Garry oak ecosystems recovery team

Annotated Bibliography on the Ecology and Management of Invasive Species:

Rip-gut Brome (*Bromus rigidus*) and Barren Brome (*Bromus sterilis*)

Prepared by Kersti Vaino

For the Garry Oak Ecosystems Recovery Team

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Peer-Reviewed Journal Articles

Andersson, L., W. Milberg, and O. Steinmetz. 2002. Germination characteristics and emergence time of annual *Bromus* species of differing weediness in Sweden. European Weed Research Society Weed Research 42: 135-147.

Abstract: The germination ecology of four annual *Bromus* species, which differ in weediness on arable land in southern Sweden, was investigated. The most problematic species is *Bromus sterilis*, while *Bromus hordeaceus* frequently occurs on arable land. In contrast, *Bromus arvensis* is a rare weed, and *Bromus tectorum* is found infrequently in fields despite being a widespread ruderal species. Five experiments were conducted to identify germination characteristics that could explain differences in habitat and abundance: (i) intraspecific variation in dormancy level; (ii) germination response to different light conditions; (iii) light and temperature interactions at germination; (iv) timing of seedling emergence; and (v) seed persistence in soil. *Bromus sterilis* and *B. tectorum* behaved similarly in all tests. For both these species, there were large differences in dormancy level among populations and strong inhibition of germination by light. In addition, emergence from seeds sown on the soil surface was both delayed and reduced compared with buried seeds. In contrast, *B. hordeaceus* and *B. arvensis* showed generally weak dormancy, and germination was only slightly inhibited by light. It was concluded that germination characteristics alone do not explain the differences in weediness between these four species.

Cheam, A. H. 1986. Patterns of change in seed dormancy and persistence of *Bromus diandrus* Roth. (great brome) in the field (abstract). Australian Journal of Agricultural Research 37 (5): 471-481.

Abstract: Mature seeds of great brome (*Bromus diandrus* Roth.) from Western Australia were dormant when freshly harvested. This dormancy was lost progressively over summer. The rate of loss of dormancy was more rapid in the northern than in the southern accessions. Compared with bare soil, a wheat stubble microenvironment favoured the relief of dormancy during the initial period of dormancy breakdown. Shallow burial of newly shed dormant seeds also accelerated the after-ripening process. Germination of non-dormant seeds during summer was minimised by high temperatures and low soil moisture content. By autumn/winter, almost all the seeds became germinable. At 20/10¦C, the temperature regime corresponding to late autumn, 95-99% germination occurred under constant darkness, but in the light germination varied from 55 to 95%. In the field, complete mass germination did not occur but germination was a well-defined event. There was little germination following this pulse until the succeeding autumn/winter. The seed bank of great brome appears to be essentially a transient one, but this is the subject of further work. The concentration of germination at a single time of year, and the very small carryover of seeds to successive years, suggest that good control should be achieved by a single, timely cultivation or spraying.

Cheam, A. H. 1987. Longevity of *Bromus diandrus* Roth. seed in soil at three sites in Western Australia (abstract). Plant Protection Quarterly 2 (3): 137-139.

Abstract: Populations persisted for 2 to 3 years, depth of burial having very little influence on the life-span of non-dormant seeds. However, deep burial (10-15cm) of dormant seeds in a cool and moist environment promoted longevity. The most effective depth for enhancing loss of viability was 1 cm. The implications of these findings with respect to the development of an effective long-term control program for great brome are discussed.

DiTomasio, J. M., M. L. Brooks, E. B. Allen, R. Minnich, P. M. Rice, and G. B. Kyser. 2006. Control of invasive weeds with prescribed burning. Weed Technology 20: 535-548.

Abstract: Prescribed burning has primarily been used as a tool for the control of invasive late-season annual broadleaf and grass species, particularly yellow starthistle, medusahead, barb goatgrass, and several bromes. However, timely burning of a few invasive biennial broadleaves (e.g., sweetclover and garlic mustard), perennial grasses (e.g., bluegrasses and smooth brome), and woody species (e.g., brooms and Chinese tallow tree) also has been successful. In many cases, the effectiveness of prescribed burning can be enhanced when incorporated into an integrated vegetation management program. Although there are some excellent examples of successful use of prescribed burning for the control of invasive species, a limited number of species have been evaluated. In addition, few studies have measured the impact of prescribed burning on the long-term changes in plant communities, impacts to endangered plant species, effects on wildlife and insect populations, and alterations in soil biology, including nutrition, mycorrhizae, and hydrology. In this review, we evaluate the current state of knowledge on prescribed burning as a tool for invasive weed management.

Froud-Williams, R. J., R. J. Chancellor, and D. S. H. Drennan. 1984. The effects of seed burial and soil disturbance on emergence and survival of arable weeds in relation to minimal cultivation. Journal of Applied Ecology 21 (2): 629-641.

Abstract: Seeds of sixteen weed species (six grasses and ten herbs) were collected from arable field margins during 1977. Species included were *Agrostis gigantea*, *Alopecurus myosuroides*, *Arrhenatherum elatius*, *Avena fatua*, *Bromus sterilis*, *Poa trivialis*, *Capsella bursa-pastoris*, *Galium aparine*, *Papaver rhoeas*, *Plantago major*, *Polygonum aviculare*, *Stellaria media*, *Tripleurospermum inodorum*, *Veronica arvensis*, *Veronica persica*, and *Viola arvensis*. Seeds were sown in soil in pots or boxes at various depths, and either periodically or left undisturbed. Periodicity of emergence was recorded for each species. Four patterns of emergence were recorded: (i) emergence in spring alone; (ii) predominantly in autumn; (iii) in both spring and autumn; (iv) emergence indifferent to season. Most of the grasses emerged predominantly in autumn whereas the main period of emergence for many of the dicotyledonous species was in spring.

