter were located around a focal sagebrush plant 1.0-1.5 m diameter and were spaced at least 2.0 m apart for 950 sites across elevation gradients. Pre-treatment total herbaceous cover was determined for perennials and annuals at all sites. Cheatgrass invasion was examined within the plots following 0%, 50%, and 100% herbaceous removal by use of herbicide and burned and unburned treatments. Separate and combined influences of the treatments were evaluated based on the percentage aerial cover of perennial and annual grasses.

Relevant findings

- Invasibility following a fire is influenced by the type and abundance of the residual perennial herbaceous vegetation and interactions between soil water and soil nutrients.
- Cheatgrass seeds can survive two or more years in the soil.
- Cheatgrass more effectively invaded interspaces compared to establishment under shrubs.
- Biomass and seed numbers of cheatgrass increased 2 to 3 times with the removal of perennial vegetation, 2 – 6 times following the burning treatment and 10-30 times with following both herbaceous removal and burning.
- Sites in high ecological condition were much more resistant to cheatgrass invasion.
- The presence of crested wheatgrass (*Agropyron cristatum*)*,* a commonly seeded grass, which is thought to suppress cheatgrass growth and reduce fuel continuity and flammability, did not limit invasion by cheatgrass*.*

Summary interpretation

Although this study may not replicate the effects of overgrazing, especially in terms of soil nutrient dynamics, it showed how the effects of reduced competition from perennial grasses increased the invasion potential of cheatgrass. This, coupled with the effects of fire, allowed cheatgrass to significantly increase biomass and seed production, perpetuating the invasion.

Cook, C.W. and L.E. Harris. 1952. Nutritive value of cheatgrass and crested wheatgrass on spring ranges of Utah. *Journal of Range Management* 5:331-337.

Literature category: Experimental research
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this research was to investigate how the nutritive values of cheatgrass (*Bromus tectorum*) and crested wheatgrass (*Agropyron cristatum*) changed with maturity of the plant. The research was conducted in the grassland foothill area of northwestern Utah.

Summary

Fecal samples were collected from seven wethers that grazed temporary enclosures of pure stands of crested wheatgrass and cheatgrass to determine nutritive content and digestibility. The growth stage of the plant and the correlating part of the plant were recorded through the duration of the study.

Relevant findings

Sheep ate the entire cheatgrass plant through the dough stage when the plant started turning purple. After this point the sheep ate the heads and any green leaves and eventually consumed only the dry leaves and stems.

Cheatgrass nutritive value decreased with maturity.

Both cheatgrass and crested wheatgrass were shown to be good sources of energy.

Summary interpretation

From Daubenmire's 1940 study, we already know that spring grazing of cheatgrass is favored in order to reduce cheatgrass densities. Cook and Harris's study lends further support to this strategy as they show that cheatgrass is high in energy and readily consumed by sheep in the spring, making targeted grazing a viable tool for the management of cheatgrass.

Cottam, W.P. and F.R. Evans. 1945. A comparative study of the vegetation of grazed and ungrazed canyons of the Wasatch Range, Utah. *Ecology* 26:171-181.

Literature category: Documented case study/experimental research
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this study was to compare the vegetation composition between an intensively grazed canyon and a canyon that had not been grazed.

Summary

Vegetation data was collected from Emigration Canyon, a canyon that had experienced extensive grazing and livestock travel since at least the 1930s. Data was also collected from Red Butte Canyon, a canyon where grazing ceased by 1909. Dominant vegetation in the region varied from grass-sagebrush at lower elevations to scrub oak (*Quercus gambeli*) at higher altitudes. Elevations above the scrub oak (7500 ft) were dominated by aspen (*Populus tremuloides* var. *aurea*) and conifer forests. The vegetation composition of the two canyons was evaluated for density of cover and species present. Fire occurrence at the mouths of both canyons was not uncommon.

Relevant findings

Cheatgrass (*Bromus tectorum*) was present in the ungrazed canyon, Red Butte Canyon, at a frequency that was 1.5 times greater than in the grazed canyon, Emigration Canyon, but was present at both sites.

The greater density of cheatgrass at the ungrazed site may have been due to fire.

Ten species of native grasses were found at Red Butte Canyon that were not present in Emigration Canyon.

Summary interpretation

We can infer from the presence of native species at the ungrazed site, that were missing from the grazed site, that overgrazing can decrease the competitive ability of native grasses. This may result in the eventual extinction of those species from an area. This study attributed the greater density of cheatgrass at the ungrazed canyon to be a result of fire, but the difference in cheatgrass densities between the two sites may actually be a result of the grazing that occurred at only one site.

Courtois, D.R., B.L. Perryman, and H.S. Hussein. 2004. Vegetation change after 65 years of grazing and grazing exclusion. *Journal of Range Management* 57:574-582.

Literature category: Documented case study
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

To quantify vegetation change after 65 years of grazing exclusion the authors compared vegetation characteristics inside and outside exclosure areas at 16 sites. The 16 chosen study sites, dispersed across sagebrush steppe and grassland communities in the Great Basin, were initially established in 1936. The sites in this study were located within 7 distinct plant communities. Four of the sites were dominated by black sagebrush (*Artemisia nova*) associated with Indian ricegrass (*Achnatherum hymenoides*) and bottlebrush squirreltail (*Elymus elymoides*). Four of the sites were dominated by Wyoming big sagebrush (*A. tridentata* spp. *wyomingensis*) with bottlebrush squirreltail, and 3 were co-dominant with bud sagebrush (*A. spinescens*), Indian ricegrass and Basin wildrye (*Leymus cinereus*). Two sites were dominated by basin big sagebrush (*A.t.* spp. *tridentata*) with bottlebrush squirreltail and Indian ricegrass. Another two sites were dominated by Lahontan sagebrush (*A. arbuscula* spp. *longicaulis*) with a bottlebrush squirreltail understory. Two sites were dominated by Bailey greasewood (*Sarcobatus baileyi*) or black greasewood (*S. vermiculatus*) with Indian ricegrass understories. One site was a low sagebrush –Sandberg bluegrass (*Poa secunda*) community. One site was dominated by winterfat (*Krascheninnikovia lanata*).

Summary

Vegetation parameters inside and outside the exclosure were compared. Using the line intercept method, basal cover of herbaceous species and canopy cover of shrubs were estimated. Plant density by species was examined with the use of $1m^2$ quadrats placed at 5m intervals along each transect. Plant heights and live plant counts were taken. In addition, biomass samples for grass and forb species were collected at peak productivity stage. Cover data were used to determine species richness index values.

Relevant findings

The authors noted that while the exclosed areas have been free from grazing for 65 years, these areas may have been greatly affected by heavy grazing prior to the implementation of the Taylor Grazing Act of 1934. As a result, these areas may have transitioned from one stable state into another before the exclosures were established.

Few differences were found in vegetation parameters. Little change was found between cover and density values between grazed and exclosed sites. Species diversity index values, likewise, differed little between grazed and exclosed sites, however, the authors called for longer term monitoring in order to better ascertain the effects of natural range of variation. Cheatgrass (*Bromus tectorum*) densities were found to be higher within a few of the exclosed areas (2 of 12 sites in 2001 and 1 of 11 sites in 2002). While citing the need for more research, the authors suggested that grazing termination may continue to result in higher levels of cheatgrass.

Summary interpretation

This study indicates that the removal of grazing from a site may not significantly affect species cover, density and composition. However, the absence of grazing in an area may result in more decadent shrub growth, and higher cheatgrass densities.

Daubenmire, R.E. 1940. Plant succession due to overgrazing in the *Agropyron* bunchgrass prairie of southeastern Washington. *Ecology* 21:55-64.

Literature category: Experimental research
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this research was to investigate how heavy grazing affects the frequency of cheatgrass (*Bromus tectorum*) and bunchgrass (*Agropyron* spp.) in bunchgrass prairie in southeastern Washington.

Summary

Four hundred plots located at four different stations where grazing history ranged from no grazing to heavy grazing were evaluated for the frequency of different species. Severity of grazing was determined by the "abundance and stature" of bunchgrass plants. The species were sorted into four categories based on their behavior under the influence of heavy grazing: plants that decreased in frequency, plants that increased in frequency, plants not significantly affected, and plants that appeared to be in intermediate stages. Clipping experiments were also conducted where bunchgrass and cheatgrass were clipped to different heights at different times in their lifecycles.

Relevant findings

- With heavy grazing pressure from sheep, cheatgrass can be eliminated from a site within a few years, but bunchgrass densities can be reduced, as well.
- Cheatgrass is palatable and nutritious in the spring and is "practically eliminated" with heavy spring grazing.
- Cheatgrass should not be considered a species that invades solely due to overgrazing.
- Cheatgrass will rapidly reenter an area if grazing is reduced: Dense patches of cheatgrass were found throughout the study area and this could be accounted for by a lack of uniformity in the spring grazing.
- Cheatgrass density was higher in areas that were further away from water.
- Ccessation of grazing for as little as 2 years would result in rapid domination of cheatgrass in the study area.
- A clipping study of bunchgrass showed that bunchgrass vigor was greatly reduced by defoliation during the spring but the impact was much lower if clipping occurred during the summer or fall.
- Where bunchgrass was weakened, cheatgrass readily increased in both size and density.
- In terms of animal impact, only areas that experienced extreme trampling, such as bedding grounds, resulted in bare ground.

Summary interpretation

From this study we can conclude that heavy grazing of cheatgrass before seeds become viable can be an effective method for reducing the cheatgrass seed bank in areas that are dominated by cheatgrass. On the other hand, if bunchgrasses are grazed during their period of active growth, the competitive advantage will be shifted toward cheatgrass. Thus an area's specific composition of cheatgrass and bunchgrass will determine a specific grazing plan for that area. Solid stands of cheatgrass will obviously be easier to manage since no bunchgrass is present that needs to be considered. Based on this study's results, eliminating grazing from a cheatgrass-dominated area will not reduce the cheatgrass problem.

Emmerich, F.L., F.H. Tipton and J.A. Young. 1993. Cheatgrass: Changing perspectives and management strategies. *Rangelands* 15(1):37-40.

Literature category: Professional resource knowledge/Documented case study
Specific topic: Grazing effect on cheatgrass/cheatgrass and fire interactions
Reviewed by: Brianna Goehring

Introduction

The purpose of this article was to describe the management of a cow/calf operation in Winnemucca, Nevada that included the utilization of cheatgrass (*Bromus tectorum*) in its grazing program in order to illustrate that cheatgrass can be used as an asset rather than viewed as a problem.

Summary

Cheatgrass played an integral role in the grazing program of the cow/calf operation described as it served as important winter forage for cattle. The operation managed 1100 head of brood cows that grazed salt desert range during the winter, sagebrush foothills during the spring, and river bottom pastures during the summer. Cheatgrass seeds were collected on the winter range of this ranch in October 1986 and analyzed for nutrient content. 65,000 acres of winter range burned in 1985 from wildfire.

Relevant findings

Cheatgrass seed was found to contain 9% protein and 1.6% fat. This compared to other feed grains like high-grade barley feed, corn feed meal, good-grade corn and oat feed meal, rye grain, wild oats and soft Pacific Coast States wheat that had protein contents that ranged from 9.1% to 13.5% and fat contents that ranged from 1.7% to 5.5%.

Cattle of this operation readily grazed mature cheatgrass plants.

Cattle often favored mature cheatgrass over other mature native perennials.

Young cheatgrass plants were grazed in the spring.

Shadscale (*Atriplex confertifolia*), winterfat (*Krascheninnikovia lanata*) and four-wing saltbush (*Atriplix canescens*) were winter range shrubs that provided protein for the cattle during the winter but were not adapted to the frequency of fire that cheatgrass often experienced.

Summary interpretation

This case study indicates that cheatgrass can successfully be utilized as a palatable source of energy for cattle on winter ranges and can be incorporated into cattle grazing plans. One challenge that goes with this is that the increased frequency of fire that comes with cheatgrass may burn out desirable shrubs that are important sources of protein for cattle on winter range. The higher frequency of fire would be a constant risk for such a cattle operation that utilizes cheatgrass, but the grazing impact could potentially offset the cheatgrass fuel load.

Finnerty, D.W. and D.L. Klingman. 1962. Life cycles and control studies of some weed brome grasses. *Weeds* 10:40-47.

Literature category: Experimental research
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this research was to determine what environmental conditions were necessary for panicle production and flowering of weed brome grasses and to see what methods were effective for control of weed brome grasses. The study took place in Lincoln, Nebraska.

Summary

Seeds of downy brome (*Bromus tectorum)*, hairy chess *(B. commutatus* Schrad.), Japanese chess (*B. japonicas* Thumb.), and cheat (*B. secalinus* L.) were given different vernalization periods and different dates-of-planting. Weed seeds were also mixed with smooth brome grass seeds to see how that affected germination. Control by mowing where mowing date varied and application of different herbicides were also applied to the weed brome grasses.

Relevant findings

A direct correlation existed between the growth stage of the weed brome grass and time of mowing for the success of mowing as a weed control method. Mowing was most effective when done one week after the heads emerged; when mowing occurred later, viable seeds were produced.

Summary interpretation

This study also supports the 1940 Daubenmire research that indicates that if cheatgrass seed production can be prevented for two years by spring grazing, then the cheatgrass in that region will be under control if not completely eliminated. Proper timing in relation to growth stages of cheatgrass—not calendar dates—is crucial for prescribed grazing to have the desired outcome.

Finney, M., 2001. Design of regular landscape fuel treatment patterns for modifying fire growth and behavior. *Forest Science* 47(2): 219-228.

Literature category: Model-based research
Specific topic: Fire effects
Reviewed by: Eva Strand

Introduction

This model-based research intends to evaluate effects of disconnected fuel treatments and treatment patterns on the spread of fire. Strategies for landscape level fuel management are to contain fires and to alter fire behavior. The specific goal of this research was to find a treatment pattern that minimized fire spread rate with a minimum area treated. Optimizing fuel treatment area and patterns to minimize fire spread is important because of limited funds for fuel treatments.

Summary

Forest landscapes with a variety of fuel treatments and fuel treatment patterns were modeled in the fire spread simulation software Farsite. The size and shape of fuel treatments (W and L in Figure 1) were varied as well as the distance and overlap between treatments (O and S in Figure 1). Topography, fuel moisture and weather were held constant during the simulations and spotting of fire was not incorporated.

Relevant findings

The dimensions of the treatment blocks (W and L in Figure 1) and the distance between blocks (O and S in Figure 1) are important for the effects on fire spread.

Fire weather will affect the effectiveness of different treatment patterns in reducing fire spread. Ideally, the fuel treatment pattern should target fires burning under certain weather and fuel conditions.

Simulated fire spread in treated areas was reduced to 41-49% of the spread in the untreated area (Figure 2). The fire spread rate in the dark (treated) areas in Figure 2 are 10% of the spread in untreated areas.

Summary interpretation

Fuel treatments can contain fires and alter fire behavior and spread. The size and shape of treatments as well as the distance and overlap between treatments are important considerations to make when planning fuel treatments. Fire weather and fuel conditions will affect the effectiveness of the treatments on fire spread.

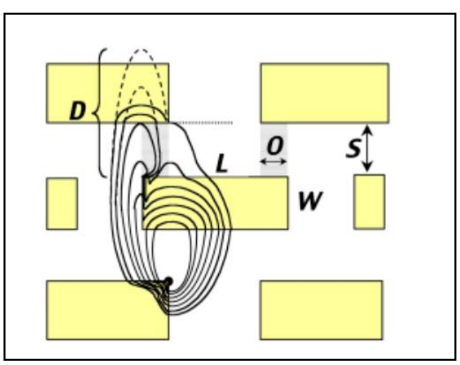
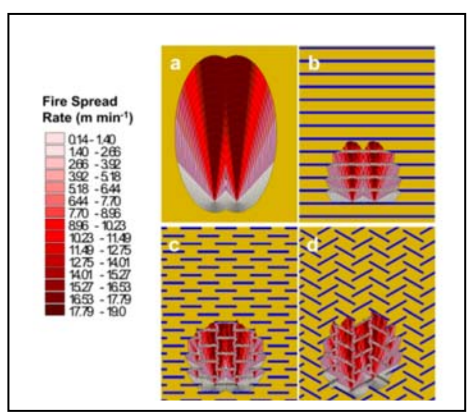


Figure 1 left

Figure 2 right



Fleischner, T.L. 1994. Ecological costs of livestock grazing in western North America. *Conservation Biology* 8: 629-644.

Literature category: Professional resource knowledge
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

The effects of livestock grazing on several different ecosystem components were catalogued in this paper.

Summary

The author discounted the "herbivore optimization" and "overcompensation" theories purported by many. Taking issues with the argument that livestock simply replace native bison, the prevalence and role of these herbivores within the region was questioned. The author suggested that these theories have little validity in arid rangelands of the West where the landscape is characterized by caespitose bunchgrasses and a prevalence of microbiotic soil crusts.