Gill, G. S. and S. A. Carstairs. 1988. Morphological, cytological and ecological discrimination of *Bromus rigidus* from *Bromus diandrus*. Weed Research 28: 399-405.

Abstract: Morphological characters of different populations of brome found in the northern wheatbelt of Western Australia (Geraldton) pointed to the presence of *Bromus diandrus* and another taxon, most likely *B. rigidus.* This was later confirmed by the counts of somatic chromosomes made from root meristems of seedlings from different accessions. This is the first report of *B. rigidus* from Western Australia, and observations so far suggest that it is a serious weed of crops on the sandplains of the northern wheat-belt. The accessions of B. *diandrus* exhibited a much faster loss of seed dormancy than *B. rigidus.* Such short duration of seed dormancy coupled with rapid germination of non-dormant seeds of 6. *diandrus* is likely to render it both more prone to premature germination following summer rainfall events and more susceptible to pre-sowing cultural and herbicide treatments following break of the season. *Bromus rigidus* appears to be well adapted to the Mediterranean climate of the northern wheatbelt of Western Australia, and is more likely to demonstrate seed carryover from one season to the next, thus making it a more troublesome weed.

Gill, G. S. and W. M. Blacklow. 1985. Variations in seed dormancy and rates of development of great brome, *Bromus diandrus* Roth., as adaptations to the climates of southern Australia and implications for weed control (abstract). Australian Journal of Agricultural Research 36 (2): 295-

304.

Abstract: Seeds of great brome, *B. diandrus*, were collected from 14 sites across southern Australia and sown at Perth, W.A. The duration of seed dormancy varied among the seed accessions when produced at the common field site of Perth, which suggested that variations in dormancy were genetically controlled. The environment of Perth shortened the duration of dormancy in all the accessions but did not affect their ranking, indicating a lack of genotype x environment interaction. The duration of dormancy was positively correlated (r = 0.78) with the duration of the rain-free summers of the site of collection. Dormancy was not due to hard-seededness and non-dormant seeds germinated within 40 h of wetting at 20¦C. The seed dormancy was limited to about 5 months under the storage conditions examined. Dormant seed was stimulated to germinate by gibberellic acid (2.89 mM) and dormant seed of the accession from Geraldton also responded to removal of the lemma and palea or to leaching with water. The time taken for accessions to 'panicle peep' was positively correlated (r = 0.83) with the length of the rainy winters of the sites of collection. The results show great brome has adapted genetically to the climate of southern Australia.

Gordon, D. R. and K. J. Rice. 1993. Competitive effects of grassland annuals on soil water and blue oak (*Quercus douglasii*) seedlings (abstract). Ecology 74 (1): 68-82.

Abstract: Four California annual grassland species were used to examine the hypothesis that different plant species have equivalent competitive effects. We investigated the effects of the annuals on soil water availability and the growth responses of blue oak (*Quercus douglasii* Hook & Arn.) to neighbor-induced water depletion. Neighborhoods of annuals were composed of species from the California annual grassland with differing phenology and morphology that were hypothesized to show non-equivalent competitive effects on both a per-individual- and a per-unit-tissue basis. Three introduced species of winter annuals were sown at each of three densities (10, 30, or 100 seeds/dm^2) around a single oak acorn. The grass *Bromus diandrus* Roth. and the forb *Erodium botrys* Cav. flower in early spring, while the grass *B. mollis* L. flowers slightly later. A native summer annual forb, *Hemizonia luzulaefolia* DC., was sown at only the intermediate density. Plants were grown outdoors in 15 cm diameter x 1 m deep tubes filled with soil from an oak woodland site. Identity and density of annual species had independent and interactive effects on the water resource level.

Han, X., S. P. Dendy, K. A. Garrett, L. Fang, and M. D. Smith. 2008. Comparison of damage to native and exotic tallgrass prairie plants by natural enemies. Plant Ecology 198: 197-210.

Abstract: We surveyed the prevalence and amount of leaf damage related to herbivory and pathogens on 12 pairs of exotic (invasive and noninvasive) and ecologically similar native plant species in tallgrass prairie to examine whether patterns of damage match predictions from the enemy release hypothesis. We also assessed whether natural enemy impacts differed in response to key environmental factors in tallgrass prairie by surveying the prevalence of rust on the dominant C4 grass, *Andropogon gerardii*, and its congeneric invasive exotic C4 grass, *A. bladhii*, in response to fire and nitrogen fertilization treatments. Overall, we found that the native species sustain 56.4% more overall leaf damage and 83.6% more herbivore-related leaf damage when compared to the exotic species. Moreover, we found that the invasive exotic species sustained less damage from enemies relative to their corresponding native species than the noninvasive exotic species. Finally, we found that burning and nitrogen fertilization both significantly increased the prevalence of rust fungi in the native grass, while rust fungi rarely occurred on the exotic grass. These results indicate that reduced damage from enemies may in part explain the successful naturalization of exotic species and the spread of invasive exotic species in tallgrass prairie.

Harradine, A. R. 1986. Seed longevity and seedling establishment of *Bromus diandrus* Roth. (abstract). Weed Research 26 (3): 173-180.

Abstract: Some aspects of the seed and seedling biology of *Bromus diandrus* Roth. were investigated with the aim of formulating non-chemical control methods. *B. diandrus* seeds remained viable for at least 2 years when dormancy was enforced by environmental conditions, although 95% of seed was capable of germinating within 27 days of shedding from the parent plant when conditions were favourable. Seeds buried at 50 or 150 mm depth in field soil germinated or lost viability within 6 months. Seedling establishment was greatest and most rapid from seeds buried at 50 mm with 97% of total seedling emergence occurring within 1 month of burial. Less than 1% of seeds buried at 150 mm produced seedlings. Establishment of seedlings from surface-sown seed occurred over 18 months. The prevention of seeding by the application of paraquat to flowering plants of *B. diandrus* in the field led to a significant reduction in the population in the following year. Control methods based on these results are suggested.

Hilton, J. R. 1984. The influence of dry storage temperature on the response of *Bromus sterilis* L. seeds to light. New Phytologist 98 (1): 129-134.

Abstract: The response of two populations of *Bromus sterilis* L. seed to light at 15°C was studied over 12 months when seeds were stored at different temperatures. White and red light inhibited the germination of both collections of seed, inhibition persisting for longer periods at low (4°C) than at high (23 °C) temperatures. The two populations of seed behaved similarly in their response to all light treatments.

Holmes, T. H. and K. J. Rice. 1996. Patterns of growth and soil-water utilization in some exotic annuals and native perennial bunchgrasses of California. Annals of Botany 78: 233-243.

Abstract: In western California, exotic cool-season annuals appear to have widely replaced native perennial bunchgrasses as the herbaceous community dominants in grasslands, oak savannas, and oak woodlands. We argue that because these two herbaceous plant types possess very different life histories, this invasion may have correspondingly altered seasonal patterns of soil-water availability. To begin to assess this hypothesis, in this study we compared exotic cool-season annuals and native perennial bunchgrasses in terms of growth, biomass allocation, rooting distribution, root morphology, and soil-water utilization. Exotic cool-season annuals completed their life cycle early in the dry season through rapid growth apparently made possible by a high proportional allocation to shoots in combination with the efficient production of roots of high specific root length. Further, annuals tended to concentrate root growth and soil-water utilization in the upper soil profile. In contrast, native perennial bunchgrasses allocated a high proportion of their biomass to the production of a deep root system, which allowed them to continue soil-water utilization well into the dry season and contribute to the formation of a very dry soil profile. Taken together, these contrasting patterns suggest that the invasion of exotic cool-season annuals might have produced a corresponding increase in the amount of water present at depth in the soil profile during the dry season.

Hoopes, M. E. and L. M. Hall. 2002. Edaphic factors and competition affect pattern formation and invasion in a California Grassland (abstract). Ecological Applications 12 (1): 24-39.

Abstract: We used soil analyses, a greenhouse experiment, and a field experiment to examine the roles of competition and abiotic soil factors in plant community pattern formation in a California grassland. We collected soils from five microhabitats: one dominated by the native perennial grass *Sporobolus airoides* Torrey (alkali sacaton), two dominated by the nonnative annual grass species *Hordeum marinum* (Hudson) ssp. *gussoneanum* (Parl.) Thell (foxtail) and

Bromus diandrus Roth (ripgut grass), and bare soil created either by gopher mounds or by high salt concentrations (sodic soils). We used principal components analysis (PCA) to determine whether soils from these five microhabitats differed in any discernible pattern. In the greenhouse we examined the emergence, growth, and survival of the native perennial in soil from the five habitat types. In the field we then examined a combined survival and reproduction measure to assess how competition with the two nonnative annual grasses affected the fitness of *S. airoides*. PCA revealed that *B. diandrus* soils were distinct from soils occupied by *S. airoides*, although the perennial emerged, grew, and survived well on these soils in the greenhouse. Despite some differences in soil quality in the greenhouse experiment, sacaton emergence, growth, and survival were possible in all five soils. Those *S. airoides* plants that survived in sodic soils grew far larger than plants grown in other soils; survival, however, was very low in sodic soils. Sacaton actually performed worst in soils from areas dominated by *S. airoides*. In the field experiment, total available soil nitrogen affected reproduction and survival. In addition, soil ammonium levels interacted with competition from *B. diandrus* to produce lower survival than in control plots. There was no survival in the presence of high densities of *H. marinum gussoneanum*. The two nonnative species seem to represent threats from two distinct types of invaders: (I) "selective invaders," which only invade a narrow range of habitats but can restrict natives from those habitat types, and (2) "twin invaders," which have similar niches to the native and can exist over almost the same range of habitats as the native. Twin invaders can potentially reduce fitness or threaten the persistence of the native over much of its range.

Keeley, J. E., M. Baer-Keeley, and C. J. Fotheringham. 2005. Alien plant dynamics following fire in Mediterranean-climate California shrublands. Ecological Applications 15 (6): 2109-2125.