Relevant findings

Livestock can alter plant communities by actively selecting for a particular species. Also, due to individual plant vulnerability, plants may be affected by grazing differently. With regards to cheatgrass (*Bromus tectorum*), the author added that livestock may, through disturbance, open niches for cheatgrass to propagate. Furthermore, livestock may eat native species that could potentially out-compete cheatgrass. Livestock have also been implicated in the spread of noxious seed in fur and dung.

Summary interpretation

Livestock grazing may promote the continued spread of cheatgrass. In addition to carrying weed seeds in fur and dung, livestock disturb areas, thereby making them more susceptible to invasion by noxious weeds. Livestock may also eat natural competitors of cheatgrass. Impacts are more severe in arid and semiarid climates such as those found in the West.

Frischknecht, N. C., and A. T. Bleak. 1957. Encroachment of big sagebrush on seeded range in northeastern Nevada. *Journal of Range Management* 10: 165-170.

Literature category: Documented case study
Specific topic: Grazing effects
Reviewed by: Andréa Kuchy

Introduction

A survey of an 825 acre grazed crested wheatgrass (*Agropyron cristatum*) planting in Nevada was conducted. Slightly more than one-fifth of the present total big sagebrush (*Artemisia tridentata*) plants established after the grass became established in the survey, one decade after treatment.

Summary

This study attempted to answer how long crested wheatgrass will persist under grazing, and to what extent it can prevent sagebrush and other undesirable species from re-establishing. Four main brush-removal and seeding treatments were applied to the area. Young grass and brush grew undisturbed by livestock for the first year and up to the fall of the second growing season, when light grazing by cattle was permitted.

Relevant findings

Sagebrush less than 3 years of age were 20 times as numerous as plants 3 to 7 years of age, with the youngest plants localized on plots where grazing use had been consistently heavy, indicating that brush invasion had accelerated.

Sagebrush plants of the 8-l0 year age class tended to stabilize at a constant number, between 4 and 5 plants per 100 square feet.

Recent rapid sagebrush establishment was related to heavy use of crested wheatgrass, and the seedling plants occurred on only 15.6 percent of the plots, primarily in pastures where use had been heaviest.

The area plowed in late fall contained more sagebrush plants that emerged shortly after treatment than the area plowed the previous summer (before seed maturity) or the following spring.

Summary interpretation

Sagebrush will re-establish on a site more quickly following grazing treatments.

Fuhlendorf, S.D., D.D. Briske, and F.E. Smeins. 2001. Herbaceous vegetation change in variable rangeland environments: the relative contribution of grazing and climatic variability. *Applied Vegetation Science* 4: 177-188.

Literature category: Experimental research
Specific topic: Other: Grazing and climatic fluctuations interactions on rangelands
Reviewed by: Bruce H. Brockett

Introduction

A 44-year record of herbaceous change in a semi-arid savanna was analyzed for three contrasting grazing regimes to evaluate the relative contribution of confined livestock grazing and climatic variability, as agents of vegetation change. Some researchers asserted that grazing is the primary agent of change, whilst others placed strong emphasis on climatic variation. This paper investigated the relative impact of these two agents of ecological change.

Summary

The study area was located at the Texas A&M University Agricultural Research Station. The vegetation was a savanna/parkland (woody cover as high as 40%), with varied topography and fire history. The area used for the experiment was previously heavily grazed, and stocked at three stocking rates: (1) ungrazed, (2) moderate, and (3) heavy. In 1948 three transect lines (ungrazed, moderate and heavy) were established with measurements of: (1) plant density and (2) diameter at the soil surface for each rooted perennial plant measured annually from 1949-1965 within a quadrat, and then converted to a circular area for each plant. From 1965-1993, sampling intervals were sporadic and treatment units were not evaluated during each sampling period. Perennial grass responses were analyzed as short-grass and mid-grass response groups to simplify vegetation responses. Some of the outputs were the change in: (1) basal area/plant, (2) total basal area/m^2, and (3) total density/m^2, from 1949-1993.

Relevant findings

- Grazing and climatic variability are both important agents of change in herbaceous vegetation.
- Grazing intensity had a significant, directional effect on the relative composition of short and mid-grass response groups.
- Interannual precipitation was not significantly correlated with response groups.
- Interannual precipitation was significantly correlated with total plant basal area, while time since the commencement of the grazing regime was not.
- Response groups did not show distinct group composition, or plant density responses to grazing intensity and climatic variability.
- Grazing and climatic variability are important agents of vegetation change in semi-arid systems, but appeared to operate on distinct temporal scales.

Summary interpretation

Climatic fluctuations superimpose fluctuations on an otherwise directional change following episodic climatic fluctuations (e.g. extreme droughts or frost events). Episodic climatic events induce short-term fluctuations on directional patterns established by grazing.

Fuhlendorf, S.D. and D.M. Engle. 2001. Restoring heterogeneity on rangelands: ecosystem management based on evolutionary grazing patterns. *BioScience* 51:625-632.

Literature category: Professional resource knowledge
Specific topic: Targeted grazing/historic role
Reviewed by: Shannon Hatch

Introduction

This paper suggested that new paradigms of rangeland management are needed in order to increase landscape heterogeneity. The authors suggested that increased biodiversity could result from grazing done in a fashion mimicking pre-European patterns. Fire's critical role in changing landscape heterogeneity, in conjunction with grazing, was discussed.

Summary

While this study focused primarily on the Great Plains region of the United States, an area well adapted to the combined effects of herbivory and fire, the authors concluded that changes in grazing regimes, in combination with prescribed fire, could help promote rangeland heterogeneity. The authors questioned traditional rangeland management practices, which tend to force homogeneity by focusing on the increase of biomass of palatable forage species for cattle. The authors suggested a new rangeland management paradigm, which emphasizes the creation of more heterogeneous patches across the landscape. The interaction of fire and grazing was found capable of producing a dynamic patch mosaic of plant communities. The authors proposed the use of burned focal patches as a means of implementing a shifting mosaic of plant structure and function in response to fire.

Relevant findings

Continuous moderate grazing results in areas where little of previous year's biomass accumulation is being targeted by livestock. Small, heavily grazed patches become interspersed within ungrazed or lightly grazed patches.

Uniform livestock distribution across the landscape has been the goal of many rangeland managers. These traditional approaches reduce vegetation heterogeneity as they favor the uniform production of vegetation palatable to cattle.

Landscape heterogeneity, promoting an increased biodiversity, can be achieved if grazing is done in a fashion that mimics historical grazing patterns and regimes.

The interaction of fire and grazing can produce a dynamic patch mosaic of plant communities.

Summary interpretation

Targeted grazing could be designed to achieve a more heterogeneous landscape. Increases in biodiversity, resulting from changed grazing regimes, may help to ameliorate problems caused by annual grass invasions.

Harris, G.A. 1967. Some competitive relationships between *Agropyron spicatum* and *Bromus tectorum*. *Ecological Monographs* 37(2): 89-111.

Literature category: Experimental research
Specific topic: Cheatgrass/grazing interactions
Reviewed by: Bruce H. Brockett

Introduction

Cheatgrass (*Bromus tectorum*) has invaded, and dominated several million acres, which were previously dominated by bluebunch wheatgrass (*Agropyron spicatum*). Ecological relationships between bluebunch wheatgrass and cheatgrass have been described previously but based on people's opinions rather than on formal research. Cheatgrass shows considerable plasticity in its responses to site variation and its yield can vary as much as 1000%.

Summary

Field studies were conducted at two locations, and in addition in a laboratory. Competition, rooting depth, and soil moisture relationships were studied using 20-acres of bluebunch wheatgrass seedlings in Washington, while root growth studies were conducted in a nursery site in Pullman, Washington.

	Agropyron spicatum	*Bromus tectorum*
Classification	Perennial	Annual with considerable plasticity. Under most conditions it is a winter annual, but in the field the plant has been observed to persist through two winters (and the intervening summer).
Plant growth	Leaf growth on mature plants begins in September or October when increased soil moisture and cool temperatures coincide. Leaves grow only slightly during winter (may be 12-15 cm in height when spring snow melts).	Cheatgrass leaves grow little in the fall (mean 2-4 cm tall when snow covered).
Boot stage	Early June	Early spring, March-May
Reproductive stage	Ends in summer dormancy in mid-July	Once growth begins the reproductive cycle is completed rapidly. Plant dies usually by late May.On droughty sterile soils bears one spikelet on dense monospecific stand. Where soil moisture, fertility or light intensity are not limiting individual plants

Grazing	Sensitive to grazing during the reproductive phases	Only reaches grazing height for cattle in spring 2-3 weeks later than associated perennial grasses
Yield		Yield varies by 1,000% from year-to-year (Hull 1949). Yields in normal years are normally comparable to, or in excess of perennial grass yields on similar sites.
Nutritive value, curing and fire hazard		After maturity cheatgrass forage becomes unpalatable and low in nutritive value, and presents a fire hazard. Once cured the sharp-callused seeds could cause blindness and lumpy jaw (actinomycosis) in grazing animals due to puncture wounds.
Seeds	Seeds mature midsummer, and shatters progressively over a period of several weeks after that date.	Seeds mature in late spring, or early summer, falls to the ground and germinates with cool, wet weather and short days (fall rain).
Seedling survival	Seedling survival inversely related to cheatgrass density: highest on sparse cheatgrass sites (86%). Leaf heights exhibited an inverse relationship with cheatgrass density	Cheatgrass exhibited a direct relationship with increasing density of cheatgrass.

Relevant findings

Cheatgrass does not compete strongly with seedlings of bluebunch wheatgrass. At moderately low temperatures and in moderately moist soil (fall weather), *cheatgrass* has a small advantage over bluebunch wheatgrass in the rate of germination. Early germination provides a competitive advantage.

Harrison S., B.D. Inouye, and H.D. Safford. 2003. Ecological heterogeneity in the effects of grazing and fire on grassland diversity. *Conservation Biology* 17:837-845.

Literature category: Documented case study
Specific topic: Grazing effects on fire
Reviewed by: Eva Strand

Introduction

The purpose of this study is to evaluate how landscape-level heterogeneity (i.e. soil attributes) may contribute to the variable effects of fire and grazing on native and exotic species richness in a small Natural Reserve in northern California. This landscape is characterized by oak and chaparral.

Summary

The study was conducted in an area where the mosaic of serpentine and nonserpentine soils created natural landscape heterogeneity. Serpentine soils act as refuges for many native species as these soils are poor in calcium and other nutrients and contain various metals and therefore resistant to invasive species. Serpentine soils contained more native species than nonserpentine soils in the study area. Species composition was measured on serpentine and nonserpentine soils where about half the plots had been excluded from grazing since 1985. Measurements were made before and after a fire in the fall of 1999. The article was focused on three hypotheses: 1) Fire and grazing will affect species composition more on nonserpentine soils because of the higher productivity. 2) Fire and grazing will affect the species composition differently on the two soil types. 3) The results are dependent on the spatial scale of the measurments.

Relevant findings

Native and exotic species richness was affected by soil, fire, and year. On serpentine soils (nutrient poor) native species richness was higher on grazed sites while native species richness was lower on grazed compared to ungrazed nonserpentine sites. Both native and exotic species richness increased after the fire. On nonserpentine soils the exotics accounted for most of the increase in richness. The authors postulate that species may react differently to a disturbance depending on the site condition and potential (soil type) and that a disturbance tends to increase the alien invasion in areas that are already invaded.

Summary interpretation

Site potential, here exemplified by soil type, is important in the results of a disturbance on native and exotic species richness. In this case study the native species richness increased with disturbance (fire or grazing) for the serpentine soils (poor in nutrients) while the exotic species richness increased with disturbance on the nonserpentine soils. The initial condition on these sites (more natives on the serpentine soils) likely played an important role for the case study. The site potential, legacy, and current condition should be carefully considered before the application of a fire or grazing disturbance.

Havstad, K.M. 1994. Sheep grazing as a range improvement tool. *Sheep Research Journal (Special Issue)*:72-78.

Literature category: Scientific Synthesis
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this synthesis was to describe how sheep grazing can be used to improve rangelands and manipulate vegetation composition. It also included an overview of the ecological functionality of herbivores on rangelands.

Summary

Grazing is a natural and integral part of range systems that includes a broad variety of herbivorous species such as nematodes, grasshoppers, jackrabbits, and ungulates, but unmanaged grazing can result in severe ecosystem alteration and nonnative species invasion.

Relevant findings

Sheep have successfully been used during reseeding efforts to trample seeds into moist ground to desired depths.

Summary interpretation

Sheep can help accomplish two goals in relation to the suppression of cheatgrass *(Bromus tectorum)*: 1) reduced seed production and reduced cheatgrass densities, 2) reseeding of managed areas with desired species.

Heyerdahl E.K., R.F. Miller, R.A. and Parsons. 2006. History of fire and Douglas-fir establishment in a savanna and sagebrush-grassland mosaic, southwestern Montana, USA. *Forest Ecology and Management* 230: 107-118.

Literature category: Experimental research
Specific topic: Grazing/fuels
Reviewed by: Bruce H. Brockett

Introduction

Over the past century woody plant encroachment (trees into grass and shrublands) has taken place across western North America, and this includes Douglas-fir trees (*Pseudotsuga menziesii* var. *glauca*), expanding into mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*). The objectives were to quantify the relative area covered by mountain big sagebrush and Douglas-fir. Woody plant encroachment has been ascribed to factors that include combination of change in the fire regime, domestic grazing (directly and through it influence on fire), and climate.

Summary

The study area was located north of the Big Hole River near Wise River, Montana. From the mid-1850's land use changed dramatically in this region. The survey design was repeated systematic sampling (50 variable-radius plots 500 m apart and covering 1030 ha). Roads, streams, rock outcrops and the boundaries between vegetation types were avoided by placing the center of 15 plots 36 m along a randomly chosen azimuth.

Fire history was reconstructed by sampling 83 fire-scarred trees within and between plots. In addition to fire scars some supporting evidence of surface fires was obtained. The history of tree establishment within each plot was estimated using an n-tree density-adapted sampling method. To identify the potential drivers of woody plant establishment in the study area a time series of tree establishment to fire size (reconstructed fire size for given year as the area of the smallest convex polygon, containing all the plots or trees with fire evidence (1700-2003), domestic livestock grazing (number of sheep and cattle in Montana (1867-2004). and climate (Palmer Drought Severity Index (PDSI) reconstructed from tree rings (1700-2003)). The authors modeled the effect of fire on the dynamics of Douglas-fire establishment and persistence in the study area using LANDSUM (Landscape Fire Succession Model) (Keane et al. 2002, 2004).

Possible reasons for woody plant encroachment:

1. The simulation model of Douglas-fir dynamics (with or without fire) provided support that fire was likely the driver of these dynamics. However, there were difficulties in parameterizing the simulation model at fine spatial scales and therefore the results should be regarded as relative, rather than quantitative. Prior to 1855 there was sufficient variation in fire frequency to limit Douglas-fir establishment, but not frequent enough to eliminate mountain big sagebrush. The authors suggest that fire in the past was important in creating heterogeneous landscapes in savannas, mountain big sagebrush and grasslands.

2. Domestic livestock grazing increased in the study area dramatically from the mid-1800's, with grazing reducing fine fuel loads and resulting (in other areas) in fire exclusion.

3. Decades of low summer precipitation (low PDSI from 1840-1870), could have been the second factor that encouraged Douglas-fir establishment in the study area in the mid-1800's. Mountain big sagebrush is

enhanced during dry-periods because of its deep roots, and over-wintering foliage and litter, which increases soil organic matter and thus water holding capacity. There was variation in Douglas-fir encroachment in the study area, which could have been related to the mosaic of soil moisture.

Relevant findings

Vegetation in the study area changed dramatically since 1855, with the previous vegetation likely consisting of a mosaic of sagebrush-grasslands with stable islands of Douglas-fir, while currently it is dominated by Douglas-fir forest.

Prior to 1855 there was sufficient variation in fire frequency and intensity to limit Douglas-fir establishment, but frequent enough to eliminate mountain big sagebrush.

The authors suggest that fire in the past was important in creating heterogeneous landscapes in savannas, mountain big sagebrush and grasslands.

Summary interpretation

Woody plant encroachment in Douglas-fir ecosystems is due to complex interactions between fire frequency and intensity, grazing, and climate.

Hobbs, R.J. and L.F. Huenneke. 1992. Disturbance, diversity, and invasion: implications for conservation. *Conservation Biology* 6:324-337.

Literature category: Scientific synthesis
Specific topic: Grazing/ fuels
Reviewed by: Shannon Hatch

Introduction

A number of disturbance factors, and their role in the promotion or acceleration of invasion by non-native species was discussed. The authors provided background on the definition and role of disturbance; fire, grazing, soil disturbances, nutrient inputs, trampling, and fragmentation were discussed.