Abstract: Over 75 species of alien plants were recorded during the first five years after fire in southern California shrublands, most of which were European annuals. Both cover and richness of aliens varied between years and plant association. Alien cover was lowest in the first postfire year in all plant associations and remained low during succession in chaparral but increased in sage scrub. Alien cover and richness were significantly correlated with year (time since disturbance) and with precipitation in both coastal and interior sage scrub associations. Hypothesized factors determining alien dominance were tested with structural equation modeling. Models that included nitrogen deposition and distance from the coast were not significant, but with those variables removed we obtained a significant model that gave an $R^2 = 0.60$ for the response variable of fifth year alien dominance. Factors directly affecting alien dominance were (1) woody canopy closure and (2) alien seed banks. Significant indirect effects were (3) fire intensity, (4) fire history, (5) prefire stand structure, (6) aridity, and (7) community type. According to this model the most critical factor influencing aliens is the rapid return of the shrub and subshrub canopy. Thus, in these communities a single functional type (woody plants) appears to the most critical element controlling alien invasion and persistence. Fire history is an important indirect factor because it affects both prefire stand structure and postfire alien seed banks. Despite being fire-prone ecosystems, these shrublands are not adapted to fire per se, but rather to a particular fire regime. Alterations in the fire regime produce a very different selective environment, and high fire frequency changes the selective regime to favor aliens. This study does not support the widely held belief that prescription burning is a viable management practice for controlling alien species on semiarid landscapes.

Kon, K. F. and W. M. Blacklow. 1998. Identification, distribution and population variability of great brome (*Bromus diandrus* Roth) and rigid brome (*Bromus rigidus* Roth) (abstract). Australian Journal of Agricultural Research 39 (6): 1039-1050.

Abstract: Seventeen populations of *Bromus* spp. were sampled from across southern Australia and accessions in the state herbaria of Western and South Australia were examined. Rigid brome (*B. rigidus*) differed from great brome (*B. diandrus*) in having shorter, sparser hairs

on leaf laminae, more compact and erect panicles with shorter spikelet branches. In rigid brome, the abscission scars on the rachillae were elliptical and the lemma calluses were elongated (> 1 mm), while in great brome, these characters were circular and short (5 1 mm). Rigid brome was further differentiated into a long and short-awned biotype. Rigid brome was hexaploid, 2n = 42, and great brome an octoploid, 2n = 56. Rigid brome is widely distributed across southern Australia, often growing unrecognized in association with great brome. Rigid brome matured earlier than great brome, and there was high genetic variation (26-34% of total variation) in the time of maturity of both species. Seed production in rigid brome and great brome ranged from 1156 to 2908 and 661 to 3380 seeds per plant, respectively. A short-awned ecotype of rigid brome from Geraldton, W.A., had 30% residual innate dormancy. This, together with the earlier maturity of ecotypes of rigid brome, may make it more difficult to control than a great brome when both species coexist in the field. Leaves of great brome were susceptible to rust (*Puccinia bromoides* Guyot), but associated ecotypes of rigid brome were rust free.

MacDougall, A. S., B. R. Beckwith, and C. Y. Maslovat. 2004. Defining conservation strategies with historical perspectives: a case study from a degraded oak grassland ecosystem. Conservation Biology 18 (2): 455-465.

Abstract: The role of diversity in buffering environmental change remains poorly tested in natural systems. Diversity might enhance stability if different species have different disturbance susceptibilities (i.e., functional complementarity). Alternatively, diversity might decrease stability because, at high diversity, populations are predicted to be more temporally variable and therefore more vulnerable to extinction following perturbation. There is theoretical support for both hypotheses but limited empirical evidence. I examine these issues with experimental burning along a natural diversity gradient in a savanna where fire has been suppressed for 150 years. I examined how two components of stability, resistance (invasion by added and naturally recruiting species) and resilience (recovery of the pre-disturbance light levels, the primary limiting resource in this system), varied with diversity. I also examined how the abundance of dominant species and soil depth affected stability, as both are negatively correlated with diversity and could have hidden impacts (e.g., invasion resistance on shallow soils correlated with diversity but caused by moisture stress). Species-rich communities were stable because they contained fire-tolerant species that, despite their rarity, significantly increased in cover after fire, reduced light availability, and limited seedling survival. Species-poor communities were rapidly invaded, apparently due to the combined effects of (1) trade-offs between competitive ability and disturbance tolerance (dominants in species-poor areas were competitive but fire sensitive), and (2) low functional complementarity. Colonization by woody plants was also significantly higher in low-diversity plots; these species are known to form a new stable state that excludes all savanna taxa. The abundance of dominants and soil depth were negatively correlated with diversity because they appear to determine its spatial variation in the absence of fire, but diversity alone accounted for variation in stability. Without burning, most subordinates are confined to shallower soils where they play a minor role in controlling resource flows and production. Diversity, therefore, was more important for buffering the effects of change than controlling ecosystem function under undisturbed conditions. If applicable to other systems, the results indicate that species loss will compound the negative effects of environmental change on ecosystem function by limiting the ability of ecosystems to respond.

MacDougall, A. S., J. Boucher, R. Turkington, and G. E. Bradfield. 2006. Patterns of plant invasion along an environmental stress gradient. Journal of Vegetation Science 17: 47-56.

Abstract: Question: Do stressful environments facilitate plant invasion by providing refuges from intense above-ground competition associated with productive areas, or prevent it by favouring locally adapted native species? Location: An invaded and fragmented oak savanna ecosystem structured along a landscape-level stress gradient associated with soil depth, elevation, and canopy openness. Methods: Vegetation and environmental data were collected

from 184 plots in seven savanna remnants along the gradient. Using multivariate (CCA) and *post-hoc* regression analyses, we determined the relationship between environment and the richness and abundance of invasives. Results: 46 of 119 species were naturalized exotics. CCA indicated the importance of environmental variation (mostly soil depth) for community structure but not for invasion; invasive species richness was similar in all areas. However, the abundance of invasives and their impacts on native diversity appear to increase significantly in less stressful habitats. Deeper soils had lower evenness and significantly fewer native species. This result was associated with dominance by exotic perennial grasses and large increases in vegetation height, suggesting strong above-ground competition. Conclusions: Low-stress environments were not more invasible *per se* but appear to be more susceptible to invasion by species with strong competitive impacts. The causes of decreasing exotic impact with decreasing soil depth may reflect shifts in competitive intensity or an increased importance of stress tolerance, both of which may favour natives. Alternatively, this ecosystem may simply lack high-impact invaders capable of dominating shallow soils. Conservation challenges are twofold for this endangered plant community: controlling invasives that currently dominate deeper-soils and accounting for a diverse pool of invaders that proliferate when the current dominants are removed.

MacDougall, A. S. and R. Turkington. 2007. Does the type of disturbance matter when restoring disturbance-dependent grasslands? Restoration Ecology 15 (2): 263-272.

Abstract: The reintroduction of burning is usually viewed as critical for grassland restoration; but its ecological necessity is often untested. On the one hand, fire may be irreplaceable because it suppresses dominant competitors, eliminates litter, and modifies resource availability. On the other hand, its impacts could be mimicked by other disturbances such as mowing or weeding that suppress dominants but without the risks sometimes associated with burning. Using a 5-year field experiment in a degraded oak savanna, we tested the impacts of fire, cutting and raking, and weeding on two factors critical for restoration: controlling dominant invasive grasses and increasing subordinate native flora. We manipulated the season of treatment application and used sites with different soil depths because both factors influence fire behavior. We found no significant difference among the treatments-all were similarly effective at suppressing exotics and increasing native plant growth. This occurred because light is the primary limiting resource for many native species and each treatment increased its availability. The effectiveness of disturbance for restoration depended more on the timing of application and site factors than on the type of treatment used. Summer disturbances occurred near their reproductive peak of the exotics, so their mortality approached 100%. Positive responses by native species were significantly greater on shallow soils because these areas had higher native diversity prior to treatment. Although likely not applicable to all disturbance-dependent ecosystems, these results emphasize the importance of testing the effectiveness of alternative restoration treatments prior to their application.

Maranon, T. and J. W. Bartolome. 1993. Reciprocal transplants of herbaceous communities between *Quercus agrifolia* woodland and adjacent grassland. Journal of Ecology 81 (4): 673-682.

Abstract: Oak woodlands in California intermingle with annual grasslands. They frequently have a grassy understorey, which has a distinct species composition and abundance unlike adjacent open communities. Soil blocks were reciprocally transplanted in autumn (at seed stage) between oak understorey and open grassland. Changes in species composition and species population densities were monitored over the following two years. Species composition of adult plants in the reciprocally transplanted soil blocks resembled the original 'donor' seed bank in the first spring after transplant, but in the second year it was not very different from the surrounding community in the 'receptor' habitat. In a second experiment, soil blocks from both habitats were transplanted onto the top of an uniform soil base in large boxes in a fenced experimental site, and half of them were then subjected to artificial dense shade. Total plant density was severely reduced by shading, although *Bromus diandrus*, *Carduus pycnocephalus*

and *Stellaria media* were the species least affected. Reduced radiation under evergreen oak canopy caused high seedling mortality of the transplanted open species and seems the main factor precluding their distribution in the oak woodland. This hypothesis is further supported by the finding that artificial shading severely reduced the seedling density of open species. Reciprocally, strong interference by dominant tall grasses seems to limit the establishment of understorey species in the open grassland.

Pickart, A. J., L. M. Miller, and T. E. Duebendorfer. 1998. Yellow bush lupine invasion in Northern California coastal dunes I. Ecological impacts and manual restoration techniques. Restoration Ecology 6 (1): 59-68.

Abstract: We studied the ecological effects of the invasion of coastal dunes by *Lupinus arboreus* (yellow bush lupine), an introduced species, and used the results to develop manual restoration techniques on the North Spit of Humboldt Bay. Vegetation and soil data were collected in five vegetation types representing points along a continuum of bush lupine's invasive influence. We collected data on the number and size of shrubs, vegetation cover, and soil nutrients. One set of plots was subjected to two restoration treatments: removal of lupine shrubs only, or removal of all nonnative vegetation and removal of litter and duff. Treatments were repeated annually for four years, and emerging lupine seedlings were monitored for three years. Prior to treatment, ammonium and nitrate were found to increase along the lupine continuum, but organic matter decreased at the extreme lupine end. Yellow bush lupine was not the most significant variable affecting variation in soil nutrients. After four years, nonnative grasses, including *Vulpia bromoides*, *Holcus lanatus* (velvet grass), *Bromus* spp. (brome), and *Aira* spp. (European hairgrass), were significantly reduced in those restoration plots from which litter and duff was removed. Native species increased significantly in vegetation types that were less influenced by lupine. By the third year, soil variables differed among vegetation types but not by treatment. Bush lupine seedling emergence was higher, however, in plots receiving the litter and duff removal treatment. Based on these results, we conclude that bush lupine invasion results in both direct soil enrichment and indirect enrichment as a result of the associated encroachment of other nonnative species, particularly grasses. Although treatment did not affect soil nutrients during the period of this study, it did reduce establishment of nonnative grasses and recruitment of new bush lupine seedlings. Restoration should therefore include litter and duff removal. In areas that are heavily influenced by lupine and contain few native propagules, revegetation is also required.