Summary

While disturbance is a critical component of many systems, disturbance can also accelerate invasion by non-native plants. The authors discussed how different disturbance factors may be addressed by managers looking to re-incorporate disturbance into ecosystems susceptible to invasion by exotic species.

Relevant findings

While some argue that grazing is only a disturbance in ecosystems with little history of grazing. The authors suggest that disturbance should be defined as any significant change in grazing regimes. Just as overgrazing or the introduction of grazing to a system unaccustomed to grazing is considered a disturbance, so too could the removal of grazing from an ecosystem with a long history of grazing be considered a disturbance.

In areas with a long history of grazing, species diversity if often increased by grazing; however, in areas such as the American Southwest, grazing has been linked to a decline in species diversity. Furthermore, many of these areas have changed from perennial grasslands to shrub-dominated desert shrub communities as a result of grazing.

Summary interpretation

The applicability of targeted grazing as an invasive species management tool may ultimately depend on the grazing history of a particular site. Likewise, post-fire recovery rates and grazing deferment plans must be site specific based on prior disturbance regimes.

Holechek, J.L. T.T. Baker, J.C. Boren, and D. Galt. 2006. Grazing impacts on rangeland vegetation: what we have learned. *Rangelands* 28(1):7-13.

Literature category: Synthesis paper
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

The intent of this paper was to provide, to the general public, a comparison of the literature regarding the effects of managed livestock grazing and grazing exclusion in the western United States. Semiarid and arid lands were given focus in this paper.

Summary

The authors examined several different studies in an attempt to elucidate trends in vegetation responses due to grazing or lack of grazing. Objectives varied for many of the studies examined, as did the scope of the projects. Many of the studies evaluated vegetation trends, while others examined productivity or drought response.

Relevant findings

After examining several different studies, the authors found that long-term managed grazing compared with grazing exclusion, reduced, on average, grass production by 13% and total vegetation production 4%.

Two long term studies examined indicated that managed grazing is sustainable in arid regions.

Two other studies indicated that grazing exclusion may result in vegetation stagnation. In absence of disturbance, decreaser grass production was found to be lower on chaparral rangeland in south-central Texas. Fewer desirable shrubs were found on desert shrub rangelands in Nevada.

Summary interpretation

Moderate grazing may beneficially impact vegetation response in arid and semi-arid regions. Vegetation stagnation may occur when grazing is excluded.

Hulbert, L.C. 1955. Ecological studies of *Bromus tectorum* and other annual brome grasses. *Ecological Monographs* 25: 181-213.

Literature category: Experimental research
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this research was to investigate various ecological and physiological processes governing the lifecycle of cheatgrass (*Bromus tectorum*). These studies were undertaken to provide scientific support data to guide cheatgrass management. The research included quantitative studies in native grasslands, studies on the effects of clipping cheatgrass, and studies on seed viability and seed dispersal.

Summary

Over 800 experimental plantings of cheatgrass were made between the Lewiston, Idaho Study Area and the Pullman, Washington Study Area and numerous field observations were made in Washington, Oregon, Idaho, and Montana. Observations and collected data were used to examine variations in phenology, morphology and winter hardiness; to examine cheatgrass growth and reproduction; and to determine the ecological role and occurrence of cheatgrass.

Relevant findings

- Cheatgrass that persisted in small stands with little disturbed native vegetation consisted of small plants and produced few seeds. Cheatgrass density and seed production was much greater in a similar area where native vegetation had been lightly disturbed by rodent excavation.
- Cheatgrass plants clipped at the dough stage when plants had achieved full size and were 1% purple resulted in death of all but one cheatgrass plant.
- Cheatgrass seeds were viable as soon as cheatgrass plants start to turn purple but some viable seeds were also found in plants that were still entirely green (just prior to the dough stage).
- Dense stands of cheatgrass matured earlier than sparse stands of cheatgrass.
- Cheatgrass seeds germinate as soon as conditions are favorable and seeds that do not germinate, yet remain viable for a year, are uncommon.

Summary interpretation

From this research we can conclude several important points: In mixed stands of native vegetation and cheatgrass that have experienced little disturbance, native vegetation still holds the competitive advantage and disturbance may be necessary to facilitate the spread of cheatgrass. If seed production of cheatgrass can be suppressed through grazing, it should only take a few years to deplete the cheatgrass seedbank since cheatgrass seeds do not tend to remain ungerminated, yet viable, for longer than one year. We can also see from the clipping studies that the timing of grazing in terms of the growth stage of cheatgrass is critical if seed production is to be suppressed.

Hull A.C. and J.F. Pechanec. 1947. Cheatgrass—A challenge to range research. *Journal of Forestry* (45):555-564.

Literature category: Scientific synthesis
Specific topic: Grazing effect on cheatgrass / fire and cheatgrass interactions
Reviewed by: Brianna Goehring

Introduction

The purpose of this paper was to examine the relationship between cheatgrass (*Bromus tectorum*) and grazing and cheatgrass and soil protection in southern Idaho.

Summary

This paper reviewed the occurrence of cheatgrass in southern Idaho and explored which conditions promoted or suppressed cheatgrass growth.

Relevant findings

- Cheatgrass production is especially high during wet years.
- Cheatgrass averaged over 150,000 seeds per pound, which calculated to a natural seeding rate of 478 pounds per acre.
- Cheatgrass yields were similar to crested wheatgrass (*Agropyron cristatum*) yields on southern Idaho locations from 1940-1946.
- Cheatgrass production fluctuated more in relation to weather than did perennial grasses.
- Mowing before seed was ripe resulted in Idaho ranges where cheatgrass was almost completely absent the following season but thick stands of Russian-thistle (*Salsola kali-tenuifolia*) took its place.
- Green cheatgrass forage was grazed by all classes of livestock in the spring.
- Cattle and sheep will graze dry cheatgrass forage throughout the winter but a protein supplement was often necessary to prevent loss of body condition.
- Overgrazing of cheatgrass decreased the number and height of cheatgrass plants.
- Residue from ungrazed cheatgrass forage created a fire hazard the following growing season.
- “Cheatgrass has undeniably increased the number of fires, produced larger and faster spreading fires, and extended the fire season by 1 to 2 months.”

Summary interpretation

This synthesis suggests that cheatgrass as a reliable source of forage depends upon rainfall received and the stocking rate of livestock used for that range. Although cheatgrass is not considered ideal rangeland, it must still be managed if it is to be used for forage production. If the goal is to reduce cheatgrass densities rather have a continual supply of cheatgrass forage, cheatgrass may be heavily grazed in order to reduce cheatgrass populations. We can also infer that grazing of cheatgrass reduces residue and thus reduces fire hazard.

Keeley, J.E. and T.W. McGinnis. 2007. Impact of prescribed fire and other factors on cheatgrass persistence in a Sierra Nevada ponderosa pine forest. International Journal of Wildland Fire 16:96-106.

Literature category: Experimental research
Specific topic: Cheatgrass / fire interaction
Reviewed by: Eva Strand

Introduction

The purpose of this research was to investigate how fire and other factors (canopy gap size, daily duration of sunlight, litter cover and depth, soil texture, nutrients, and pH) affect the persistence of cheatgrass (*Bromus tectorum*) in ponderosa pine (*Pinus ponderosa*) forests in Kings Canyon NP, California. The study was prompted by previous observations indicating an increase in cheatgrass cover after attempts to increase fire in the system to mimic historic fire regimes.

Summary

A field experiment was conducted where seventy 5x5 m plots were randomly assigned one of four treatments: 1) No burn, 2) Autumn 2001 burn, 3) Summer 2002 burn, and 4) autumn 2002 burn. Cheatgrass and cover of other species as well as fuel composition were recorded before and after treatments. The fire behavior (max temperature, total duration of elevated temperature, and fire line intensity) was monitored during the experiments.

Relevant findings

Cheatgrass cover or biomass did not vary significantly with fire treatment. The strongest predictor of post-fire cheatgrass cover was pre-fire cheatgrass cover, but only 12% of the variance was explained. Post-fire cheatgrass cover was affected positively by cheatgrass in the seed bank and negatively (weak relationship) by the fireline intensity.

Seed survival of cheatgrass was evaluated. Dry seed can endure temperatures of 110º C for 1 hour while moist seeds experienced much reduced germination at 80º C and no germination at 100º C. Under the experimental burning conditions 40% of the above ground cheatgrass seed was predicted to survive.

Summary interpretation

From this study we can conclude that a disturbance or action that reduces viable cheatgrass seed above ground or in the seed bank will reduce the risk for cheatgrass dominance in woodlands or shub steppe. High intensity fires are more likely to reduce viable cheatgrass seed than low intensity fires, however they will also likely negatively affect native shrub steppe species recovery and open up the landscape for annual plant invasion.

Keeley, J.E., D. Lubin, and C.J. Fotheringham. 2003. Fire and gazing impacts on plant diversity and alien plant invasions in the southern Sierra Nevada. *Ecological Applications* 13:1355-1374.

Literature category: Documented case study
Specific topic: Fire/cheatgrass interaction; Grazing affect on cheatgrass
Reviewed by: Eva Strand

Introduction

The effects of grazing and fire disturbance on native and exotic plant diversity was examined along an elevation gradient in the Sierra Nevada Range, California, a landscape dominated by blue oak savanna, chaparral, and coniferous forest.

Summary

Native and alien species diversity was sampled at multiple scales, from point to community diversity (1 – 1000 m^2), in areas with varying history with regards to grazing and fire. Soil samples at the sites were analyzed for pH, texture, and nutrients. The authors took advantage of the broad patterns of grazing history where National Park lands were ungrazed and adjacent public lands managed by the BLM were grazed. A digital fire history was available for the area and utilized in plot selection.

Relevant findings

Species richness decreased with increasing elevation at all scales, largely an effect of the increased number of alien species at lower elevation. Total herbaceous cover, exotic herbaceous cover and the number of exotic species decreased with increasing elevation. In the blue oak savanna the alien species richness and cover was 20-30% higher in grazed than in ungrazed areas (50-55% alien/native cover on grazed sites vs. 40% on ungrazed and 27-30 alien species richness on grazed sites vs. 20 on ungrazed). Ungrazed sites showed a positive relationship between native and alien species richness while this relationship was not significant for grazed sites. In chaparral, species richness was 2.5 times higher in third-year burns compared to first year burns, largely due to increased alien richness. There was a significant correlation between alien and native species richness in the conifer forest. Fire severity and time since fire significantly affected species diversity. An inverse relationship was found between post-fire tree canopy cover and alien species cover indicating that post-fire alien dominance is more likely after a severe burn. Unburned coniferous forest was largely free from exotic species.

Summary interpretation

In this study, plots with a legacy of grazing (i.e. BLM lands) had a marginally higher cover of alien species compared to ungrazed National Park lands (50-55% alien/native cover on grazed sites vs. 40% on ungrazed), hence we can conclude that grazing may act as a vector for spread of invasive species. Alien species cover was higher after a recent fire than on unburned lands and also higher on lands that burned under high severity conditions compared to low severity. High alien species richness and high native species richness are positively correlated in portions of the elevation gradient studied and on the ungrazed National Park lands. This research result is contradictory to previous beliefs that areas of high native species richness are more resistant to alien invasion and rather suggest that environmental conditions in these areas are such that they support many species (regardless of whether they are native or exotic).

Kerby, J.D., S.D. Fuhlendorf, and D.M. Engle. 2006. Landscape heterogeneity and fire behavior: scale-dependent feedback between fire and grazing processes, *Landscape Ecology* 22:507-516.

Literature category: Model-based research
Specific topic: Grazing effects on fire
Reviewed by: Eva Strand

Introduction

The purpose of this study was to examine the importance of fuel heterogeneity on the relationship between fire spread, behavior and spatial scale. Modeled landscapes of different fuel patches and grain size were assessed using single-point fire ignitions in a cellular modeling procedure in a tallgrass prairie ecosystem.

Summary

Fire spread simulations were performed in the FARSITE software on four different landscapes of different grain size varying from 2.25-144 ha but all with the same mean landscape fuel load. Fuel loads ranging from 458-7171 kg/ha were randomly assigned to landscape patches, simulating variations in grazing pressure. Weather conditions and topography were held constant for all scenarios.

Relevant findings

Simulations showed that heterogeneous landscapes with smaller grain size experienced smaller burned areas compared to landscapes of large patch size at the same total fuel load. The simulated burned area increased significantly when the fuel load was high in the ignition cell. The shape complexity of the total burned area increased with decreasing grain size and with increasing fuel load at the ignition point. The proportion of fire type (backfire, flankfire, headfire) was not significantly affected by patch grain.

Summary interpretation

Disturbances that affect the heterogeneity of fuel loads, grazing for example, affect the total area burned and the complexity of the perimeter in a fire. Fires are smaller and have more complex shapes in heterogeneous landscapes. Grazing could possibly be used to create heterogeneity in sagebrush steppe landscapes and thereby decrease the risk of large fires.

Klemmendson, J.O. and J.G. Smith. 1964. Cheatgrass (*Bromus tectorum* L.). *Botanical Review* 30:226-258.

Literature category: Scientific synthesis
Specific topic: Grazing fuels/fire/historic role; cheatgrass/fire interaction
Reviewed by: Andrea Stebleton

Introduction

This paper reviews the literature on cheatgrass (*Bromus tectorum*). This review was the beginning of a cooperative research programs to facilitate management of cheatgrass in southern Idaho, lead by the Intermountain Forest and Range Experiment station and the Bureau of Land Management.

Summary

This review addresses the current literature knowledge pre-1959. Topics discussed included: history and occurrence of cheatgrass in the US, description and growth habit, habitat, phenology, viability, germination, dispersal and longevity of seed, root system, ecological role, grazing value, soil-plant relations, smut and other disease, and control opportunities.

Relevant findings

- Cheatgrass was introduced to the US from Europe in the middle of the nineteenth century.
- Cheatgrass is a prolific seed producer depending on the individual plant vigor. There is an average of 150,000 seeds per pound.
- During a year with late spring rain, a second crop of cheatgrass has been observed following the first crop's senescence.
- Small amounts of cheatgrass can persist in competition with intact native vegetation.
- Cheatgrass doesn't readily invade native perennial vegetation unless some disturbance, grazing, fire or drought, offers it the opportunity.
- Cheatgrass is highly palatable and can be nearly eliminated by uniformly heavy spring grazing. However, grazing intensity must be maintained to prevent cheatgrass from quickly dominating the area.
- Due to cheatgrass' high risk of ignition, it permits fires to start and spread very quickly.
- Cheatgrass dries up earlier and much quicker and completely than perennials creating a higher fire risk.
- The amount of time cheatgrass remains green and it palatability ultimately depends on the amount of soil moisture. It responded quicker to precipitation during a drought that perennials.
- Cheatgrass seeds failed to germinate following exposures to 150 degrees C for 5 minutes; it is much more heat tolerant than perennial grasses.
- Cheatgrass is most easily controlled by seeding to adapted perennial grasses after sufficient seedbed preparation. The most successful treatment was plowing with a moldboard plow, completely burying cheatgrass seed to a depth where germination is inhibited.

Summary interpretation
Various characteristics allow cheatgrass to successfully compete with perennial grasses including: adaptability to disturbed sites, early germination, resistance to grazing, positive response to fire, ability to sequester moisture and other nutrients, high seed production and seed viability for up to a year. These characteristics can be mitigated by using fire, grazing, seeding, and chemicals, however a working knowledge of cheatgrass ecophysiology and ecology is required to successfully implement these management strategies.

Knapp, P.A. and P.T. Soule. 1996. Vegetation change and the role of atmospheric CO_2 enrichment on a relict site in Central Oregon: 1960-1994. Annals of the Association of American Geographers 86(3): 387-411.

Literature category: Experimental research
Specific topic: Climate change and woody plant increase
Reviewed by: Bruce H. Brockett

Introduction

Carbon dioxide enrichment was explored as a possible reason for the increase in woody plant cover at a site in Oregon. Relationships between vegetation change over 34 years and the agreement of these changes with expected changes in plant growth, possibly attributed to increased CO_2, was explored. The study area was located at Island Research Natural Area (IRNA) in central Oregon. The IRNA contains two distinct vegetation associations: (1) western juniper/big sagebrush/bluebunch wheatgrass association, and (2) the western juniper/antelope bitterbrush/bluebunch wheatgrass association. Soils on the juniper/sagebrush/wheatgrass association are brown loams, with sandy loams on the juniper/bitterbrush/wheatgrass association.

Summary

Discoll (1962; 1964) collected data for five vegetation components: (1) species foliar cover, (2) basal area and total foliage cover of perennial herbs, (3) foliage cover of shrubby and suffruscent species, (4) maximum average height of mature shrubby and suffruscent species, and (5) densities of shrubby and suffruscent species. The authors of the paper used identical techniques to replicate the Discoll's survey (with the exception of the juniper survey).

Relevance of findings

Vegetation change over 34 years was characterized by increases in woody species cover, modest changes in perennial grasses cover, with reductions in annual grass cover. Western juniper cover more than doubled from 1961 to 1994. Comparisons of aerial photographs taken in 1961, 1979, 1985, and 1994 showed the rate of increase to be greatest between 1961 and 1979, slowing but still increasing thereafter. Authors suggested that their results are in agreement with proposed CO_2 theories. There was a decrease in cheatgrass cover, which was inconsistent with the expected changes due to CO_2 enrichment. This was attributed to climatic variability resulting in pulses of germination and recruitment. The increase in sagebrush and juniper was probably linked to an increase in CO_2 however further research is needed to test this hypothesis.

Summary interpretation

Changes in woody cover and density (possibly due to increased CO_2) in sagebrush-steppe and juniper woodlands of the West would affect: (1) fire regimes, (2) range productivity, and (3) watershed dynamics.

Knick, S.T., and J.T. Rotenberry. 1997. Landscape characteristics of disturbed shrub steppe habitats in southwestern Idaho (USA). Landscape Ecology 12:287-297.

Literature category: Documented case study
Specific topic: Cheatgrass / fire interaction
Reviewed by: Eva Strand

Introduction

Five zones of sagebrush (*Artemisia* spp.) steppe habitats in a 290,000 ha region around the Snake River Birds of Pray National Conservation Area, Idaho, were compared with respect to patch size distribution of shrub habitat, cheatgrass (*Bromus tectorum*) presence, fractal dimension of shrub patches, and a measure of patchiness.

Summary

The five zones analyzed were: 1) Wildfire, 2) Wildfire Ordnance, 3) Wildfire Military Training, 4) Agriculture-Wildfire, and 5) Wildfire-Agriculture. Prior to the 1930's the entire shrubland dominated area was grazed heavily throughout the year. Numerous fires in 1980-1988 converted approximately half of the native shrub community to grasslands dominated by cheatgrass and other annuals. The fire frequency decreased from > 75 years to 5-10 years. The patch size distribution and arrangement was determined from Landsat imagery classified into shrubland and grassland with an 80% thematic accuracy.

Relevant findings

The presence of cheatgrass was positively correlated to landscape patchiness and negatively correlated to the number of shrub cells (counted on Landsat imagery). The authors found a synergistic effect between the fragmentation of the shrub steppe caused by fire disturbance and the invasion and subsequent dominance of exotic annuals. Areas containing a higher proportion of perimeter between shrub and grasslands or having smaller shrub patches were more likely to contain cheatgrass. Recovery of sagebrush steppe after a disturbance is dependent on the sagebrush seed dispersal, which is largely wind driven. Natural shrub re-seeding will therefore likely be slow in large shrub-free grassland patches.

Summary interpretation

Dominance of annual plants is more likely to occur in fragmented shrub steppe landscapes than in large continuous areas of sagebrush. The annual plants invade patches of native shrub steppe at the shrubland/annual grassland interface and the invasion is therefore highly affected by the shrub steppe patch size distribution and spatial arrangement. Disturbances affecting the shrub steppe patch mosaic therefore indirectly affect the susceptibility to annual plant invasion.

Laycock, W.A.1967. How heavy grazing and protection affect sagebrush-grass ranges. *Journal of Range Management* 20:206-213.

Literature category: Experimental research
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this research was to determine the effects of spring and fall grazing on sagebrush-grass range with an emphasis on the impact on threetip sagebrush (*Artemisia tripartite*) on the Upper Snake River plains of southeastern Idaho.

Summary

Two 80-acre native-range pastures were heavily grazed by sheep in either the fall or in both the spring and the fall from 1924 through 1949. In 1950 a 10-acre exclosure was separated from the spring/fall grazed pasture so that recovery could be compared with that of a 1941 exclosure in the fall grazed pasture. In 1950-51 both main pastures were split to incorporate new treatments of fall only and spring only use in each. Observations of different impacts at all sites were recorded throughout the study.

Relevant findings

- Heavy spring grazing increased sagebrush and cheatgrass (*Bromus tectorum*) and decreased perennial grasses and forbs.
- The decrease in perennial grasses and forbs may have occurred because these species were being grazed during their active stage of growth.
- Heavy late fall grazing decreased sagebrush and increased perennial grasses and forbs.

Summary interpretation

This study's results suggest that grazing mixed perennial/cheatgrass range in the spring will result in an increase in cheatgrass because the perennial species experience more of a competitive disadvantage from defoliation than does the cheatgrass. The effects of spring grazing on cheatgrass and perennial grasses is likely very sensitive to the timing of grazing in relation to the phenology of the annual and perennial grasses. Fall grazing may prevent perennial grasses from experiencing that competitive disadvantage that allows cheatgrass to increase.

Lesica, P., S. V. Cooper, and G. Kudray. 2007. Recovery of big sagebrush following fire in southwest Montana. *Rangeland Ecology and Management* 60:261-269.

Literature category: Documented case study
Specific topic: Post-fire effects
Reviewed by: Andréa Kuchy

Introduction

This study investigated how vegetation changes with time as succession proceeds from immediate post-fire to mature stands. In southwest Montana, 38 sites, each 20 X 50 m, were sampled. The sites dominated by 3 subspecies of big sagebrush (*Artemisia tridentata* Nutt.), and post-fire recovery was investigated.

Summary

Sampling occurred on 38 randomly selected sites dominated by one of three subspecies of big sagebrush: mountain (ssp. *vaseyana*), basin (ssp. *tridentata*), or Wyoming (ssp. *wyomingensis*) below 2450 m in elevation in June and July of 2003 and 2004. Canopy cover of sagebrush was estimated using the line intercept method, and divided into four size classes. Age was estimated by counting annual growth rings and soil samples were collected for analyses.

Relevant findings

- Near complete mortality of big sagebrush in recently burned stands were observed, and the speed with which it recolonized on burned sites depended on subspecies. Mountain big sagebrush recovered to pre-cover levels of canopy after 32 years while the recovery time was shorter for basin sagebrush and much longer for Wyoming sagebrush.
- < 2% recovery of Wyoming big sagebrush occurred after 23 years within the 6 stands, however it should be noted that 4 of the 6 stands had no sagebrush cover even after 17 years post-fire.
- There was no correlation between the rate of mountain big sagebrush canopy recovery and mean annual precipitation, heat load, or soil texture; a statistical model with all 3 abiotic variables explained less than 1% of the variation in recovery rate.
- Post-burn recruitment occurs more frequently at sites receiving greater precipitation.
- 50% of three-tip sagebrush plants in burned plots were recruited within the 4 years immediately following fire.
- No statistically significant differences were found in the rate of big sagebrush height or canopy cover recovery between prescribed fire treatment and wildfire occurrence.

Summary interpretation

Abiotic factors associated with faster recovery of mountain big sagebrush canopy cover were not identified, thus, these results should be viewed as site-specific. The distance to the nearest seed source and the severity of the fire may play important roles in sagebrush recovery, however these variables were not quantified.

Liedloff, A.C., M.B. Coughenour, J.A. Ludwig, and R. Dyer. 2001. Modeling the trade-off between fire and grazing in a tropical savanna landscape, northern Australia. *Environment International* 27: 173-180.

Literature category: Model-based research
Specific topic: Grazing and fire interactions
Reviewed by: Bruce H. Brockett

Introduction

Savannas are widespread in northern Australia and consequently their sustainable use is critical. In tropical savannas, fire and grazing influence their tree-grass character. Frequent fires open up the tree layer and change the grass layer from perennials to one dominated by annuals. Annual grasses in turn produce large fuel loads that perpetuate frequent hot fires. Grazing reduces fuel loads because livestock consume forage. The trade-off between fire and grazing was modeled uses a process based model (SAVANNA). The majority of the tropical savannas of Australia are used for cattle grazing.

Summary

This study combined the results of fire studies conducted in Victoria River District and Kakadu National Park, with a simulation model to understand the effects of fire and grazing on savannas. SAVANNA was used to simulate a range of fire regimes and grazing pressures at Kidman Springs. Forty-year simulations were run (1957-1996) using historical climate data. Two savanna types were simulated which represented the range of soil types and associated vegetation in the area. Two fire frequencies were used: every 2 and 5 years.

Relevant findings

With fire excluded, a gradual increase in tree and shrub cover occurred. Low intensity fires did not affect tree cover, while intensive fires reduced tree cover regardless of fire frequency. In the absence of fire, the model produced an increase in the proportion of large trees (> 10 m tall) and an increase in saplings (< 1.5 m tall). The model suggested that a savanna could support both grazing intensities while providing perennial grasses. Heavy grazing on red loam soils reduced the biomass of perennial grasses over the 40-year simulation to low levels. A rather surprising result was that moderate grazing on a savanna woodland produced greater annual grass biomass than either heavy grazing or no grazing. Intense fires reduced tree cover, while any fire, especially intense fires, heavily impacted shrubs. Savanna soil types responded differently to fire. Red loams soils were least resistant to fire, while the savanna grassland coped better with burning.

Summary interpretation

This paper raises a number of management implications, which require a trade-off between burning and grazing. If fires are required for reducing trees and shrubs in the savanna, then under a grazing system there may be insufficient fuel to yield sufficiently intense fires to be effective. The simulations show that sustainable savanna management is more complicated than simply selecting an appropriate fire regime and applying it.

Link, S.O., C.W. Keeler, R.W. Hill, and E. Hagen. 2006. *Bromus tectorum* cover mapping and fire risk. *International Journal of Wildland Fire* 15:113-119.

Literature category: Experimental research
Specific topic: Cheatgrass / fire interaction
Reviewed by: Andrea Stebleton

Introduction

The purpose of this research was to determine the relationship between fire ignition probability and the cover of cheatgrass (*Bromus tectorum)*, native perennial plants, litter and soil in Saddle Mountain National Wildlife Refuge in Grant County, Washington. The authors also compared the intensity of color band reflectance from aerial photography and cheatgrass cover to allow for fine resolution maps of cheatgrass cover. These relationships provided managers with tools that can be utilized for assessment of fuel reduction costs compared to the costs associated with differing degrees of fire risk associated with cheatgrass.

Summary

A field experiment was conducted where percent cover of vascular plant species, bare soil, soil cryptograms, litter and cheatgrass was determined in late August and early September 2002. 176 plots were used in the fire risk assessment and 226 plots were used in the comparison to color band reflectance. Fires were ignited on the upwind side of the plots with a cigarette lighter, and were determined a sustained fire if they grew to an area of 100 m^2. Aerial photographs were taken in late September 2002, photos were separated into red, green and blue bands, and the average color band intensity was associated with measured cover of cheatgrass in the plots.

Relevant findings

The fire ignition risk was 100% when the cover of cheatgrass was 45% or more; when cheatgrass cover was 12% or less, fire risk dropped to 46%.

When cover of native perennials, litter, and soil was near 31% the risk of ignition and sustainable fire was significantly reduced.

In regards to values reported, it is speculated that wind speeds greater than 5.7 km/h would increase fire risk, and fuel moistures greater than 7.5% would decrease fire risk.

Summary interpretation

From this study we can conclude that percent cover of cheatgrass has a large effect on the probability of ignition as well as the ability of fire to spread. Because percent cover of cheatgrass and fire risk are positively correlated, management strategies that reduced cheatgrass cover and promote native perennial growth will have reduced the fire risk for that area.

Loeser, M.R.R., T.D. Sisk, and T.E. Crews. 2007. Impact of grazing intensity during drought in an Arizona grassland. *Conservation Biology* 21(1):87-97.

Literature category: Experimental research
Specific topic: Grazing affect on cheatgrass; grazing affect on fuels
Reviewed by: Andrea Stebleton

Introduction

This paper analyzed the grazing intensity gradient over an 8-year controlled experiment with significant climatic variation in a high elevation, semi-arid grassland near Flagstaff, Arizona. The grazing intensity gradient represented cattle density, grazing intensities, and interannual climatic variation. This experiment was conducted to assess the conservation implications of alternative grazing practices.

Summary

Two areas of 320 ha, were selected for studying grazing intensities from 1997 – 2004. Each area consisted of three blocks in areas dominated by grassland vegetation and sparse trees. The three blocks consisted of three different treatments, high impact treatments, cattle removal, and moderate grazing impacts. Moderate grazing impacts served as the control since it was the most similar to the typical condition of the site. Enclosures in the high impact treatment for short-duration grazing simulated impacts on herbaceous vegetation. A modified Whittaker plot was used at the center of the 1-ha treatment areas to better determine heterogeneity within the plant community. The 1997 data was collected prior to the introduction of cattle on the moderate and high impact treatments. Cheatgrass (*Bromus tectorum*) occurrence was measured with frequency data between the different treatments. Plant cover was calculated as the average among all the 1-m^2 subplots.

Relevant findings

- Cheatgrass decreased in all treatments for the first 5 years of the study, and became nearly absent after the drought in 2002. Cheatgrass dominated in high impact grazing treatments (80% cover in the subplots) in 2003. It increased to 100% cover in 2004 in the high impact grazing treatments.
- Basal and foliar cover of cheatgrass in the high impact treatments was two times greater than in any other treatment.
- Grazing treatments effect on plant cover was dependent on fluctuations of precipitation.
- High impact grazing increased annual grass cover and decreased perennial forb cover. Perennial grasses and annual forb cover did not respond consistently.
- High impact grazing had little effect on native plant cover until the 6^{th} season when it interacted with early season drought which reduced its cover by half.
- Exotic plant cover was 13% higher in high impact treatments than in other treatments.
- Grazing was considered a dispersal mechanism for cheatgrass, however it can also spread to areas not subjected to grazing.
- Intermediate levels of grazing may inhibit cheatgrass colonization; this requires further research.

Summary interpretation

Grazing can be a useful tool for cheatgrass management, however it can also perpetuate cheatgrass invasion. Continuous monitoring of grazing intensity and its synergistic effects with interannual precipitation amounts can afford the most successful cheatgrass management.

Ludwig J.A., M.B. Coughenour, A.C. Liedloff, and R. Dyer. 2001. Modelling the resilience of Australian savanna systems to grazing impacts. *Environment International* 27:167-172.

Literature category: Model-based research
Specific topic: Grazing impacts of savanna systems
Reviewed by: Bruce H. Brockett

Introduction

Resilience is defined as the capacity of a system to endure the impacts of disturbance without changing to a different system. System resilience can take two forms: (1) a system may resist change, and (2) if a system does change it will recover quickly. Savanna grasses differ in resilience to disturbances. Grazing affects grass tussocks, which leads to a decline in vigor, and an increase in plant mortality. Measuring the change in perennial grasses away from cattle watering points should provide insights into how resistant savanna systems are to impacts around watering points.

Summary

The change in plant cover at distances from water for two soil types (savanna woodlands on red loams, and savanna grasslands on black clays) was evaluated. A process-based model SAVANNA was used to model rainfall and grass biomass. The model, which used a weekly time-step was run for 100 years. Two levels of animal stocking were applied: (1) moderate, and (2) heavy. Over a 100-year simulation, resistance to grazing was evaluated for a 50-year period from 1923-1973. Savanna woodlands on red-loams had low resistance to both moderate and heavy grazing. In contrast savanna grasslands on black-clays were very resistant to grazing pressure and showed little change in biomass over the 50-year period.

Relevant findings

This study indicates that savanna systems on calcareous red-clay loam soils need to be managed carefully if perennial grass biomass is to be maintained at high levels.

Summary interpretation

It is important to establish the resilience of a system. This paper provided a method to establish such a linkage and further provides a procedure for linking field work with model outputs.

Madany, M.H. and N.E. West. 1983. Livestock grazing-fire regime interactions within montane-forests of Zion National Park, Utah. *Ecology* 64:661-667.

Literature category: Documented case study
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

This study was undertaken to examine the relative importance of fire cessation and livestock grazing on grazed and ungrazed mesas in southern Utah. Ungrazed study sites were chosen due to their isolation from both grazing and fire.

Summary

The study sites were located in Zion National Park, Utah; the majority of the plots were located between 2070 and 2255 m. Ponderosa pine (*Pinus ponderosa*), Gambel oak (*Quercus gambelii*) dominated the area; however, Rocky Mountain juniper (*Juniperus scopulorum*), pinyon pine (*Pinus edulis*) and bigtooth maple (*Acer grandidentatum*) were also important community constituents. Plots were established on grazed and ungrazed mesas. In addition to gathering historical land use information for this area, the authors collected sapling, shrub, forb, and graminoid cover data. A fire history was constructed from cross sections taken from 111 fire scarred trees.