Perchemlides, K. A., P. S. Muir, and P. E. Hosten. 2008. Responses of chaparral and oak woodland plant communities to fuel-reduction thinning in Southwestern Oregon. Rangeland Ecology and Management 61 (1): 98-109.

Abstract: Fire suppression has led to large fuel accumulations in many regions of the United States. In response to concerns about associated wildfire hazards, land managers in the western United States are carrying out extensive fuel-reduction thinning programs. Although reductions in cover by woody vegetation seem likely to cause changes in herbaceous communities, few published studies have reported on consequences of such treatments for native or exotic plant species. We compared vegetation and abiotic characteristics between paired thinned and unthinned chaparral and oak woodland communities of southwestern Oregon 4-7 yr posttreatment and contrasted impacts of manual vs. mechanical treatments. Herbaceous cover increased on thinned sites, but species richness did not change. Herbaceous communities at thinned sites had an early postdisturbance type of composition dominated by native annual forbs and exotic annual grasses; cover by annuals was nearly twice as high on treated as on untreated sites. Absolute and proportional cover of native annual forbs increased more than any other trait group, whereas exotic annual forbs and native perennial forbs declined. Exotic annual grass cover (absolute and proportional) increased, whereas cover by native perennial grasses did not. Shrub reestablishment was sparse after thinning, probably because of a lack of fire-stimulated

germination. Manual and mechanical treatment impacts on abiotic site conditions differed, but differences in vegetation impacts were not statistically significant. Fuel-reduction thinning may have some unintended negative impacts, including expansion of exotic grasses, reductions in native perennial species cover, persistent domination by annuals, and increased surface fuels. Coupled with sparse tree or shrub regeneration, these alterations suggest that ecological-state changes may occur in treated communities. Such changes might be mitigated by retaining more woody cover than is currently retained, seeding with native perennials after treatment, or other practices; further research is needed to inform management in these ecosystems.

Pollard, F. 1982. Light induced dormancy in *Bromus sterilis*. Journal of Applied Ecology 19 (2): 563-568.

Abstract: The response of two populations of *Bromus sterilis* L. seed to light at 15°C was studied over 12 months when seeds were stored at different temperatures. White and red light inhibited the germination of both collections of seed, inhibition persisting for longer periods at low (4°C) than at high (23 °C) temperatures. The two populations of seed behaved similarly in their response to all light treatments.

Rew, L. J., R. J. Froud-Williams, and N. D. Boatman. 1995. The effect of nitrogen, plant density and competition between *Bromus sterilis* and three perennial grasses: The implications for boundary strip management (abstract). Weed Research 35 (5): 363-368.

Abstract: The competitive ability of *Festuca rubra* L., *Holcus lanatus* L. and *Poa trivialis* L. when grown from seed, in monoculture and in 1 :1 additive mixtures with *Bromus sterilis* L. was studied. *B. sterilis* was more aggressive when grown in additive mixtures with *F. rubra* than *P. trivialis* or *H. lanatus*. *H. lanatus* was less dominated by *B. sterilis* at the second harvest; visual observations suggested that this dichotomy was due to its slower initial growth rate, and its subsequent dense vegetative growth habit. There was no statistically significant difference between the Relative Yield Total (RYT) of *B. sterilis* in additive mixtures with *F. rubra*, *H. lanatus* or *P. trivialis*, indicating that they were competing for the same resources. *B. sterilis* produced significantly more reproductive tillers and seeds as a result of nitrogen application, and such production was accentuated in the absence of interspecific competition. The implications of sown grass strips for field margin management are discussed.

Roberts, H. A. 1986. Persistence of seeds of some grass species in cultivated soil. Grass and Forage Science 41: 273-276.

Abstract: Freshly collected ripe caryopses of twenty-five indigenous grasses were mixed with the top 7-5 cm of sterilized soil confined in cylinders sunk in the ground and cultivated three times yearly. There was a flush of seedlings of most species shortly after sowing, but species differed in the persistence of viable seeds. About one third, including *Bromus sterilis, B. hordeaceus, Lolium perenne ssp. perenne, Arrhenatherum elatius a.nd Alopecurus pratensis,* produced few seedlings after the initial flush. Others such as *Deschampsia cespitosa, Holcus lanatus* and *Poa trivialis,* recognized as forming persistent seed banks in grassland soils, produced appreciable numbers of seedlings in the second year after sowing. Most persistent were species that occur as arable weeds *(Avena fatua, Poa annua)* or in wetlands (*Glyceria plicata, G. maxima, Alopecurus geniculatus).* Emergence from the seed bank generally followed soil disturbance but some species *(Aira praecox, Avena fatua, A. sterilis* ssp. *ludoviciana, Danthonia decumbens)* exhibited consistent seasonal patterns which may be associated with cyclic changes in germination requirements of the buried seeds.

Robinson, G. R., J. F. Quinn, and M. L. Stanton. 1995. Invasibility of experimental habitat islands in a California winter annual grassland . Ecology 76 (3): 786-794.

Abstract: In an experimental test of plant community invasibility, we introduced seeds of a native ruderal, California poppy (*Eschscholzia californica*), at fixed density into experimental plots in a California winter annual grassland. Each of the 42 plots, which ranged in size from 2 m super(2) to 32 m super(2), had been studied for 4 yr previous to the introduction, with the common observation that a subset of plots of each size consistently held more species than others. It was primarily in these more species-rich plots that establishment and reproduction by the experimental invader occurred. Success of the invader per plot, measured as the total number of plants germinating, producing seeds, or perennating, varied with plot size, but the statistical contribution of plot size was secondary to that of local species number. Contributing variables were the extent of small mammal disturbance (positive) and the degree to which a single resident plant species (in particular, *Bromus diandrus*) dominated a plot (negative). In contrast to theories of competitive exclusion via niche partitioning, species-rich plots were more invasible.