Relevant findings

Reductions in herbaceous coverage and increases in woody species growth were attributed to livestock grazing. While changes in vegetation structure resulted in decreased fire frequency on the grazed mesa, ungrazed mesas retained savanna like conditions despite the absence of frequent fire.

Heavy grazing may lead to an increase in gambel oak stem density; individual clones may be able to more readily establish when the grassy interspaces between oak mottes are disturbed.

Biotic factors most likely control ponderosa pine regeneration. The dense sod associated with perennial grasses is the main controlling factor of tree regeneration; however allelopatic interactions between grasses and ponderosa pine seedlings, and competition for limited soil moisture may also inhibit pine seed germination.

Summary interpretation

Grazing may help to accelerate functional and structural changes in ponderosa pine forests. As grazing depletes the herbaceous layer, it reduces fire frequency while simultaneously enabling pine seedling regeneration.

Mata-Gonzalez, R., R.G. Hunter, C.L. Coldren, T. McLendon, and M.W. Paschke. 2007. Modelling plant growth dynamics in sagebrush steppe communities affected by fire. *Journal of Arid Environments* 69:144-157.

Literature category: Model-based research
Specific topic: Cheatgrass / fire interaction
Reviewed by: Eva Strand

Introduction

Plant production in burned and unburned cheatgrass (*Bromus tectorum*) dominated sagebrush (*Artemisia* spp.) steppe at the US Army Yakima Training Center, Washington, USA, was modeled using the mechanistic model EDYS.

Summary

EDYS is a spatially explicit mechanistic simulation model for estimating plant production based on climate, soil characteristics, hydrology, plant ecophysiology, animal interactions, stressors, fire events, and management. EDYS was used to simulate plant production in sagebrush steppe communities dominated by cheatgrass. The model was parameterized with ecophysiological properties specific to the plants on the site and the environmental input parameters were estimated at the study site. Simulations were conducted over a 50-year period for burned and unburned scenarios. Four years of field data was used for model validation.

Relevant findings

Simulation results showed that cheatgrass dominated the steppe for 13-15 years where after rabbit brush (*Chrysothamnus nauseosus*) and perennial grasses began to dominate the sites. After 39 years into the simulation big sagebrush (*Artemisia tridentata*) and perennial grasses were the dominant species. On burned sites the simulations showed that cheatgrass dominance was prolonged by 4 years indicating that perennial species were more competitive than annuals in the absence of a disturbance. In all model outputs the cover of cheatgrass was highly variable between years. High variability in cheatgrass cover (by a factor of 10) has been observed and is attributed to variability in weather. A dry spring and low nitrogen content in the soil drastically reduces cheatgrass biomass production. This high variability was not observed for the perennial grasses indicating a higher resilience for these species compared to the annuals. The authors finally suggested that a weather stream where the spring is dry and the summer is wet would favor perennial grasses over cheatgrass.

Summary interpretation

Cheatgrass is competitive early in succession and can outcompete seedlings of native grasses with shallow root systems. Later in succession surviving slow growing native grasses begin to occupy deeper soils and will within 13-15 years outcompete cheatgrass in the absence of a fire. Cheatgrass cover is highly variable and dependent on precipitation and requires relatively high nitrogen content in the soil.

Melgoza, G., R.S. Nowak, and R.J. Tausch. 1990. Soil water exploitation after fire: competition between *Bromus tectorum* (cheatgrass) and two native species. *Oecologia* 83:7-13.

Literature category: Documented case study
Specific topic: Cheatgrass/fire interaction
Reviewed by: Andrea Stebleton

Introduction

The purpose of this research was to determine the patterns of soil water use post-fire in arid environments and to investigate the competitive relationship between cheatgrass (*Bromus tectorum*) and native plants based on productivity and water status of the perennial grasses in Bedell Flats, north of Reno, NV. This study tested how the competitive ability of cheatgrass contributed to its post-fire dominance.

Summary

A field experiment was conducted comparing competition following a fire for soil water and overall productivity between rabbitbrush (*Chrysothamnus viscidiflorus)* and Needle and Thread grass (*Stipa comata)*, to cheatgrass. 48 individuals, 32 from the recently burned area and 16 for an area that hadn't burned in over 12 years, were identified for each species and assessed during 1987 and 1988. Soil water was measured at the edge of the plant canopy and 0.5m away from the canopy edge with a neutron probe. Plant water potential was measured with a pressure chamber. Aboveground biomass was measured by destructive sampling at the end of the 1987 growing season.

Relevant findings

Post-fire competition between cheatgrass and adult perennial plants negatively affected productivity and water status of the perennial plants

Once cheatgrass established in open spaces around perennial native species, it was able to suppress their productivity and water status for extended periods of time. Cheatgrass dominance was also enhanced because of its greater grazing tolerance.

Cheatgrass' annual life-form as well as its ability to germinate readily over a wide range of moisture and temperature conditions, to quickly establish an extensive root system and to grow early in the spring, contribute to its successful colonization.

Summary interpretation

Once established, cheatgrass' invasibility potential following fire is facilitated by its ability to suppress native perennial growth and to sequester the available water. This contradicts the widely held belief that if native adult perennials exist on a site, it is less susceptible to invasion. This study brings up the importance of site condition as an indicator for potential invasion, not just the presence/absence of native species.

Menakis, J.P., D. Osborne, and M. Miller. 2003. Mapping the cheatgrass-caused departure from historical natural fire regimes in the Great Basin, USA. USDA Forest Service Proceedings RMRS-P-29. p. 281-288.

Literature category: Model-based research
Specific topic: Cheatgrass/fire interaction
Reviewed by: Andrea Stebleton

Introduction

This study evaluated the extent of change from historical fire regimes following the introduction of cheatgrass (*Bromus tectorum)* in the Great Basin. Using the Course Scale layers, Fire Regime Condition Class (FRCC), an assignment of FRCC 1 indicated that fire regimes are within their historical range for an area, while FRCC 3 indicate that fire regimes have been significantly altered from the historical range. This study provided the Department of the Interior an accurate perspective on the scale of restoration efforts required to convert areas of the Great Basin into healthy productive rangelands.

Summary

To map the effect of cheatgrass on the historical fire regimes, several map layers were integrated: a cheatgrass layer classified from 2000 satellite imagery by the National Science and Technology Center (NSTC), the Fire Regime Condition Classes map, Potential Natural Vegetation Groups and Current Cover Types version 2000 layers. From these maps, areas where cheatgrass occurred in FRCC layer classes FRCC 1 or FRCC 2, they were assigned a new FRCC 3; those areas of cheatgrass already in FRCC 3, stayed defined at FRCC 3.

Relevant findings

- Cheatgrass aggressively outcompetes native seedlings following fire, especially in semi-arid rangelands of the Interior West.
- Cheatgrass can not ecologically occur in high elevations or wet grasslands.
- Cheatgrass results in a significant increase in fire size and frequency, compared to native shrub/grass vegetation.
- Using fire regime condition class (FRCC) as a measure of departure from historic fire regimes, a shift from shrub/grass dominated ecosystem to one dominated by cheatgrass results in a shift from FRCC 1, fire regimes that are within their historical range, to FRCC 3, indicating that there is a significant departure from the historical fire regime and that the risk of losing key ecosystem components is high.
- After incorporating cheatgrass spatial data in the Course Scale FRCC map of the Great Basin, FRCC 3 increased by 11%.
- Most of the departure from historical fire regimes in rangelands and shrublands can be attributed to exotic species invasion resulting in changes in fire frequency and severity.

Summary interpretation

This study shows that managers in the Great Basin underestimated the extent of departure from the historical fire regime due to cheatgrass invasion. Cheatgrass causes such a large departure because it increases the fire frequency and event size. These areas may need high levels of restoration treatments, including chemical and/or mechanical treatments, prior to the use of fire to restore the historical fire regime within the Great Basin.

Miller, R.F. and L.L. Eddleman. 2001. Spatial and temporal changes of sage grouse habitat in the sagebrush biome. Oregon State University Agricultural Experiment Station. Technical Bulletin 151. 35p.

Literature category: Professional resource knowledge
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

This paper provided pertinent background on factors affecting sagebrush (*Artemisia tridentata*) spatial and temporal distribution. Sage grouse requirements were emphasized as were causes linked to declining habitat and population numbers.

Summary

Different sagebrush communities throughout the West were described; individual plant associations for each region were discussed. The effects of long and short term climatic change were explored as were the effects of disturbance factors.

Relevant findings

- Prior to European settlement, fires in sagebrush communities typically burned in a patchy fashion, leaving unburned islands.
- Sagebrush and grass were probably dominant with a strong perennial and forb component.
- Excessive livestock grazing by European settlers in the late 1800s caused major vegetative changes within as little as 10-15 years.
- Utah was settled in the 1840s while eastern Oregon and Nevada began to be populated by Europeans in the late 1860s. There were an estimated 26 million cattle and 20 million sheep grazing Western lands by the early 1900s.
- It was estimated that grazing capacity of Western lands had decreased 60-90 percent by the 1930s.
- Excessive grazing can lead to an increase in density and cover of shrubs and annual grasses and forbs; perennial species typically decline.
- Cheatgrass (*Bromus tectorum*) does not do as well in black sage (*Artemisia nova*) communities. It also does not readily establish in more mesic and cooler areas typified by mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) and low sagebrush (*Artemisia arbuscula*) (above 1500 m northern portion of the sagebrush biome and above 1600 m in the southern portion).
- Medusahead (*Taeniatherum caput-medusae*) is competitive at some low sagebrush sites below 1500 m.

Summary interpretation

Historically, grazing significantly altered rangeland structure and function. As a result, fire frequencies have been reduced; in some areas higher sagebrush density and cover of shrubs and annual plants has resulted.

Miller R.F. and J.A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. *Journal of Range Management* 52:550-559.

Literature category: Experimental research
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

The purpose of this research was to examine how coexisting changes in mean fire intervals, the introduction of livestock and favorable climatic changes affected the post-settlement expansion of juniper in the semiarid Intermountain West. While many scientists had purported the idea that these factors attributed to juniper expansion, few studies had been conducted to investigate the synchronous effects of reduced fire frequency, grazing, and climate.

Summary

Field studies were undertaken in a 5,000 ha watershed in south central Oregon. The study site was characterized by 2 main communities: mountain big sagebrush (*Artemisia tridentata* spp. *vaseyana*) with Idaho fescue (*Festuca idahoensis*) and low sagebrush (*A. arbuscula*) with sandberg bluegrass (*Poa sandbergii*). Elevation ranged from 1,450 to 1,875 m.

Tree ring data were used to determine pre-settlement climatic conditions. Tree coring of western juniper (*Juniperus occidentalis*) was conducted to determine juniper age distribution. As fire history is difficult to determine from juniper trees, fire history records and mean fire intervals were determined from ponderosa pine (*Pinus ponderosa*) stands located in the study area. In low sagebrush (*Artemisia arbuscula*) the death dates of fire killer juniper were use to determine fire events. Fire records coinciding with the introduction of livestock in to the areas and the dates of fire suppression were summarized.

Relevant findings

The authors found that post-settlement western juniper expansion was, in fact, associated with: an increase in domestic livestock, the reduction in fire frequency, and increased precipitation. Livestock have been implicated in juniper expansion for a number of reasons. Livestock reduce fine fuels, they can alter plant community structure, and they can reduce competition from herbaceous species. The authors found that only 5 small fire events occurred in the study area after the introduction of livestock. Increased sagebrush cover, resulting from grazing vegetation modification, may have provided safe sites for juniper establishment and sapling growth.

Summary interpretation

Historically, livestock reduced the availability of fine fuels for wildland fire. Fire probability was subsequently reduced. Grazing was also linked to an increase in sagebrush cover; safe sites may have aided in the establishment and growth of juniper saplings. Similar effects may be observed today given comparable grazing regimes and stocking rates.

Mosley, J.C. 1996. Prescribed sheep grazing to suppress cheatgrass: A review. *Sheep and Goat Journal* 12:74-81.

Literature category: Scientific synthesis
Specific topic: Grazing effect on cheatgrass, cheatgrass / fire interaction
Reviewed by: Brianna Goehring

Introduction

The purpose of this synthesis was to describe the strategy of using prescribed sheep grazing on cheatgrass range as a management tool. This review also included the related topics of sheep diet selection and performance on cheatgrass (*Bromus tectorum*), cheatgrass ecology, and cheatgrass-fire relationships.

Summary

Sheep grazing can not only suppress cheatgrass but can also reduce fine-fuel loads and disrupt fine-fuel continuity. Although sheep grazing is effective for controlling cheatgrass, complete eradication is not often a reasonable goal.

Relevant findings

The success of a prescribed grazing plan depends on "the manger's ability to control diet selection by the sheep."

Because sheep are easily managed via herding or fencing, the timing, frequency, intensity, and distribution of grazing can readily be controlled.

Cheatgrass should be grazed one week in the spring and then once more one to three weeks (when new inflorescences develop on plants) after the initial grazing.

Grazing must occur before the cheatgrass turns purple—timing is the most critical factor for the control of cheatgrass through grazing.

Summary interpretation

Through the numerous examples of scientific research that Mosley cites in this synthesis, we can infer that prescribed sheep grazing is definitely a plausible tool for the management of cheatgrass. A prescribed grazing plan will depend on the extent of the infestation. Areas of cheatgrass mixed with bunchgrasses need to be managed differently than areas of pure cheatgrass. Uniform grazing of cheatgrass will occur where these dense stands exist. Grazing of dry cheatgrass can be done to reduce mulch. Sagebrush cover can also be reduced through grazing in order to shift competitive advantages toward perennial grasses.

Murray, R.B. 1971. Grazing capacity, sheep gains: cheatgrass, bunchgrass ranges in southern Idaho. *Journal of Range Management* 24:407-410.

Literature category: Experimental research
Specific topic: Grazing effect on cheatgrass
Reviewed by: Brianna Goehring

Introduction

The purpose of this research was to compare the nutritive value and carrying capacity of bunchgrass range and cheatgrass range in the Snake River Plain of southern Idaho.

Summary

Twelve 5-acre pastures that consisted predominantly of either cheatgrass *(Bromus tectorum)* or perennial bunchgrass were heavily grazed by yearling sheep for three consecutive 2-week periods for four grazing seasons.

Relevant findings

For three of the four years, weight gains were not significantly different between sheep grazed on bunchgrass and sheep grazed on cheatgrass.

The remaining year saw a greater increase in gain from the cheatgrass.

Grazing capacity was slightly higher for bunchgrass range with slightly lower daily gains, while the reverse was true for cheatgrass.

Summary interpretation

This study shows that the animal-benefit from grazing cheatgrass is comparable to other more desirable perennial ranges.

Mutch, R.W. 1967. Cheatgrass coloration a key to flammability? *Journal of Range Management* 20(4): 259-260.

Literature category: Experimental research
Specific topic: Cheatgrass/fire interactions
Reviewed by: Bruce H. Brockett

Introduction

The objective was to study the curing rate of cheatgrass on four plots in western Montana, and northern Idaho. As cheatgrass cures it changes color from: green to purple, to straw color. The author proposed changes in coloration as an indicator of flammability because the colors were correlated with curing. Cheatgrass introduced into eastern North America from Europe about 1850, invading the west prior to the turn of the century. It was suggested that cheatgrass provides a flammability bridge between open grasslands and forests, and grows in the 6-22 inch precipitation zone which is characterized by severe fire weather.

Summary

Four stands in Western Montana and Northern Idaho were selected some of which were studied in both 1964 and 1965. Despite being located on diversified sites, they exhibited similar drying curves. When plant color was green then moisture content was > 100%, and when purple then moisture content ranged from 30-100%, and when straw colored then moisture < 30%.

Relevant findings

Plant coloration was consistent enough to use as an indicator of moisture content, and thereby as an indicator of the flammability of the grass. Curing rate from 100% to 30% (purple to straw) ranged from 8 – 23 days (average 14 days). Cheatgrass was not ignitable when in either the green or purple stages.

Summary findings

Because cheatgrass is an important and widespread grass management needs to cope with its extreme susceptibility to fire.

Nader G., Z. Henkin, E. Smith, R. Ingram, and N. Narvaez. 2007. Planned herbivory in the management of wildlife fuels. *Rangelands* 29:18-24.

Literature category: Scientific synthesis
Specific topic: Grazing effects on fire
Reviewed by: Eva Strand

Introduction

This paper presents techniques that have been explored to prevent the start and spread of wildfires on rangelands. Methods for fuels management are discussed; mechanized treatment, herbicides, prescribed fire, hand cutting, and prescribed grazing.

Summary

The authors compare the effectiveness and costs for different methods for fuels management in rangelands. Prescribed grazing is discussed in much detail, comparing effects of grazing animal species, stocking rates, season of grazing, animal condition, and desired outcome of the grazing treatment.

Relevant findings

- The objective of fuel reduction is to change the fire behavior by changing the fuel bed depth, fuel loading, vegetative cover, and ladder fuels such that the flame length never reaches four feet.
- Grazing is an appropriate tool when addressing small diameter fuels such as the 1-hour and 10-hour fuels. Grazing can impact these fuels by ingestion and trampling.
- Many factors affect the success of using grazing as fuels management: species of livestock, the animal's previous grazing experience, time of year in relation to plant physiology, stocking rate, grazing duration, plant secondary compounds, and animal physiological state.
- Grazing before seed set can change seed-bank dynamics.
- Repeated grazing of perennial species can deplete root carbohydrates and cause mortality that alters species composition.
- Each species of grazing animal has a unique utilization pattern. Cattle are effective in grass removal while sheep and goats are effective on forbs and browse.
- Lactating and young animals are not recommended for fire fuel control because in these situations the animals may be required to eat below their nutritional needs.

Summary interpretation

Livestock grazing can be used in a targeted manner to control fine fuels (1- and 10- hour fuels). Care must be taken to select the appropriate combination of animal species, animal condition, season, duration and intensity of grazing, to reach desired fuel management objectives.

Nelle, P. J., K. P. Reese, and J. W. Connelly. 2000. Long-term effects of fire on sage grouse habitat. *Journal of Range Management* 53:586-591.

Literature category: Documented case study
Specific topic: Effects of fire
Reviewed by: Andréa Kuchy

Introduction

This study documented the long–term (> 10 years) impact of fire on mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana)* grassland in the Upper Snake River Plain, Idaho. The study investigated the long–term impact of fire on sage grouse nesting and brood-rearing habitats.

Summary

In this study twenty different-aged burns resulting from wildfires and prescribed fires were sampled, from 1996 to 1997. Canopy coverage and height of vegetation, and relative abundance of invertebrates, were estimated at burned and unburned sites within burns. Approximately 20,000 sheep and 1,660 cattle graze the area each year from May/June to September/October. Each burn was sampled four times, twice in burned vegetation and twice in unburned vegetation.

Relevant findings

Mean sagebrush canopy cover 14 years post-burn was less than one-half compared to unburned vegetation, mean sagebrush height was 69% of unburned vegetation, and no significant difference in forb cover was detected among different-aged burns on the Upper Snake River Plain.

36 years was suggested as being sufficient time to recover for some areas, though not necessarily for areas heavily burned and/or having unfavorable post-burn climatic conditions. Fourteen years after burning, sagebrush had not returned to pre-burn conditions.

Sagebrush height was within the range used by nesting grouse by 6 to 14 years post-burn, but sagebrush canopy cover (only 8%) was insufficient for nesting.

Summary interpretation

Critical nesting and brood-rearing habitats could be seriously detrimental to a sage grouse population if vegetation over a large area remains in sub-optimal conditions for many years; burning to remove sagebrush on the Upper Snake River Plain is not justifiable as a sage grouse management practice because only unburned vegetation in the area offers suitable nesting habitat.

Peckanec, J.F. and A.C. Hull. 1945. Spring range lost through cheatgrass fires. *National Wool Grower* 35(4):13.

Literature category: Documented case study
Specific topic: Cheatgrass / fire interaction and grazing effects post-fire
Reviewed by: Andrea Stebleton

Introduction

The purpose of this research was to assess the effects of fire on cheatgrass (*Bromus tectorum*) herbage production in southeastern Idaho. This study was prompted as a contradiction to the widely held belief that fire doesn't affect the early spring production of cheatgrass. During the time of the study, sheepmen had a direct economic interest in the loss of cheatgrass as spring forage.

Summary

Experiments, conducted near the Dubois Airport in southeastern ID, measured the amount of cheatgrass herbage produced from burned areas. These areas were not fenced to limit grazing to post-fire grazing. Observations were recorded and assessed in the light that cheatgrass is necessary forage for sheep, and cheatgrass stands must be protected from wildfires.

Relevant findings

High intensity fires cause a reduction in cheatgrass the following year.

Perennial plant vigor is reduced when fire occurs in late May or early June, when cheatgrass is available to burn.

Overgrazing on burned areas can occur in the late spring because plants stay green and palatable longer. This practice often kills perennials and forbs and permits further invasion of cheatgrass.

Summary interpretation

From these observations we can conclude that the interaction of fire and grazing have impacts on the interactions between cheatgrass and perennial grasses. Since cheatgrass provided a recipient fuelbed for fire during the period of time when perennial grasses are green and actively growing, fire caused a marked increase in perennial grass mortality. Grazing of burned areas, the year following a fire, reduced perennial grass persistence and allowed for cheatgrass dominance.

Pedersen, E.K., J.W. Connelly, J.R. Hendrickson, and W.E. Grant 2003. Effect of sheep grazing and fire on sage grouse populations in southeastern Idaho. *Ecological Modeling* 165: 23-47.

Literature category: Model-based research
Specific topic: Other: grazing and fire effects
Reviewed by: Bruce H. Brockett

Introduction

Populations of sage grouse in United States and Canada are declining range-wide, with livestock-grazing considered one of the causes of the decline. However, no data were available to support this statement. Therefore a model was used to simulate the effects of grazing and fire on temporal and spatial aspects of sagebrush community vegetation and sage grouse population dynamics.

Summary

The conceptual model considered temporal and spatial relationships and incorporated a discreet-time, stochastic compartment (based on difference equations) with a weekly time step. Sheep, in the model, grazed sage grouse habitats in both spring and fall. The model describes the dynamics of sage grouse population and vegetation of sagebrush rangelands in southeastern Idaho (80 km north of Idaho Falls). Temporal relationships were developed for sagebrush community dynamics, and sage-grouse population dynamics. For sage-grouse, only the female portion of the population was modeled. The spatial relationships accounted for the presence of sheep grazing through sage grouse breeding habitat during the breeding season.. The modeled grazing zone was a 67 300 ha spring area divided into four areas of 16 825 ha each. In the event of a fire (in the model) it was assumed that fire removed all vegetation from the burnt area. Equations were developed for: (1) sagebrush community dynamics (sagebrush canopy cover, sagebrush height, and forb biomass dynamics, and grass biomass), and (2) sage grouse population dynamics. The assumptions of the model were listed.

Relevant findings

Simulated sagebrush canopy cover reached a maximum 21-30 years (man = 25) post-fire. Simulations suggest that large high frequency fires may lead to the extinction of sage grouse populations, while infrequent and small fires may benefit sage grouse if sheep grazing is absent. Under any fire management scenario grazing could reduce the sage grouse population. Sheep grazing may contribute to sage grouse declines.

Summary findings

Models such as this could be use to look at sheep, cattle, and fire relationships in sagebrush under different scenarios.

Pellant, M. 1996. Cheatgrass: The Invader That Won the West Interior Columbia Basin Ecosystem Management Project. Available at: *http://www.icbemp.gov/science/pellant.pdf*. Accessed 27 September 2007.

Literature category: Scientific synthesis
Specific topic: Cheatgrass / fire interaction
Reviewed by: Eva Strand

Introduction

Cheatgrass (*Bromus tectorum*) is an introduced annual grass occupying 3.3 million acres of public lands in the Great Basin with another 76.1 million acres infested or susceptible to infestation. Historic livestock grazing reduced native herbaceous vegetation and left a void which cheatgrass, a prolific seed producer, now occupies.

Summary

Cheatgrass germinates in the autumn of early spring, which gives it a competitive advantage over native perennials, particularly in the upper soil layer (< 1 ft). Cheatgrass biomass production is highly variable, 3461 and 361 lb/acre in a wet and dry year respectively, has been reported. It is further tolerant to grazing, increases with frequent fires, and can survive periodic drought because seeds are viable in the soil for up to 5 years. Cheatgrass cures early, is extremely flammable, which has altered the wildfire return interval from 32-70 years in sagebrush steppe to less than 5 years in certain areas in southern Idaho. As a result of frequent fires the plant diversity has decreased and important sagebrush steppe habitats have been lost.

Relevant findings

Cheatgrass is an important spring forage plant for livestock with suggested carrying capacities of 1.5-3 acres per AUM on 'good' cheatgrass range and 5-8 acres pre AUM on other Idaho rangelands. Later in the season the forage quality declines as the grass matures. Cattle may utilize dry cheatgrass if water is present or the grass is softened by rain, providing winter usage with the side benefit of reduced fuel loads.

Little information is currently available to identify thresholds of cheatgrass dominance whereby a disruption in ecological processes, native plant composition or soil instability occurs. It has been suggested that southern Idaho cheatgrass communities are a wildfire maintained steady state and will not return to the original native vegetation upon removal of livestock. In fact, removal of livestock may accelerate cheatgrass conversion due to higher fuel loads. An acceptable ratio of cheatgrass to native plants whereby ecological processes are still functioning has not been reported. One study however reports that native plant recruitment is negatively affected when the cheatgrass density exceeds 50 plants/m^2. A native grass number less than 3 plants / m^2 is also a cause of concern when cheatgrass invasion is a possibility.

Where native plant densities are sufficient, livestock grazing can reduce cheatgrass. Burning in late spring before seed maturation also effectively reduces cheatgrass the following year. 'Greenstripping', seeding fire resistant plants in strategic locations is a proactive approach to reduce the size of wildfires.

Summary interpretation

Cheatgrass is very competitive in early succession but will likely be outcompeted by deep-rooted native perennials in the absence of a disturbance, unless the cheatgrass dominance has reached a threshold for when native species no longer will establish. Grazing reduces fuel loads and decreases the risk of fire start and spread. Removal of cheatgrass before seed maturation via grazing may reduce the cheatgrass crop the following year. Early spring fires kill cheatgrass seed before maturation and therefore reduce cheatgrass cover the following year. Cheatgrass however quickly recovers after the disturbance, returning the system to annual grasslands.

Peters, E.F. and S.C. Bunting. 1994. Fire conditions pre- and post occurrence of annual grasses on the Snake River Plain. In: Monsen, Stephen B.; Kitchen, Stanley G., compilers. Proceedings--ecology and management of annual rangelands; 1992 May 18-22; Boise, ID. Gen. Tech. Rep. INT-GTR-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. p. 31-36.

Literature category: Scientific synthesis
Specific topic: Cheatgrass/fire interaction
Reviewed by: Andrea Stebleton

Introduction

This paper discussed the fire occurrence before and after the introduction of cheatgrass (*Bromus tectorum*) and medusahead (*Tainiatherum caput-medusae*) and the subsequent effects on vegetation within the Snake River Plain. This research is in response to the need to look at fire occurrence in regions dominated specifically by cheatgrass and medusahead.

Summary

This study addressed the historic change resulting from introduction and subsequent invasion of annual grasses. The introduction of cheatgrass altered fuel distribution and loading, which has changed the fire intensity and extent. The reduction in the fire-free interval has greatly changed the historic role of fire in the Great Basin and the distribution of many species.

Relevant findings

- Fire behavior and fire spread becomes sporadic when fine fuel loading is less than 650 kg/ha.
- Prior to sagebrush establishment, perennial grass densities were too low to allow for fire spread under most environmental conditions.
- Overgrazing, reduced the understory vegetation and increased canopy densities of sagebrush and rabbitbrush. When fire burned these stands, it was stand replacing. If annual seed was present it increased following the fire.
- Within 3 – 6 years following the first fire, cheatgrass developed sufficient fuel continuity to readily support another fire. All rabbitbrush and sagebrush resprouts are lost with a fire free interval is below 5 years.
- Cheatgrass competition limits perennial grass recruitment due to earlier initiation of spring growth.
- With each subsequent fire, perennial grass seed source is lost and the perennial recruitment is dependent on dispersal from non-burned communities. This distance gets farther and farther away with increased homogeneity of burned area from increased fuel continuity created by cheatgrass.
- Perennial grass recruitment is favored in years of above-average precipitation. However, increases of cheatgrass increased fuel continuity and fine fuels, further increasing the risk for fires to ignite and spread.
- Cheatgrass production and litter accumulation are reduced in dry years decreasing susceptibility to fire.

Summary interpretation

Cheatgrass dominance changes the fire regime of an area enough to significantly alter succession, create a more homogeneous landscape, and decrease species diversity. Although historically grazing and agriculture were significant disturbances within the Snake River Plain, fire is now the primary disturbance allowing for and perpetuating the successful invasion of cheatgrass.

Provencher, L., T.A. Forbis, L. Frid, and G. Medlyn. 2007. Comparing alternative management strategies for fire, grazing, and weed control using spatial modeling. *Ecological Modelling* 209:249-263.

Literature category: Model-based research
Specific topic: Fire/grazing/invasives effects on sagebrush steppe
Reviewed by: Eva Strand

Introduction

Effects of livestock grazing, fire management, and herbicide applications were estimated via spatial modeling 20 years into the future in a 141,853 ha landscape in eastern Nevada. Seven different vegetation types occurred within the study area: shadscale (*Atriplex confertifolia*), winterfat (*Kraschenin-nikova lanata*), black sagebrush (*Artemisia nova*) with or without pinyon (*Pinus monophylla*) –juniper (*Juniperus osteosperma*), Wyoming sagebrush (*Artemisia tridentata* subsp. *wyomingensis*) with or without pinyon-juniper, pinyon-juniper woodlands, mountain mahogany (*Cercocarpus ledifolius*) woodlands, mountain big sagebrush (*Artemisia tridentata* subsp. *vaseyana*) with our without pinyon-juniper.

Summary

Six scenarios modeling the effect livestock grazing, fire, and non-native species management on the vegetation composition was simulated in the TELSA modeling software. In this model succession within potential vegetation types is treated deterministically with a predefined time-step and the disturbance (fire, grazing) are probabilistic events within a pre-defined framework. Fire set back succession to a perennial grass state in most potential vegetation types. Grazing, in the model, occurred at higher elevation in the summer and lower elevation in the winter in areas with perennial grass cover. The following assumptions related to grazing was used: 1) Grazing accelerated succession in woodlands, 2) Spring grazing in winterfat caused a reversal of woody succession. Other disturbances included were invasion by annual grasses and insect outbreaks. Management activities included mechanical treatments, prescribed fire, seeding and herbicide applications.

Relevant findings

The scenario with unmanaged fire regimes had the worst possible outcome while a high level of management (chemical applications, mechanical treatment, and prescribed burning) produced the most desirable outcome. Desirable states are considered those dominated by native perennial grasses and undesirable states are those dominated by cheatgrass, exotic forbs, and pinyon-juniper woodlands.

Grazing had little effects on landscape vegetation composition supporting the observation that simply removing livestock grazing from degraded rangelands will not result in restoration to a reference condition.

Drought will amplify negative effects of livestock grazing.

Restoration of rangelands to perennial grass dominant states requires more funding than is currently available to the BLM district where these simulations were conducted.

Summary interpretation

Active management such as seeding is necessary to restore areas where the seedbank of the sagebrush steppe/ native grass/native forbs has been depleted by frequent fires in cheatgrass dominated areas or in areas of long-term pinyon-juniper dominance, if a return to a native grassland/sagebrush steppe is desirable. Current livestock grazing regimes has a minor effect on plant communities but the effects can be amplified by drought. Removal of livestock grazing will not restore degraded rangelands to native grasses and sagebrush steppe, active management is here required (herbicide and seeding with desirable plants).

Rummell, R.S. 1951. Some effects of livestock grazing on ponderosa pine forest and range in central Washington. *Ecology* 32:594-607.

Literature category: Documented case study
Specific topic: Grazing/ fuels
Reviewed by: Shannon Hatch

Introduction

This study was undertaken to examine vegetation differences between grazed and ungrazed plateaus in central Washington. This study was prompted by a lack of information quantifying or qualifying change in ponderosa pine (*Pinus ponderosa*) forests. As both these areas were unaffected by fire, grazing was identified as the only disturbance variable.

Summary

The author compared vegetation characteristics on two plateaus in central Washington. The two plateaus were similar in geologic origin, elevation, climate, and timber type. While Meeks Table had never been grazed by livestock, Devil's Table had been heavily utilized by livestock during the 40 years leading up to this study.

The two areas were similar in geologic origin, elevation, climate, and timber type. Study plots were grouped into three classifications: (1) pinegrass-elk sedge (*Calamagrostis rubescens -Carex geyeri*) understory, open ponderosa pine overstory; (2) pinegrass-elk sedge understory, mixed ponderosa pine-Douglas fir (*Pseudotsuga menziesii*) overstory; and (3) subalpine needlegrass (*Achnatherum nelsonii*) – Sandberg bluegrass (*Poa secunda*) open grassland type. Herbaceous and shrubby understory vegetation density and composition were determined for both mesas. Herbaceous weight of pinegrass was also determined. All tress less than 4 in dbh were tallied by species and height class, while all tress greater than 4 in dbh were recorded by species and dbh class.