Sweet, S. B., G. B. Kyser, and J. M. DiTomasio. 2008. Susceptibility of exotic annual grass seeds to fire. Invasive Plant Science and Management 1: 158-167.

Abstract: Prescribed burning can control invasive annual grasses that threaten the biological and economic value of California grasslands. Susceptibility of grass seed to burning can depend on burn timing, exposure time, and type of exposure (direct flame heat or convective heat); thus, these factors can influence the success of a prescribed burning program. To further investigate these factors, laboratory simulations were conducted on barb goatgrass, medusahead, and ripgut brome at several stages of seed maturity, as determined by percent moisture of the inflorescences. Seeds were exposed either to direct flame using a Bunsen burner or to heated air in a muffle furnace. Flame treatments were conducted at one temperature (~400 C) and several exposure times (0 to 14 s), depending on the species. Furnace treatments included four temperatures (150, 200, 250, and 300 C) and seven exposure times (0, 10, 20, 30, 40, 60, or 80 s). Seed germination was analyzed for each temperature series to determine the LD_{50} and LD_{90} in seconds of exposure time. Susceptibility to furnace treatments, which simulated heat exposure of seeds on the soil surface, was not statistically different within a range of seed moisture levels for all three species. The LD_{50} values at 250 C (typical soil temperature with grassland fire) ranged from 28 to 49 s, which far exceeds the time of exposure during a typical grassland fire. Susceptibility to flame showed a similar lack of change over maturation of medusahead and barb goatgrass seeds, with LD_{90} values ranging between 4.8 and 7.4 s for all seed moisture levels. In contrast, ripgut brome seeds exposed to flame showed increasing susceptibility with reduced seed moisture content. The LD_{90} values for exposure were less than one second for seed moisture levels at or below 10%, compared to 3.7 s for seeds at 55 to 60%. Although flame susceptibility increased for ripgut brome, seeds at all maturation stages were more sensitive than medusahead and barb goatgrass. Additionally, the LD_{90} values for all three species are attainable under field conditions. Thus, burn prescriptions for these three species are not constrained by maturation stage, but should occur prior to seed drop and when fuel loading is high. This will maximize exposure time of seeds to direct flame.

Tanji, A. 2001. Response of ripgut brome (*Bromus rigidus*) and foxtail brome (*Bromus rubens*) to MON 37500. Weed Technology 15 (4): 642-646.

Abstract: Greenhouse studies were conducted to determine the responses of ripgut brome and foxtail brome to MON 37500 applied at rates up to 80 g/ha. At 30 d after treatment MON 37500 at 20 g/ha reduced fresh weight of ripgut brome by 89% when applied at the three-leaf stage and 57% when applied at the tillering stage. MON 37500 at 10 g/ha reduced fresh weight of foxtail brome by 80% when applied at the three-leaf stage and 61% when applied at the

tillering stage. Rates above 20 g/ha did not increase control of either species. In field experiments during 1998 to 1999 and 1999 to 2000 in Settat, Morocco, bread wheat tolerated MON 37500 at 67 g/ha. Ripgut brome control in the field was 78% in the first growing season and 90% in the second season when MON 37500 was applied at 27 g/ha to brome plants at the one- to four-leaf stage. A similar rate controlled tillering ripgut brome by 69% during 1998 to 1999 and 62% during 1999 to 2000. MON 37500 at 20 to 30 and 10 to 20 g/ha applied before tillering controlled ripgut brome and foxtail brome, respectively, >70%.

Other Published Sources

Levine, Alice E. 2008. Evaluating prescribed burn methods for controlling invasive *Bromus diandrus*, ripgut bromegrass (abstract). 93rd Ecological Society of America Annual Meeting. Wilwaukee, WN.

Abstract: Background/Question/Methods - Invasive annual grasses dominate many ecosystems across the country, and present a different management challenge from perennial grasses because they quickly mature and produce seeds in a single growing season. In California alone, more than 9 million hectares (22.2 million acres) of grasslands, chaparral, sage-scrub, and oak-savannah have been converted into exotic annual grasses. One among these is Ripgut bromegrass (*Bromus diandrus*), which is cold hardy and drought tolerant, and produces copious amounts of seeds relative to native species, in addition to leaving behind a permanent litter layer that suppresses the growth of other species. Aboveground management strategies such as mowing, weeding and herbicides are impractical when considering the scale at which *B. diandrus* and other invasive annual grasses are dominant, and these strategies are furthermore only effective in the short-term, as they fail to address the elimination of the larger seedbank. Prescribed burning may be applied over larger areas and may offer improved control over these methods, by consuming invasive seeds while they are still curing in grass inflorescences, and by heat-treating soil seedbanks. I am investigating the efficacy with which different intensity and frequency prescribed burns can achieve the latter. How do differences in fuel-load at the time of burning affect *B. diandrus* seedbanks, and is there a difference between a single burn and repeat burns in back-to-back years? Results/Conclusions - Thus far it has been found that *B. diandrus* seedbanks are concentrated more heavily in the aboveground litter than soil, and the reverse is true for native species, though the former has at least an order of magnitude higher density. For the first year of burning, higher fuel-load prescribed burns more effectively destroyed or sterilized *B. diandrus* seeds in the litter and soil seedbanks than low fuel-load burns. Longer fire duration and higher below-ground temperatures were responsible for the success of the higher fuel-load prescribed burns. These findings suggest that high intensity prescribed burning can effectively control invasive annual grass seedbanks, and thereby facilitate native species restoration efforts.