Relevant findings

- Grassland openings on the grazed mesa had been invaded by ponderosa pine; openings on the ungrazed mesa, however, remained free of ponderosa pine. Pinegrass densities were high in the grassland openings on the ungrazed mesa.
- On the ungrazed mesa, herbaceous and shrubby understory beneath open ponderosa pine stands averaged 35%. On the grazed mesa, this value was only 14%.
- Pinegrass biomass was measured at 850 pounds on the ungrazed mesa. Pinegrass biomass on the grazed mesa was only 240 pounds.
- Species richness was higher on the ungrazed mesa. In the open ponderosa pine stands, 19 species were found on the ungrazed mesa; 14 were found on the grazed mesa. In the ponderosa pine-Douglas fir forest, 18 species were found on the ungrazed mesa; 9 were recorded on the grazed mesa.
- On the ungrazed mesa, there were only 85 trees per acre less than 4 in dbh; on the grazed mesa there were 3,291 trees less than 4 in dbh.
- Vegetative ground cover and litter prevented the establishment of tree seedlings on the ungrazed mesa.

Summary interpretation

In certain ecosystems, the removal of understory vegetation by livestock may facilitate tree propagation and growth. Livestock may reduce fire potential by reducing grass and shrub biomass.

Sapsis D.B. and J.B. Kauffmann. 1991. Fuel consumption and fire behavior associated with prescribed fire in sagebrush ecosystems. *Northwest Science* 65:173-179.

Literature category: Experimental research
Specific topic: Fire effects on sagebrush steppe
Reviewed by: Eva Strand

Introduction

Fuels (total biomass), fuel moisture and fire weather, as well as fire behavior, and consumed biomass were measured during prescribed burning in sagebrush steppe (*Artemisia tridentata* subsp. *tridentata*) in Oregon.

Summary

Two fire treatments were conducted and compared; a fall (4 plots) and a spring (5 plots) burn. The overstory was dominated by basin big sagebrush and the understory was dominated by Idaho fescue (*Festuca idahoensis*) and bluebunch wheatgrass (*Pseudoroegneria spicata*). Each burn unit was at least 30-50 m in size and the burn treatments were randomly assigned. 1-hr, 10-hr, 100-hr, herbaceous, and downed woody fuels were measured prior to the treatments. Sagebrush cover was estimated by the line-intercept method. Shrub volume was measured and sagebrush biomass was calculated, as was the biomass of the herbaceous material. Post-fire fuels were estimated in similar manners.

Relevant findings

The fall burn resulted in a longer flame length (4.1 m compared to 1.7 m in the spring), higher rate of spread (1.6 compared to 0.3 m/s in the spring) and a higher fire line intensity (6400 compared to 880 kW/m).

Fires in basin big sagebrush are stand replacing with virtually all above ground biomass consumed.

Sagebrush foliar moisture was 186% in the spring and 97% in the fall.

The fuel consumption of fine fuel was not significantly different between treatments. However, the consumption of 10-hr and 100-hr fuels was significantly higher in the fall burn.

93% of the biomass was consumed in the fall burns compared ton 84% in the spring burns. The largest difference in fuel consumption was found in the 10-hr fuels (85% for the fall burn and 52% for the spring burn) possibly attributed to the higher foliar moisture in the spring.

Summary interpretation

Sagebrush steppe burns in a stand replacing fire regime. However the amount of fuel consumed and the fire behavior varies by pre-fire fuel conditions, which varies through the season.

Sperry, J.L., J. Belnap, and R.D.Evans. 2006. *Bromus tectorum* invasion alters nitrogen dynamics in an undisturbed arid grassland ecosystem. *Ecology* 87:603-615.

Literature category: Documented case study
Specific topic: Other: Nitrogen effect on cheatgrass
Reviewed by: Eva Strand

Introduction

The purpose of this study is to evaluate the nitrogen dynamics in two vegetation associations (C_3 and C_4) in native perennial grasslands and in communities that were recently invaded by cheatgrass (*Bromus tectorum*) in the Canyonlands National Park in Utah.

Summary

The input of inorganic N from biological soil crusts and litter was quantified by inserting ion-exchange resin bags in the litter/soil crust boundary in 1) and undisturbed native perennial grassland area, and 2) a recently (within the last 4 years) cheatgrass invaded area. The isotopic composition ($^{15}N/^{14}N$) was measured at different soil depths as well as the inorganic N composition (NO_3^- and NH_4^+). A total of 15 plots were included in the study.

Relevant findings

Biological soil crusts contain N_2-fixing cyanobacteria and lichens. In cheatgrass invaded systems the amount of litter (95% more than in native grass communities) shade the biological crusts and reduce the overall N_2 fixation in the system The input of surface N to the soil is controlled by N_2 fixation in the native grass communities and by decomposition of cheatgrass litter in invaded communities (recycling of N within the system).

Nitrogen inputs vary seasonally with the highest inputs in May.

Cheatgrass sites had a higher N concentration in the surface soils compared to native grasslands suggesting a redistribution of N in the soil profile when grasslands are invaded by cheatgrass.

Summary interpretation

Cheatgrass invasion alters the nitrogen balance in the shrub steppe such that N is recycled within the system rather than controlled by net input from N_2 fixation by biological soil crusts. Disturbances that affect biological crusts (e.g. fire and grazing) alter the nitrogen balance in grasslands.

Stohlgren, T.J., L.D. Schell, and B. Vanden Heuvel. 1997. How grazing and soil quality affect native and exotic plant diversity in Rocky Mountain grasslands. *Ecological Applications* 9:45-64.

Literature category: Experimental research
Specific topic: Grazing/ fuels
Reviewed by: Shannon Hatch

Introduction

This paper examined how grazing and soil quality affect native and exotic plant diversity at several grasslands sites across the Rocky Mountain West. The authors hypothesized that grazed sites would have higher native and exotic species richness due to disturbance. They also hypothesized that ungrazed sites would have lower native species richness due to competitive exclusion in the absence of disturbance.

Summary

Multiscale vegetation plots were placed in and adjacent to 26 long-term grazing exclosure sites in order to asses vascular plant diversity and soil characteristics. Study sites for this experiment were located in grasslands in Colorado, Wyoming, Montana, and South Dakota. Sites were chosen based on selection criteria stipulating >12 years of continued protection from grazing, and moderate to moderately heavy grazing outside the exclosures. Sites ranged in elevation from 800 to 2675 m. Differences in native and exotic species richness and cover, and exotic species frequency between enclosed sites, adjacent grazed sites, and randomly located grazed sites were determined by ANOVA. Jaccard's Coefficient was also used in order to compare species overlap between exclosed plots and adjacent plots, adjacent plots and the randomly located grazed plots, and exclosed plots and the randomly located plots. Soil characteristics were utilized in a multiple regression analysis.

Relevant findings

- Both of the study hypotheses were rejected. At the landscape scale, grazing most likely has little effect on native and exotic plant species richness at these grassland sites.
- The authors reported that grazing most likely has little effect on promoting the spread of most exotic plant species at landscape scales; however, higher cover of cheatgrass (*Bromus tectorum*) was generally found in grazed plots.
- Few plants showed any consistent response to grazing or the cessation of grazing. However, the authors felt that cheatgrass may spread faster in grazed or disturbed sites.
- Grazing appears to have less of an effect on species richness than soil fertility, climate, elevation, and other factors. Grazed sites in the Rocky Mountains with higher levels of soil nitrogen and carbon had higher levels of native and exotic species richness and cover than low fertility sites. At landscape and regional scales, species richness may largely be controlled by climate, rather than grazing.

Summary interpretation

While grazing may help to spread some noxious weeds, it does little to alter plant diversity at the landscape scale. Environmental factors may play a more significant role in species composition and vigor than grazing. When considering the potential impact of livestock, a multitude of factors must be taken into consideration.

Tipton, F.H. 1994. Cheatgrass, livestock and rangeland. In: S.B. Monsen and S.G. Kitchen [EDS.], Proceedings—Ecology and management of annual rangelands. General Technical report INT-GTR-313, Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. p. 414-416.

Literature category: Professional resource knowledge/Documented case study
Specific topic: Grazing effect on cheatgrass/cheatgrass and fire interactions
Reviewed by: Brianna Goehring

Introduction

The purpose of this article was to describe the management of a cow/calf operation in Winnemucca, Nevada that included the utilization of cheatgrass (*Bromus tectorum*) in its grazing program.

Summary

This cow/calf operation adopted a grazing plan that managed "with cheatgrass, but not for cheatgrass." Cheatgrass played an integral role in the grazing program of this operation as it served as important winter forage for cattle.

Relevant findings

Cows learned as replacement heifers to utilize cheatgrass as a source of forage.

Cheatgrass heads were consumed first when cows were turned onto winter range in October. The top portion of the dry herbage was next consumed in early November.

Sandberg bluegrass (*Poa sandbergii*) and bottlebrush squirreltail (*Sitanion hystrix*) were the first grasses to emerge in the early spring. Cows grazed these grasses until cheatgrass initiated growth and grazing preference returned to cheatgrass.

40% of this operation's range burned in the last two decades.

Secondary succession was predominantly cheatgrass, but many of the burned areas experienced an increase in perennial grasses.

Summary interpretation

This case study suggests that cheatgrass can not only be managed through grazing but that it can also become an integral part of the structure of some livestock operations. This may be a more attainable and more economical goal than eradication of cheatgrass. Livestock should be conditioned to consuming cheatgrass in order for such a grazing plan to be successful.

Vale, T.R. 1974. Sagebrush conversion projects: an element of contemporary environmental change in the western United States. *Biological Conservation* 6: 274-284.

Literature category: Scientific synthesis
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

This paper discussed the extent and effects of extensive sagebrush (*Artemisia tridentata*) conversion projects in the western United States. Numerous studies examining the effects of these treatments on vegetation characteristics were cited.

Summary

The author detailed the role of sagebrush conversion projects in rangeland improvement projects. Projects were historically used to improve depleted range where grass production for cattle consumption had declined due to the effects of overgrazing. However, the author did discuss the use of properly planned projects and their role in the creation of a more heterogeneous plant composition. Numerous problems and controversies surrounded these projects; deleterious effects on wildlife and soil erosion were discussed.

Relevant findings

Historically, cattle caused depletion of the grass understory; higher densities of brush resulted.

Prior to grazing, shrubs were dominant; however, there was a mixture of grasses and forbs in the understory.

Perennial forbs decrease most due to heavy grazing.

"Grazing systems" which alternate rest periods with periods of grazing may result in the growth of beneficial plants.

A year of rest from grazing is suggested after seeding in order to encourage plant establishment and growth.

Season of grazing rather than intensity may affect seeding success.

Grazing should be minimized in the early summer in order to assist seedling establishment.

Summary interpretation

Historically, cattle depleted grass and forb species; higher brush densities often resulted. While this paper primarily discussed the role of conversion projects in the creation of more forage for cattle on depleted rangelands, there may be some applicable uses for these techniques in the improvement of cheatgrass infested areas. While fire was not specifically mentioned, the general principles discussed in this paper would apply to areas treated by prescribed or natural fire. Care should be given when stocking cattle after vegetation treatments. The author advocated a year of rest from grazing, and use should be minimized during the early summer.

Vermeire, L.T., D.B. Wester, R.B. Mitchell, and S.D. Fuhlendorf. 2005. Fire and grazing effects on wind erosion, soil water content and soil temperature. *Journal of Environmental Quality* 34: 1559-1565.

Literature category: Experimental research
Specific topic: Fire and grazing effects
Reviewed by: Bruce H. Brockett

Introduction

The objectives of this study were to quantify the effects of patch burning and grazing on soil characteristics (wind erosion, soil water content, and soil temperature in sand sagebrush (*Artemisia filifolia*)).

Summary

The sampling design included 24, 4-ha plots near Woodward, OK. Four plots were burnt during autumn (mid-November), four in spring (mid-April), and four control (non-burnt) plots. Treatments were randomly assigned to pastures. In many cases an interaction between: burning treatment, year effects, and sampling measurements (soil temperature and moisture), occurred.

Relevant findings

Effects of burning on erosion, soil moisture, and soil temperatures were found to be dependent on season of burning, sampling considerations, and environmental effects (e.g. "year" effects). Increased erosion on autumn-burnt plots may be explained by weather conditions and lack of plant growth through the dormant period. Burning treatment, years, and sampling height interacted in their effects on growing-season erosion. It was suggested that the reduced sagebrush canopy volume and herbage standing crop on burnt sites could have contributed to increased wind erosion during the growing-season. The authors conclude that autumn burning increased wind erosion during the dormant season. However, erosion rates are highly dependent on the coincidental occurrence of exposed soil and other factors, which would include the frequency and intensity of precipitation and wind events. Most of the growing-season wind erosion occurred during late April and May, and appeared not to be affected by patch grazing. Patch burning did not affect soil water content, suggesting that fire may have minimal effects on the water content of sandy soils because of their low water holding and deep percolation capacity.

Summary findings

Episodic events could increase post-fire erosion.

Weber, K.T., J.B. McMahan, and G.P. Russell. 2004. Effect of livestock grazing and fire history on fuel load in sagebrush –steppe rangelands. *Intermountain Journal of Sciences* 10:1-4.

Literature category: Documented case study
Specific topic: Grazing effect on fuels
Reviewed by: Shannon Hatch

Introduction

The purpose of this paper was to investigate the effect of livestock grazing on fuel load in sagebrush steppe ecosystems. This study was prompted by the quantitative needs of managers tasked with measuring and modeling wildfire risk.

Summary

The authors conducted their field research on Bureau of Land Management (BLM) land in southeastern Idaho. The area was typified as sagebrush-steppe semi-desert. The area had been subject to livestock grazing and wildfire. Both sheep and cattle were grazed at the study site; deferred, rest-rotation, and continuous/seasonal grazing systems were used. The units that were actively grazed during this study had stocking rates of 19.8 and 34.6 ha/AU. The mean number of years since fire was 16.3; however, most sites had experienced a fire event within 2 years of the study.

Fuel load was estimated at 128 sample points; points were grouped according to grazing treatment and fire history. The four categories represented were: (1) grazed with previous wildfire, (2) grazed without previous wildfire, (3) no grazing with previous wildfire, and (4) control.

Relevant findings

Livestock grazing alone can be as effective as wildfire in reducing fuel load, but only at higher stocking rates (19.8 ha/AU).

Low stocking rates (34.6 ha/AU) did not effectively reduce fuel load; previous fire had a greater effect that livestock in these instances.

Together, grazing and previous wildfire can be effective in reducing fuel load.

Summary interpretation

While other ecological considerations were neglected in this study, this paper indicated that heavy livestock stocking could be effective at reducing fuel load in sagebrush-steppe ecosystems. The use of livestock as a fuel reduction agent may be of use to some managers. The stocking rates were not properly reported because only area per animal unit (AU) with no indication of time period was noted.

West, N.E. and T.P.Yorks. 2002. Vegetation responses following wildfire on grazed and ungrazed sagebrush semi-desert. *Journal of Range Management* 55:171-181.

Literature category: Documented case study
Specific topic: Grazing effects on fire, and grazing effects post-fire
Reviewed by: Bruce H. Brockett

Introduction

Twenty-year sagebrush semi-desert plant cover data were used to investigate responses to wildfire and livestock grazing. One of the objectives of this study was to test the assumptions and adaptability of classical and state-and-transition models to describe secondary succession.

Summary

The study area was conducted on privately owned land in Central Utah. The authors regarded the site as non-typical sagebrush semi-desert. Cover data was organized and analyzed by: (1) plant species, (2) growth forms, and (3) other ground cover classes. Data analysis methods were: (1) graphical analysis, (2) ordination (multi-dimensional scaling), (3) regression, and (4) analysis of variance. The treatments applied were: (1) burnt in 1981, and some areas re-burned in 1987 but not grazed, (2) burnt 1981, grazed from 1982-2000, (3) unburned and grazed, (4) grazed from 1982 and burnt in 1996, (5) grazed from 1982 and burnt in 1987. Perennial grass cover was reduced due to the 1981 fire, increasing steadily until 1994 at the time of the second drought.

Relevant findings

Live plant cover increased during wet periods, declined during droughts. Perennial grass cover was reduced by fire. Perennial cover increased post-fire until the onset of a second drought when it declined. Annual grasses were the major cover component on all burnt macro-plots from 1982-1984, decreasing from 1989-1993. West and York (2002) expected cheatgrass to dominate post-fire. However, this did not occur, instead perennial grasses dominated. Cheatgrass was totally absent during a drought period (1989-1992). Because cheatgrass failed to dominate suggested that a threshold to an annual dominated state had not been crossed (see West and Young 2000) due to low nitrogen fixing ability of these soils. Re-establishment of sagebrush and juniper following the fire was slow. The authors concluded that no thresholds were crossed as a result of the fire and grazing treatments.

Summary interpretation

A case study such as this can be useful to explore long-term vegetation-fire-grazing interactions in sagebrush steppe. Relationships between cheatgrass and nitrogen in the soil needs to be further explored.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plains: ecological and management implications. In: McArthur, E. Durant; Romney, Evan M.; Smith, Stanley D.; Tueller, Paul T., compilers. Proceedings--symposium on cheatgrass invasion, shrub die-off, and other aspects of shrub biology and management; 1989 April 5-7; Las Vegas, NV. Gen. Tech. Rep. INT-276. Ogden, UT: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. p. 4-10.

Literature category: Documented case study
Specific topic: Cheatgrass / fire interaction
Reviewed by: Andrea Stebleton

Introduction

This paper discussed the dramatic change in the fire regime of the Snake River Plains as a result of increased cheatgrass (*Bromus tectorum*) quantity and continuity of fine fuels. It assessed the changes in landscape diversity and consequences for secondary succession. It further described predictable patterns of vegetation change associated with increased fire frequencies.

Summary

Twelve sites with, different fire histories, were chosen with the following criteria: known fire history, no artificial revegetation, and vegetation had not been significantly affected by domestic livestock. Fire dates, climatic records, and some vegetation data were recorded over the past 31 years at each site and compared with the vegetation currently on the site. Mechanisms of change on the sites were addressed based on different plant regenerative strategies.

Relevant findings

- Fire frequency increased from 35 – 110 years to 3 – 5 years due to cheatgrass invasion.
- Because of the continuity cheatgrass provided, fires burned more uniform leaving less unburned vegetation.
- Cheatgrass changed the fire regime of sagebrush-steppe by creating a more continuous fuel that carried wildfire to widely spaced shrubs.
- The amount of fine fuel produced by cheatgrass didn’t always increase as cheatgrass began to dominate, but fuel continuity increases. Large bunchgrasses increased amount of fine fuel without increasing fine fuel continuity.
- Cheatgrass demonstrates a positive correlation with fire frequency; increased fire frequency reduces species diversity, and increases the amount of annuals in the community which decreases other life forms.

Summary interpretation

Fine fuel continuity caused by cheatgrass, has a more important effect on changing fire regimes than the amount of fine fuel. Management should focus on reducing fuel continuity to thereby reduce fire frequency and size. This allows for exchange of more propagules between the different patches and increased perennial regeneration potential by decreasing fire kill by frequent fires.

Wisdom, M.J., M.M. Rowland, and R.J. Tausch. 2005. Effective management strategies for sage-grouse and sagebrush: a question of triage? Transactions, North American Wildlife and Natural Resources Conference 70: in press.

Literature category: Model based research
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

This paper addressed the need for the adoption of prioritized restoration planning within the sagebrush biome of the western United States. Managers should identify the probability of irreversible threshold effects for a given area. The resistance and resiliency of that site should also be taken into consideration when determining management action. The authors advocated focusing on sage-grouse supporting areas, especially those that have moderate or high potential to be restored or maintained.

Summary

This paper advocated holistic management that addresses the myriad human disturbances affecting the sagebrush ecosystem. Vulnerable areas exhibiting high restoration potential should be prioritized given limited funding.

The authors mapped, using precipitation and elevation as proxies, community resistance and resiliency for the Intermountain West. Spatial rules were developed to estimate the potential to maintain existing sagebrush or restore former sagebrush supporting areas.

Areas with high restoration potential were located in Wyoming, eastern Idaho, and northern Nevada.

Relevant findings

Human associated impacts have greater ramifications in areas that are dry and warm; sagebrush overstories become harder to maintain and native grass understories decline in the face of disturbance. Restoration in these areas may be less effective, and/or results may slow to materialize.

Summary interpretation

Given limited funding, rangeland managers should prioritize restoration activities given a site's response potential. Biophysical characteristics can be useful in helping to determine restoration success for an area.

Wisdom, M.J., M. Vavra, J.M. Boyd, M.A. Hemstrom, A.A. Ager, and B.K. Johnson. 2006. Understanding ungulate herbivory-episodic disturbance effects on vegetation dynamics: knowledge gaps and management needs. *Wildlife Society Bulletin* 34:283-292.

Literature category: Scientific synthesis
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

This paper examined the lack of knowledge regarding the interactions of herbivory with episodic disturbances. The authors suggested the creation of new models to examine interactions of grazing with other disturbance factors and regimes.

Summary

The authors examined 82 contemporary (since 1990) journal articles presenting empirical results on the effects of ungulate grazing. The goal of this study was to identify knowledge gaps and management needs associated with the combined effects of grazing and other disturbance factors. Specifically, the authors wanted to document the degree to which past studies examined grazing in lieu of other landscape disturbances; studies focusing on multi-species grazing, varying grazing densities, and repeated-measures sampling design were of special interest. The authors also wanted to develop a modeling system that considered the synergistic effects of herbivory and other disturbance factors.

Relevant findings

- Vegetation structure and function modification by livestock may result in a multitude of ecosystems effects, such as changes in nutrient cycling and energy flow.
- As herbivores have a disproportionate effect on the modification of floral and faunal communities, they may be considered keystone species.
- The complex nature of ungulate herbivory-episodic disturbance interactions is most likely dependent on a number of factors, including: ungulate species, ungulate densities, patch choices, landscape patterns, and the frequency and intensity of disturbance.
- Crown fire occurrence may be exacerbated the combination of fire suppression and herbivory, which reduces fine fuels while simultaneously promoting the growth of unpalatable trees which may act as ladder fuels.
- Better models, based on more targeted research, are needed in order to better understand herbivory-episodic disturbance interactions.

Summary interpretation

Grazing and episodic disturbance should be considered synergistic factors. Individual effects of the two are difficult to tease out; better modeling, based on landscape scale experiments, may help in the guidance of management actions.

With, K.A. 2002. The Landscape Ecology of Invasive Spread. *Conservation Biology* 16:1192-1203.

Literature category: Scientific synthesis
Specific topic: Landscape structure effects on invasive species spread
Reviewed by: Eva Strand

Introduction

The goal of this research is to evaluate the effects of landscape structure, i.e. spatial patterns, on the spread of invasive species and invasibility of native plant communities.

Summary

Previous models describing spread of organisms across landscapes have assumed spread across a homogeneous surface i.e. not accounted for landscape heterogeneity. Landscape structure may affect several stages of the invasion process, i.e. introduction, germination, establishment, dispersal to new sites. Percolation theory incorporates effects of habitat connectivity and fragmentation on a species ability to spread across the landscape. It is desirable to determine fragmentation thresholds for then species is able to (alternatively no longer able to) spread across the landscape.

Relevant findings

- Spread of invasive species into native plant communities may be affected by the landscape structure in the following ways:
- Effects of landscape structure on dispersal vectors
- Effects on various stages in the invasion process such as propagule spread, establishment and population growth.
- Effects on the spatial distribution of the invasive species facilitating its spread (e.g. satellite populations)
- Landscape structure may promote or alter the interaction between species such that invisibility increases (e.g. edge effects).
- Affect the native species such that their resistance to invasion decreases
- Alter disturbance dynamics such that invasibility is enhanced
- Long distance dispersal vectors ultimately control species spread even when long distance dispersal is rare.
- To understand species spread across a landscape it is necessary to determine how landscape connectivity affects the ability of the organism to move across the landscape.

Summary interpretation

Understanding the effects of landscape structure on invasive species spread provides additional opportunities for management and restoration to minimize alien species invasions. A better understanding of the relationship between landscape structure and species spread may also be useful in evaluating the potential for native species to colonize an area after a widespread disturbance and to plan restoration efforts.

Wyoming Interagency Vegetation Committee. 2002. Wyoming guidelines for managing sagebrush communities with emphasis on fire management. Wyoming Game and Fish Department and Wyoming BLM. Cheyenne, WY.

Literature category: Model based research
Specific topic: Grazing/ fuels/ fire/ historic role
Reviewed by: Shannon Hatch

Introduction

This document described vegetation objectives and treatment recommendations for nine different sagebrush (*Artemisia tridentata*) species in Wyoming. Focus was given to the use of prescribed fire as a vegetation management tool.

Summary

Many of the sagebrush communities in Wyoming exist in late successional stages dominated by plants that are older than 50 years; understory plant quantity and diversity are often reduced under these conditions. The authors of this document advocated the use of active restoration techniques in areas dominated by monocultures of even aged sagebrush stands. Mention was given to other techniques employed to alter sagebrush stands (chaining, herbicide use, etc.), however, fire management was the main focus of this publication. Specific management guidelines were given for each of the nine dominant sagebrush species in Wyoming.

Relevant findings

- Livestock grazing may have the greatest impact on sage-grouse habitat as it is ubiquitous; it is the main land use that affects herbaceous composition, cover and height.
- Livestock grazing also impacts sagebrush density, canopy cover and reinvasions rates.
- Poor grazing practices may have led to denser, more monotypic stands of sagebrush with reduced, and simplified herbaceous understories.
- Problems associated with livestock overuse can be worsened by drought conditions.
- Over the last several decades, grazing systems were often used in an effort to improve the herbaceous bunchgrass understory in sagebrush communities. Fine fuels increased as a result of these efforts. Changes in seasonal grazing practices such as moving use from spring and early summer to fall and winter grazing in lower elevation zones have also increased biomass of the herbaceous understory species. As a result of these changes, there is often more fuel available during the summer, when lighting fires are commonplace.
- If treated areas are grazed too soon, there may be a permanent reduction in herbaceous forage and nesting cover.
- Grazing deferment for two growing seasons is usually suggested; this time period is allotted to allow plant establishment.
- Before grazing is allowed on a treated site, determination of the desired plant community (DPC) objectives is necessary. Some areas may require a long recovery time post-treatment in order to meet land use goals. Improper grazing can lead to invasion by weeds if areas are utilized too soon.
- Continual heavy spring grazing may increase the presence of annuals and noxious weeds.

- Continual heavy fall or winter grazing may push the site more towards a grass/forb community, while heavy spring and summer use may move the site towards a community more dominated by shrubs and trees.
- Alternate grazing sites must be provided to permittees in order for landscape scale treatments to succeed.

Summary interpretation

Improper grazing contributes to the decline of sagebrush steppe vegetation. Structure and function can be greatly affected; drought or other landscape scale disturbances can exacerbate problems and subsequent recovery. Fires may become more frequent in areas where grasses have increased due to the employment of grazing systems designed to increase biomass production.

Fire can be a useful tool in the restoration of many sagebrush species and their associated understory components, however, managers need to consider the effects of grazing on treated areas. Grazing should be deferred for a minimum of two years in order to facilitate the re-growth of herbaceous species. Grazing deferment will also help to alleviate noxious weed establishment and spread. Season of use and stocking rates should also be considered.

Young, J.A., R.A. Evans, R.E. Eckert Jr., B.L. Kay. 1987. Cheatgrass. *Rangelands* 9(6):266-270.

Literature category: Scientific synthesis
Specific topic: Cheatgrass / fire interaction and grazing effects on cheatgrass.
Reviewed by: Andrea Stebleton

Introduction

The purpose of this paper was to highlight the debate and research in the Intermountain West between the argument that cheatgrass (*Bromus tectorum*) was useful forage compared to the view that it was a major rangeland weed that significantly increased wildfire risk. The authors suggested that range management needs to move from grazing management of perennial grasses to better grazing management of cheatgrass.

Summary

This paper outlined a brief history of the origin of cheatgrass, its adaptation and invasion strategies, and its competitive ability in sagebrush ecosystems. It outlined the research behind the different arguments that supported the usefulness of cheatgrass as forage, as well as those that identified the problems cheatgrass brought to the sagebrush communities, most through its interaction with fire. Rangeland management strategies based on these arguments were discussed and future implications and suggestions were made.

Relevant findings

Cheatgrass was a major forage species in the Intermountain area.

Competition from cheatgrass for moisture was a major factor limiting perennial forage species in big sagebrush ecosystems. Available soil moisture was the limiting factor for native seedling establishment in cheatgrass-dominated stands. Only during years of abnormally high summer precipitation did native perennial grasses have a competitive chance against cheatgrass.

Once cheatgrass was introduced to the sagebrush steppe rangelands, it spread through excessive grazing and reduction of the native perennial vegetation after 1870.

Early spring grazing of cheatgrass is desirable for cheatgrass control as well as offered good forage for livestock; however this is the time that perennial grasses are most susceptible to grazing. Early grazing on perennials prevented flowering and reduced its competitiveness against further cheatgrass invasion. Cheatgrass seeds increased small mammal activity, enough to create sufficient disturbance to perpetuate cheatgrass.

Closing a burned area to grazing for 2 years was a common practice to allow for the recovery of the remnant perennial grasses or seeded plants. In the second year cheatgrass increased enough to pose an immediate fire risk. In areas where cheatgrass dominated before burn, deferment of grazing is not recommended because perennial recovery was not feasible and the area was unfit for seeding.

One cheatgrass plant, under optimum conditions, produced 5,000 seeds.

Cheatgrass plants in the pre-burn population produced self-pollinated hybrid seeds with high plasticity. This allows for natural selection of a cheatgrass to be best adapted for the site it occupied.

The reduction of grazing from year round to 9 – 10 months in the salt deserts and sand dunes was suggested to have allowed the further invasion of cheatgrass and resulted in hazardous fuel accumulations.

Grazing dry cheatgrass greatly increased the incidence of lumpy-jaw infections in cattle and caused sever eye injuries.

Above-average spring rainfall allowed high productions of cheatgrass, which during dry summers resulted in huge uncontrollable wildfires.

Cheatgrass was a fine-textured fuel that dried by mid July. This increased the ignition potential and length of the fire season in sagebrush communities. It also increased fire spread because it provided a continuous fuel layer of fine fuels which typically doesn't exist in sagebrush ecosystems.

When burn severity is high in sagebrush-cheatgrass communities, the seeding of perennial grasses has a high probability of successful establishment because most of the cheatgrass seeds are destroyed.

It is cautioned that depending on cheatgrass as the main winter forage is risky because this forage could be eliminated by a summer fire, which on public lands results in no grazing for 2 more years, according to post-fire deferment regulation.

Summary interpretation

Grazing cheatgrass can be beneficial for livestock when cheatgrass is green; however there are many other factors that need to be considered before making management decisions regarding cheatgrass. These include: 1) the reduction of native perennial grasses and other forage species due to competition with cheatgrass, 2) increased ignition potential and fire spread, 3) current rangeland management requirements relating to grazing pre- and post-fire, and 4) the genetic and reproductive plasticity of cheatgrass which makes the species conducive to colonization and persistence within an ecosystem. None of these arguments stand alone and all must be considered before we will be able to effectively develop a plan to manage cheatgrass.

Ziska, L.H., J.B.Reeves III, and B. Blank. 2005. The impact of recent increases in atmospheric CO_2 on biomass production and vegetative retention of Cheatgrass (*Bromus tectorum*): implications for fire disturbance. *Global Change Biology* 11: 1325-1332.

Literature category: Experimental research
Specific topic: Cheatgrass/ fire interaction
Reviewed by: Bruce H. Brockett

Introduction

Cheatgrass (*Bromus tectorum*) is a recognized annual weed of the western United States. To determine interactions between rising carbon dioxide concentration (CO_2), and the potential changes in biomass accumulation and fuel load, C:N ratio and the digestibility of cheatgrass from different elevations to recent and near-term projections in atmospheric CO_2 (the values of CO_2 corresponded to the CO_2 concentrations which existed at: (1) beginning of the 19th century, (2) during the 1960's, (3) the current CO_2, and (4) the projection for 2020. Because cheatgrass is a fire-adapted species, increasing fire frequency favors its establishment and spread. Carbon dioxide induced changes would effect the time needed to reach a minimum fuel threshold, as well as the total fuel load.

Summary

Cheatgrass seed was collected at low, mid and high elevations in northern Nevada, and grown until 87 days after sowing. Carbon, nitrogen analysis, and digestibility analysis was conducted. By 87 days post-sowing CO_2 significantly increased leaf area, leaf weight, root weight, and vegetative biomass averaged over all populations. The sensitivity to CO_2 decreased with increasing elevation. Carbon dioxide also affected the C:N ratio, plant age, and the population was significant as CO_2 by age, and population by age.

Relevant findings

As biomass production occurs more quickly with increased CO_2, the minimum fuel thresholds would be reached earlier in the time-period between burns.

A greater amount of time would be spent proportionally above the minimum fuel load threshold required to start a fire, which could lead to greater fire frequency under global climate change.

Increased grass biomass would lead to increased fireline intensity, temperature, and rate of spread would increase, which would reduce the number of non-fire adapted species in the community.

Summary interpretation

From this study one can conclude that increased CO_2 concentration could lead to increased fire frequency, which would affect some sagebrush-steppe species negatively. However, the increased CO_2 would need to be accompanied with increased light, nutrients, or water.