Pollak, O. and T. Kan. 1998. The Use of Prescribed Fire to Control Invasive Exotic Weeds at Jepson Prairie Preserve. In Ecology, Conservation, and Management of Vernal Pool Ecosystems – Proceedings from a 1996 Conference. Witham, C. W., E. T. Bauder, D. Belk, W. R. Ferren, Jr., and R. Ornduff (eds.). California Native Plant Society. Sacramento, California. pp. 241-249.

Abstract: Jepson Prairie in Solano County, an outstanding example of remnant California Central Valley vernal pool and grassland habitats, is threatened by invasive exotic species. This paper describes the results of a 200-acre late-spring prescribed fire conducted at Jepson Prairie in June of 1995 and aimed at reducing the cover of an extensive infestation of Medusahead (*Taeniatherum caput-medusae*). Burned and unburned control plots are compared with respect to changes in community composition within three habitat types. The habitat types - mound, intermound, and swale - correspond to three topographic/hydrologic regimes within vernal pool complexes. Ocular estimates of percent cover (using Daubenmire cover classes) were recorded

for six species guilds: native grasses, exotic grasses, native early forbs, exotic early forbs, native late forbs, and exotic late forbs. Cover of thatch, bare ground and residual dry matter was also measured. Results show significant decreases in the cover of exotic annual grasses (including Medusahead) and thatch in burned mound and intermound habitats. Cover of native grasses and native early forbs increased on burned mound and intermound habitats. However, exotic early forbs also increased on burned mounds and intermounds, due mainly to an increase in cover of *Erodium* spp. The results provide strong evidence that late-spring burning reduces the cover of non-native annual grasses, such as Medusahead, while increasing the dominance of native species and the cover of native grasses and forbs. Prescriptions for management of vernal pool and grassland habitats in California should include late-spring prescribed fire in areas that have heavy infestations of Medusahead or an accumulated thatch layer.

Principe, Z. A. and D. H. Deutschman. 2004. Fire effects on oak recruitment in a Southern California woodland. In Proceedings of the Symposium: Fire Management: Emerging Policies and New Paradigms. Sugihara, N. G., M. E. Morales, and T. J. Morales (eds.). Association for Fire Ecology. pp. 64-77.

Abstract: Two spring prescribed burns were monitored in an effort to quantify the effect of fire on seedlings and saplings of *Quercus engelmannii* (Engelmann oak). Prior to the fires, 2950 individuals in both of the burn units and adjacent control areas were measured and had canopy location recorded. Immediately following the burns, plots were re-surveyed and fire damage was assessed for all individuals. Plots were re-sampled after seven months to quantify survival and the ability of individuals to resprout. The majority of seedlings (24%) were killed by fire but most saplings survived (77%). Survival and recovery of seedlings and saplings was influenced by the amount of fire damage, pre-fire size, and to a lesser extent, the site and canopy location. In an experiment conducted within the burn units, fuel loads (biomass) were manipulated around groups of seedlings to investigate the effects of fire intensity on seedling survivorship. Seedlings in plots with additional fuel had modest increases in fire damage but this did not lead to reduced seedling survival. Fire damage and seedling survival was highly variable across the experimental block suggesting large natural heterogeneity in fuel loads and thus the resulting fire intensities. In the final experiment, the effects of biomass removal and herbivory on the emergence of new seedlings was investigated. Viable *Quercus engelmannii* acorns were planted in a factorial experiment with three levels of biomass removal (burned, mowed, and control) crossed with two levels of herbivory (protected and unprotected). Biomass removal by either mowing or burning resulted in increased seedling recruitment from acorns. The mowing treatment had the greatest positive effect on emergence. The herbivore exclosures failed to deter pocket gophers. Taken together, these studies demonstrate that fire is a major factor affecting *Q. englemannii* recruitment. However, it may be difficult to implement fire as a management tool to enhance Engelmann oak woodlands since recruitment is a complex function of local fire intensity, individual plant size and other environmental factors.

Online Resources

Flora of China. 2006. Flora of China Vol. 22 (*Poaceae*). http://flora.huh.harvard.edu/china/mss/volume22 / index.htm. Science Press, Beijing, China and Missouri Botanical Garden Press. St. Louis, MS.

Calflora. 2008. Calflora: Information on California plants for education, research and conservation. http://www.calflora.org/. The Calflora Database [a non-profit organization]. Berkeley, CA.

Clayton, W. D., K. T. Harman, and H. Williamson. 2008. GrassBase - The Online World Grass Flora. http://www.kew.org/data/grasses-db.html. The Board of Trustees, Royal Botanic Gardens, Kew.

E-Flora BC. 2008. E-Flora BC: Electronic Atlas of the Plants of British Columbia. http://www.eflora.bc.ca/. Klinkenberg, B. (ed.). Lab for Advanced Spatial Analysis, Department of Geography, University of British Columbia. University of British Columbia, Vancouver, BC.

Farmer, C. 2005. Skye Flora: Flowering plants and ferns recorded as growing wild on the Isle of Skye. http://www.plant-identification.co.uk/skye/index.htm.

United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). 2008. Plants Database. http://plants.usda.gov/.